ABSTRACT
The paper includes five parts: 1) trends in urban development and in development of traffic congestion and disturbances, climate change, and consequent challenges, 2) needs and a method for determining impacts of congestion and disturbances, 3) a case study of one radial route in Helsinki area, 4) discussion improvement possibilities, 5) conclusions and recommendations.

The following trends causing traffic congestion are indicated: continuous and often uncontrolled growth of cities, increase of cars stocks and growing congestion in cities, inability of the conservative transport sector to solve the traffic problems, which other sectors with help of uncontrolled urban development are creating, energy crisis and climate change, some attempts to solve transportation problems like congestion pricing.

Needs and a method for determining impacts of congestion and disturbances: The method (= Vemosim Method) uses differentiation of congestion conditions, computer simulation to estimate unit impacts of congestion (= congestion impact rates per kilometre for various type vehicles) and applies the unit impacts to travel demand statistics to develop route or network estimates. The impacts caused by traffic congestion or other disturbances are determined as differences of impacts in congested/disturbed traffic conditions and free flow traffic conditions. The congestion conditions are differentiated according to time of the day, route section, and driving direction, and traffic according to vehicle categories. Each of them is represented by one or more type vehicles (car, van, coach, single unit truck, truck + semi trailer, and truck + trailer). The essence of the method is there that the unit impacts (= congestion impact rates per kilometre for various type vehicles) are produced by using a computer simulation based on vehicle dynamics and three sets of input data, namely the technical data of type vehicles incl. engine maps, of roads and streets, and of driving technique. The unit impacts include: increases of fuel consumption, emissions, driving time, etc. which traffic congestion causes. The unit impacts are evaluated by using the unit values determined by transportation authorities in Finland. The impact analysis discovers the consequences of traffic congestion in measurable quantities, numerically in quantitative and in monetary terms. The decision makers can see the impacts in concrete, numeric figures and thus will have a better grip about the problems in order to decide what kind of improvement measures are necessary. The impact analysis gives, also, other useful information like impacts on transport efficiency, marginal impacts when traffic speed decreases or increases by small amount (1 - 10 km/h), and the suitability of the fuel tax for road pricing.

The method uses a concept disturbance/congestion degree DCD, which is defined as follows:
$DCD = (1 - \frac{Va}{Vt}) \times 100$, where $DCD =$ disturbance/congestion degree [%], $Va =$ average speed [km/h], and $Vt =$ target speed [km/h].

The quantitative unit impacts are: 1) fuel consumption, 2) emission amounts of regulated emissions (NOx, CO, HC, PM and CO2), and 3) driving time. They are produced, differentiated by

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type vehicle according to time interval, route section and driving direction.
The method produces, among others, the following information:

• quantities of fuel consumption, emissions and driving time separately or summed for different vehicle categories and for the whole traffic
• monetary impacts (vehicle operating costs, emission costs, time costs and driving costs, as well as the fuel tax) for different vehicle categories and for the whole traffic
• the allocation of congestion impacts between different actors (vehicle categories, tax authority and society as whole)

Case study: One radial route in the Helsinki area. The traffic data are taken from the automatic traffic counting points of the route and speed measurements are made by the floating car method. The essential results of the case study are:

• The traffic disturbance/congestion causes significant extra driving costs (32 million Euro/a) and thus economic losses to the society, extra fuel consumption 5.6 million liters/a), extra emissions (15 million kg of CO2/a) causing health problems and increased climate change, decreases of productivity to the transport sector and indirectly to the whole society, but extra fuel taxes (3.2 million Euro/a) to the taxation authority
• The costs of pollutant emissions are negligible, less than 2 % of driving costs (when the unit values given by the Finnish transport authorities are applied).
• The marginal impacts change fast when the average speed of disturbed/congested traffic changes, and they change exponentially if the average speed decreases.

Discussion improvement possibilities: Five principal improvement measures are discussed in general, and one of them, the bus transportation, in more details. Taking into account the good and some times superior features of bus transportation compared to rail transportation (low own mass compared to trains, energy efficiency of buses already now and, especially, in the future with more energy efficient engines, ability to use existing street and road network and thus low need for infrastructure investments, and flexibility to serve passengers), it should be utilized more, and improve, especially, the main radial routes for bus transportation. Good examples from many cities (Curitiba, Bogota and Mexico City) support this. Simultaneously the car traffic, which seems to increase (future electric vehicles) could benefit, too.

The conclusions

• Transportation problems in big cities seem to grow for the time being causing inefficiency of many activities, and climate change, too.
• There is need for methods to analyze the consequences of transportation problems.
• The Vemosim Method developed is an example how the congestion impacts can be analyzed, and the results produced in concrete form (in quantitative and monetary terms) to decision makers so that it is easier to understand the consequences and get a grip on the problems.
• New improvement ideas are needed which take into account the facts that
  o the conservative transportation sector lonely is not able to solve the problems which other sector of society are creating
  o the best features of different transportation modes (e. g. buses) shall be utilized more

The recommendations: The public sector which has monopolized the urban and land use planning, and planning of transport routes and network, should

• control and steer the growth of cities so that they grow in sustainable way and so that the transportation system can be developed for the growth
• improve radial routes into “boulevards”; then the concrete measures are:
  o separated lanes for different vehicle groups (buses - cars, vans and small trucks – bicyclists - pedestrians)
  o significant four-way level intersections into grade separations and interchanges
  o arrange intelligent transport systems to support bus and coach transportation
• use transport telematics in intelligent way to mitigate traffic congestion/disturbances
• introduce more flexibility into work times in order to reduce peak-hour traffic
• apply congestion pricing together with other ITS services in order to share its high costs
Summary

The paper describes some mega trends, which are or may be basic reasons to the traffic congestion phenomena in cities, indicates the need for analysis of disturbance and congestion consequences. It introduces a method based, among others, on vehicle dynamics incl. engine maps of different type vehicles, how to estimate disturbance and congestion impacts in a concrete way, shows which are the congestion impacts on one radial route in Helsinki. Then it discusses the potential improvement measures in general, and draws conclusions including recommendations.

In recommendations the need for improvement of main radial routes in cities are emphasized and the utilization of bus transportation, because it is in many aspects superior to rail transportation. The own mass of buses is low and that is why the energy efficiency is very good already now, it can use existing roads and streets with minor improvements and requires no new infrastructure investments like rail systems, and it is very flexible regarding passenger service.

Keywords

Urban growth, traffic congestion and disturbances, climate change, impact analysis, energy, pollutant emissions, transport power, improvements, radial routes

1 Introduction

The purpose of the presentation is to describe some development trends, which are or may be basic reasons to the traffic congestion phenomena, indicate the need for analysis of congestion consequences and introduce a method how to estimate congestion impacts in a concrete way, show which are the congestion impacts on one radial route in Helsinki, discuss the potential improvement measures in general, and draw conclusions and make recommendations.

The paper includes six parts: 1) trends in urban development and in development of traffic congestion and disturbances, climate change, and consequent challenges, 2) needs and a method for determining impacts of congestion and disturbances, 3) a case study regarding one radial route in Helsinki area, 4) discussion improvement possibilities, 5) conclusions, and 6) recommendations.

Concerning the method for determining impacts of congestion and disturbances, the first versions of the method have been presented earlier in two ITS congresses [1, 2].

2 Trends in urban development and transportation

There are many reasons to traffic congestion and it is not possible to list them easily. Some general observations are mentioned in form of some mega trends.

2.1.1 Insufficient control of urban growth and lack of flexibilities in work times

The basic reason might be that the cities have too rapid growth in relation to their planned transport systems; too many people and their activities are gathered together without increase in the capacity of transport system.

The public sector has monopolized the development of cities incl. land use planning, and lets the cities grow with insufficient control and steering. The result: the problems in transportation are increasing continuously. Transportation is problem number one in big cities globally nowadays as indicated by a study of the German Siemens Corporation. The problem concerns mainly the
developing countries but also the developed countries. The developing countries have double-timed problem with transportation: traffic congestion and traffic safety. The most victims of the annual 1.3 millions killed in traffic are from developing countries.

It takes time to change the direction of the development, and especially, the attitudes of public sector. The public sector has taken monopoly for urban planning and planning of transport infrastructure. It is time that the public sector realizes its role.

The other reason is that the timing of activities is such that traffic is occurring in a narrow time windows, see figure 4. The capacities of roads and streets are too low in relation to traffic volumes. The private sector has started to apply more flexibility in work and service times, especially, when information technology creates possibilities for that (to work and serve independent from place and time).

The transport technology today together with the land use and city planning as well as with timing rules of society seems not to be able to manage the situation.

2.1.2 Production of cars with robots is effective but innovations in transportation systems are rare

The technology development with robots has lowered the car prices onto a level where people – with their rising incomes – are able and want to use the free man’s right to buy and use individual transport mode, the passenger car. The accounting system of national product emphasizes added value but does not take into account that certain resources are diminishing and many kind of pollution are generated. Many industry sectors (car manufacturing, oil industry, etc.) have utilized the situation. The consequences are: more cars and congestion. Transportation is problem number one in big cities, like the study made by Siemens Corporation indicates.

Taking into account congestion as well as the energy and pollutant problems the vehicle industry has started to do what they can. They have developed the hybrid vehicles which can utilize a part of the energy which traffic congestion otherwise would waste. The hybrids will also reduce pollutant emissions. Additionally, the vehicle industry is starting to re-develop the electric vehicles (invented about 100 years ago), but one of the problems is the low energy density of batteries, at least for some time. If succeeded, the electric vehicles will increase car volumes on the city streets, and thus cause more congestion!

The transportation sector is conservative, and has not been able to renew itself and solve the transportation problems which others are generating. The most innovations in transportation sector are very old. Locomotive and rail systems are from 1820’s, combustion engine and automobile from 1880’s, mass automobile use in USA from 1920 and in Europe and Japan from 1950’s and 1960’s. The gas turbine was developed 1930’s but it was commonly used only after 1950’s. The introduction of new ideas for trains, at least, in city transportation (use of rubber tires in metro trains, etc.), will increase wheel friction and improve steering features of trains and allow reduction of own mass. It will increase energy efficiency of trains, but the development work will take time. The small electric cars – provided a development in battery technology – may cause increase of car traffic in cities and more congestion.

2.1 ITS is promising but real challenges are waiting

ITS (Intelligent Transport Systems) has been a very promising technology since 1970’s, and it seems to be – at least - in the near future. Japan has already many useful applications but the drivers in other countries will have to wait for them. Perhaps during next decade!

The transportation problems have increased continuously in developed countries and, especially, in developing countries. The congestion is a problem in big cities of developed countries, but in big
cities of the developing countries the problems are congestion and traffic accidents. Main part of traffic accidents, which kill 1.3 million people annually, happen in developed countries. And the number of accidents seems to increase fast.

The real challenge for the ITS is development of “a safe car”. The governments should wake up to the reality that each day more than 3500 people die in traffic accident globally. The governments together with the United Nations and car manufacturers should start to do something relevant and not to write slogans. That is why the the United Nations agreement that 2011-2020 will be the global Decade of Action for Road Safety is very welcome [3]. The car should be so safe that the driver in developing country, where the roads and streets are bad, could drive safely. That is the challenge for the transportation sector in the near future.

3 Needs and a method for determining impacts of congestion and disturbances

3.1 Features of congestion and needs for congestion analysis

3.1.1 Feature of congestion

Congestion means continuous speed changes (decelerations and accelerations) and a low average speed in traffic flow. The speed changes cause the engines of vehicles to be continuously in a transient state. As a consequence many of the extra impacts in terms of fuel consumption and pollutant emissions are created by the congestion. Additionally, driving time, noise, etc. may increase remarkably depending on congestion degree. For goods transport companies the congestion means extra costs but decreased transport product in terms of ton kilometer per vehicle hour, and for bus companies extra costs but decreased transport product in terms of passenger kilometer per vehicle hour.

Constant speed (= target speed) of vehicles is ideal from the point of fuel consumption and emissions. Any disturbance which causes a deviation from target speed (decrease or increase) causes increase of fuel consumption and emission amounts, etc, too. When the speed slows down the vehicle is driven at low gear. Then the fuel consumption per distance unit is high, see figure 1.
Traffic congestion is one of the main disturbances which eliminates constant or stable speed, others being road/street crossings, traffic signals, accidents, bad weather, other obstacles on the route, etc. Traffic congestion is sensitive to the existence of other disturbances. Even when traffic volumes are low in relation to the capacity of the route, congestion may appear if there are one or more other disturbances on the route. However, a good traffic management implemented with the traffic signal system or by other means reduces traffic congestion.

When the traffic volume in relation to route capacity is high then one can speak about congestion, and if there are other disturbances, too, the impacts are normally significant.

### 3.1.2 Needs for congestion analysis

Congestion impact analysis is needed

- because traffic congestion is increasing in most countries in general, and especially, in their city areas, and
- because congestion has a remarkable impact on
  - the efficiency of transport systems
  - the energy consumption and pollutant emissions, and thus
  - the climate change
  - because it is very useful and important to know not only verbally, but in numeric amounts the congestion impacts

When knowing the impacts numerically it is possible to get a grip on the problem, to understand the magnitude of disadvantages which congestion creates, and to have decision makers to support solving the congestion problems.

The impact analyzes discover the relationship of the increased amount of fuel tax with the energy consumption and emissions caused by congestion, too. The information about the congestion impacts and fuel tax increase helps the actors in question to understand, also, how well and in which conditions the fuel tax can function as a road pricing system.

In order to convince the decision makers and traffic planners it is necessary

- to measure, analyze and indicate how significant the consequences of traffic congestion are, and
- to indicate measures which can help in mitigating congestion problems in cities

The method developed including the case study is one attempt for this.

### 3.2 Congestion impact analysis in six phases

The impact analysis developed by Vemosim Ltd. includes six phases. The phases divide the work into manageable tasks. It helps to allocate the work between specialized experts, to carry out some phases paralleled in order to shorten the analysis time, and to control the work process.

#### 3.2.1 Six phases of congestion analysis

The phases used in congestion analysis are:

- **Phase 1:** Definition of concepts needed and their units
- **Phase 2:** Differentiation of congestion conditions
- **Phase 3:** Measurements of driving speeds according to congestion conditions
- **Phase 4:** Quantification of unit impacts by disturbance/congestion degrees and vehicle categories
Phase 5: Gathering the traffic volume data and arranging them
Phase 6: Applying the results of phases 1 to 5 and compiling the total impacts in quantitative and monetary terms

3.2.2 Some concepts

Definition of concepts used and their units are made in order that they (the quantities) are operational and can be used in quantitative analysis.

The free driving conditions are conditions, where the speed can be constant and at the level of target speed (normally speed limit). They are defined as the base conditions, which the impacts of congested conditions are compared to.

The traffic disturbance is a factor which causes changes in speed of the traffic flow. The disturbance can be traffic congestion (a high traffic volume in relation to road/street capacity), traffic signal, traffic speed retarder, traffic obstacle, accidents, bad weather, obstacle on the road/street like a sharp curve, icy surface, etc. or a combination of two or more single factors. The congestion is sometimes a result of traffic disturbances.

The disturbance/congestion degree DCD is defined here as follows:

$$DCD = 100 \times (1 - \frac{V_a}{V_t})$$  \hspace{1cm} (1)

where

- $V_a =$ average speed
- $V_t =$ target speed

Earlier [1, 2] we used the concept "the degree of congestion" which we defined in the similar way. However, later in this presentation the short term "congestion degree" is also used.

The average speed (or reached average speed) is defined as the ratio of the proceeded distance divided by the used time. The average speed is reduced by different disturbances.

If the speed reduction is caused by the lack of engine power of the vehicle the reason is not defined here as a disturbance. This kind of factor is normally a longitudinal gradient of a road. On main roads where the horizontal curves are not sharp, the vertical alignment of the road (topography of the terrain) only may have impact on the average speed, especially on heavy duty vehicles. That is why on hilly main roads the deviation of the average speed from the target speed depends on the vehicle performance and on the disturbances and congestion.

The average speed of traffic flow is calculated from the driving measurement data differentiated by route section, by time interval and by driving direction. In free conditions the average speed is very close to the target speed.

The target speed is normally the speed limit value, differentiated possibly by route section, time interval and driving direction.

Impacts of disturbances/congestion are the differences in impacts between the disturbed/congested and base conditions.

The type vehicles represent different vehicle categories in analysis. Each vehicle category has at least one type vehicle, but sometimes more, depending, how homogeneous the vehicles in the category are, and which percentage of the whole traffic volume the category represents.

Cost index is costs in congested traffic conditions divided by costs in free traffic conditions.
Transport power index is transport power in congested traffic conditions divided by transport power in free traffic conditions.

Cost-transport power index is cost index per transport power index in congested traffic conditions divided by cost index per transport power index in free traffic conditions.

The other concepts like differentiation factors, traffic volume and traffic product, etc. and their units are self-evident.

3.2.3 Differentiation of congestion conditions

Differentiation of congestion conditions is useful, and even necessary in order to indicate and quantify the congestion impacts in a clear and understandable way. Differentiation is made by time interval (= time window), route section and driving direction.

The benefits of the differentiation are self-evident and as follows: Differentiation by time interval (by hours) like 6 – 9, 9 – 15 and 15 - 18, helps to see at what time of the day the congestion and its impacts are the most serious ones. Differentiation by route section discovers where the disturbances/congestion and their impacts are generated in order that the improvement measures could be planned and implemented.

3.2.4 Measurements of driving speeds

The driving speed measurements produce the reached average speeds. Field measurements of driving speeds are made - for the time being - by the floating car method. The measurements are carried out according to congestion conditions, in other words by time interval, route section and driving direction on the whole route(s). Based on the field measurement results the reached average speeds are calculated. The target speed is normally the speed limit value. Taking into account the target speed by interval, route section and driving direction the congestion degrees are calculated. However, sometimes it is useful to indicate the target speeds and average speeds by route section, time interval and driving direction only, see figure 2.

The reliability of the congestion degrees results depends on the numbers of speed measurements. As a rough rule at least 5 to 10 measurements for each interval and direction are needed.

3.2.5 Quantification of unit impacts by congestion degrees and vehicle categories

Unit impacts of congestion [impact per vehicle kilometre] by congestion degrees and by type vehicles for the route in question are generated by the computer simulation based on vehicle dynamics and technical data of type vehicles, road and driving patterns. The method is called the VEMOSIM method. The method has been described in details, see [4] and its different applications in several presentations, see [5], [6], [7], and [8].

The principle of the VEMOSIM method

The VEMOSIM method:
1. uses the laws of vehicle dynamics, the technical data of the type vehicle incl. engine maps for fuel consumption and for regulated emissions, of the road, and of the driving technique (driving pattern).
2. calculates continuously the operation state of the engine and the motion state of the vehicle (vehicle speed) at short time interval, and produces data regarding instantaneous speed, fuel consumption, emission amounts, etc.
3. registers the produced data and calculates the averages of each item or of selected items for the given distance unit, for the whole route, etc.

VEMOSIM uses as input values three sets of technical data: data of vehicle (incl. engine),
road/street, and driving technique (target speed pattern and gear change strategy).

VEMOSIM calculates a operation state of engine and a motion state of vehicle (speed and its change), compares the current motion state of the vehicle with the goal speed, takes account the drive resistance forces, calculates and regulates traction forces, instantaneous need of power, and controls gas pedal or brake pedal.

It calculates consumed time, proceeded distance, fuel consumed, emission amounts, etc. at short time intervals (e.g. 0.1, 1, 5 s), registers the calculated results (if needed) for presentation as instantaneous, cumulative, and finally as averages per distance or per other unit for the whole route or for a selected distance.

It can be used for many analysis and optimization tasks, because it can simulate the motion of road vehicles or trains.

**VEMOSIM method for quantification of unit impacts**

When driving on a route the driver tries to maintain a constant speed, which is called a target speed (or a goal speed). In free traffic condition the target speed should be at most the same as the speed limit on the route section in question. The target speed may naturally vary along the route.

In the disturbed/congested conditions the driver is not able to maintain a constant speed (= target speed), because the traffic flow becomes disturbed. Therefore the driver must decelerate and accelerate again and again during the congestion period. This driving speed variation causes impacts like an increased need of the time, fuel consumption and emissions compared to the base conditions.

In the base condition the impacts (fuel consumption, emissions, etc.) are produced with computer simulation by using target speed without any speed change for each type vehicle.

*Congestion is created by varying the driving patterns with different randomly generated, realistic speed changes.* The number of computer drives in the congested conditions is several (normally 15). They result in several average speeds respectively. The computer simulation produces – according to these different congestion conditions - impacts which are greater than the ones in base condition.

The congestion unit impacts are the difference between impacts in congested condition and base condition, calculated per traffic product (vehicle kilometre).

The unit impacts obtained by the computer simulation are combined with the estimated disturbance/congestion degrees of the different road sections according to time intervals (disturbance and congestion degree of a road section varies from one hour to another along the road and from one driving direction to another).

The unit impacts $U_{Imp}(v,i,r,d,c)$ produced by the VEMOSIM method are as follows: where

- $U_{Imp} = \text{unit impact (per vehicle kilometer)}$
- $v = \text{vehicle category (normally five or six)}$
- $i = \text{time interval (normally three)}$
- $r = \text{route section (can be any number depending on the length of the route and the analysis)}$
- $d = \text{driving direction (two)}$
- $c = \text{impact category (normally seven: driving time, fuel consumption, NOx, CO, HC, PM and CO2)}$
Impact equations for each vehicle category

By relating the unit impacts with the reached average speed and target speed, it is possible to generate equations for each impact by type vehicle as functions of target speed and reached average speed (or of disturbance and congestion degree). The unit impact equations have been determined for each vehicle category by using the so called type vehicles. They are selected so that each of them represents the respective vehicle category, as mentioned earlier.

The computer simulations are made for each type vehicle according to different disturbance and congestion degrees and the target speed of the road section. The type vehicles are: car, van, bus & coach, single unit truck (= SUT), truck + semi trailer (= T + S) and truck + trailer (T + T). The simulation results in unit impacts by different congestion degrees and by type vehicles.

Examples of unit impacts for nitrogen oxides of a passenger car is given in table 1, and driving costs impacts for a passenger car in figure 2.

Table 1. Example of nitrogen oxides equation coefficients for a passenger car [g/km] [9]

<table>
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<tr>
<th>Target speed km/h</th>
<th>C0</th>
<th>C1</th>
<th>C2</th>
<th>Correlation coefficient</th>
<th>Standard deviation</th>
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<td>.00134788</td>
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</tr>
</tbody>
</table>

Validation of unit impact values produced by computer simulation: The simulation results regarding fuel consumption (as well as carbon dioxide amounts) are validated with field measurements [10, 11 and 12]. Concerning other pollutant emissions (NOx, CO, HC and PM) they depend on fuel consumption and are determined in laboratories (engine maps for pollutant emissions) but there are no validation measurements through field measurements for the time being. However, it is worth to mention that in most cases the coefficient between a certain pollutant emission and fuel consumption is constant, but the coefficient values of different pollutant emissions are changing with the new engine technology and the new fuel types.
Gathering and refining of traffic volume data

Traffic volume data by vehicle category is needed by time interval, route section and driving direction. When there is an automatic traffic counting system on the route, it is possible to carry out this phase easily. Otherwise the time consuming field measurements are necessary.

In Finland the automatic traffic counting system covers the most entry/exit roads and ring roads of middle-sized and bigger cities, and some main routes on rural areas, too. The counting system measures the speed of the vehicle, driving direction and some characteristics of the vehicle passing the counting point. The vehicles are divided into three basic groups: 1) passenger cars + vans, 2) buses and single unit trucks, and 3) heavy duty vehicle combinations (truck + semi-trailers and truck + trailer). Based on other traffic statistics and lengths of the different vehicles the counting results give traffic volumes by seven vehicle categories. If the density of counting points is high, it is possible to obtain the traffic volume by route section, too.

Applying the results of phases 1 to 5

The results of phases 1 to 5 are applied so that the total impacts in quantitative and monetary terms are obtained.

The unit impacts (phase 4) are combined with the estimated disturbance and congestion degrees of the different road sections according to intervals. Multiplying the unit impacts by the road lengths and traffic volumes of route sections and time intervals, separately in both driving direction, the total impacts are calculated. The results are given in quantitative terms (increased driving time, fuel consumption and emission amounts) and in monetary terms (the quantitative items are multiplied by their unit values) as driving costs (time costs, variable vehicle costs and emission costs). The amount of additional fuel tax by vehicle categories caused by traffic congestion as well as the marginal unit impact changes can be estimated, too. The results are obtained by interval, route section and driving direction, and by type vehicle and then by vehicle categories, and for the whole traffic.

The suitability of the method is indicated in practical applications concerning an arterial route in the mid-sized city of Tampere in Finland [13] and one radial route in Helsinki. The traffic data is...
taken from the automatic traffic counting points of the route and speed measurements are made by the floating car method. The case study in Helsinki is represented in the following.

4 Case study – one radial route in Helsinki

4.1 Features of the radial route

The case study concerns congestion impacts and costs on one radial route in Helsinki. The length of the radial route is about 18 km, and traffic volume varies from 20 000 to 40 000 vehicle per day from section to section. The speed data (target and average speeds) in the Helsinki case study are taken from a study made by the Helsinki City Transportation department [14].

Some aspects of the case study are given here. The collected data include the following

- reached average speeds of traffic flow by road sections, time intervals and directions
- traffic volumes by different time intervals, road sections and driving directions for each vehicle categories
- vehicle categories used: six categories (passenger car, van, coach, single unit truck, truck + semi trailer and truck + trailer)
- time intervals used (by hours) are: Helsinki case: 6 – 9, 9 – 15 and 15 – 18

The unit impacts were determined first in quantities: fuel consumption, emissions (NOx, CO, HC, PM and CO2), and time, and then evaluated in money terms. The target speed varies by road section, and the average speed varies by road section, by time interval and by driving direction.

4.2 Main results of the Helsinki case study

The congestion analysis – using differentiations - gives a lot of other information, like increase of driving costs, fuel tax and reduction of transport productivity, marginal impacts, and distribution impacts. Some figures of disturbance/congestion impacts are given in the following part.

4.2.1 Total impacts

Total annual impacts of traffic congestion/ disturbances on one radial route in Helsinki are seen in table 1. The congestion increases the driving costs 83 percent compared to the conditions where traffic speeds are at level of speed limits (= target speeds) .

In figure 3 one can see the total impacts in quantitative terms by route section when the vehicles are driving towards the center of the Helsinki city.

4.2.2 Rush hour impacts little bigger than non-rush hour impacts

The rush hours, in spite of high traffic volumes (figure 4) have small or only slightly higher disturbance/congestion unit impacts compared to the unit impacts of the mid-day traffic (perhaps the traffic management may have some effect on this?).

4.2.3 Traffic congestion increases the costs of transport enterprises but decreases their incomes

From viewpoint of transport enterprises (bus and goods transport companies) the congestion has a very negative impact, because the driving costs are increasing but the transport power which is the basis of income for the transport enterprises is decreasing.

During morning rush hours the cost-transport power indexes vary between 3.5 and 4.0 in inbound direction, and during afternoon rush hours they are little lower varying between 2.6 and 2.9 in outbound direction.
Table 1. Total annual impacts of traffic congestion/disturbances on one radial route in Helsinki

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
<th>Free traffic conditions</th>
<th>Congested traffic conditions</th>
<th>Difference</th>
<th>Absolute</th>
<th>Relative [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption</td>
<td>Mega litres</td>
<td>5.6</td>
<td>11.3</td>
<td>5.7</td>
<td>+96</td>
<td></td>
</tr>
<tr>
<td>Nitro oxides, NOx</td>
<td>t</td>
<td>40</td>
<td>72</td>
<td>32</td>
<td>+79</td>
<td></td>
</tr>
<tr>
<td>Carbon mono oxides, CO</td>
<td>t</td>
<td>78</td>
<td>582</td>
<td>503</td>
<td>+644</td>
<td></td>
</tr>
<tr>
<td>Carbon hydrogen, HC</td>
<td>t</td>
<td>4</td>
<td>18</td>
<td>14</td>
<td>+324</td>
<td></td>
</tr>
<tr>
<td>Carbon dioxides, CO2</td>
<td>kt</td>
<td>14.2</td>
<td>27.6</td>
<td>13.4</td>
<td>+95</td>
<td></td>
</tr>
<tr>
<td>Driving time</td>
<td>Mega vehicle hours</td>
<td>1.6</td>
<td>2.8</td>
<td>1.2</td>
<td>+77</td>
<td></td>
</tr>
<tr>
<td>Fuel tax</td>
<td>Mega Euro</td>
<td>3.1</td>
<td>6.3</td>
<td>3.2</td>
<td>+100</td>
<td></td>
</tr>
<tr>
<td>Driving costs</td>
<td>Mega Euro</td>
<td>39.0</td>
<td>71.3</td>
<td>32.3</td>
<td>+83</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Impacts in quantitative terms by route sections caused by traffic disturbance and congestion when vehicles are driving towards the center of the Helsinki city

4.2.4 Marginal impacts change fast with speed changes

With the VEMOSIM method it is also possible to quantify marginal benefits of some measures (among others the ITS) if one can estimate how much the measure increases/reduces the speed of the disturbed/congested traffic flow. In figure 4 one can see an example of the marginal impact changes by impact categories if the speed of traffic flow increases/decreases by a small amount (e.g. 1, 5 or 10 km/h). The marginal impacts may be very high as figure 5 shows.
4.2.5 Traffic gets extra costs and the taxation authorities extra fuel tax

The traffic disturbances incl. congestion cause a lot of extra costs to different vehicle categories, small emission costs (1.6 % of driving costs) to the society as whole but the extra fuel taxes (9.8 % of driving costs) to the taxation authorities, as indicated in figure 6.

![Figure 4](image_url)  
**Figure 4.** Distribution of traffic volume (all vehicle categories) by time interval at one point (ATCP 123) of the route

![Figure 5](image_url)  
**Figure 5.** Changes of disturbance/congestion impacts by impact categories when average speed of traffic flow increases or decreases
5 Discussion - five improvement ideas for city transportation

5.1 Five general improvement ideas

There are no simple measures to eliminate traffic congestion and its consequences, but there are measures to mitigate it. There is need of wide arsenal of measures, even radical and drastic measures to tackle the problem. The vehicle industry has started to do what they can. They have developed the hybrid vehicles which can utilize a part of the energy which traffic congestion otherwise could waste. Hopefully the public sector, which has monopolized the land use and transportation planning, and regulates work times, shall do its own part, and fulfill its duties.

Based on 1) the impact analysis of traffic congestion and other disturbances, 2) the megatrends in urban development and transportation as well as 3) energy crisis and climate change the following four improvement ideas for urban transportation are represented.

Measure 1: to control and steer the growth of cities in order to grow in a sustainable way and so that the conservative transportation sector can develop the transportation systems to meet the demand for the controlled growth.

Measure 2: improvement of radial routes of cities into “city boulevards”, especially, for bus transportation. The radial routes have normally the most voluminous traffic flows, cars, buses and goods vehicles. Then the positive and some times superior features of bus and coach transportation compared to rail transportation (low vehicle own mass, energy efficiency already now and, especially, in the future with more efficient engines, ability to use existing street and road network and thus low need for infrastructure investments, and flexibility to serve passengers), can be fully utilized.

If the space of radial routes is wide enough they should be developed into “boulevards” with separated lanes for 1) buses, 2) cars, vans and small trucks, 3) bicyclists, and 4) pedestrians. In planning and design stage the following aspects should be considered carefully: how the traffic
(cars, vans and small trucks) from the boulevard can be infiltrated smoothly into the street network, and how the boulevard can be built down to the city center where the space is limited.

**Measure 3: intelligent use of transport telematics** to mitigate traffic congestion and to improve traffic flows. By using ITS more effectively in managing the traffic flow may reduce congestion. E. g. the number of vehicles entering onto main roads should be controlled so that the traffic flow has time to infiltrate into the street network without congestion. The capacity of traffic routes can be increased, and speed stabilized. The stable speed means that the engines of the vehicles are in a steady state, and as a result fuel consumption, pollutant emission amounts, etc. decrease compared to the congested, unstable traffic flow. Using transport telematics to mitigate congestion requires investments but on the other hand it creates benefits in terms of the decreased impacts mentioned above. The role of intelligent transport telematics is important because its use can improve traffic safety, too.

**Measure 4: add more flexibility into working hours.** In order to reduce traffic volumes during rush hours the working hours should be more flexible. This phenomenon has started already. The private sector but in some cases also the public sector, has started to use flexible working and service hours, and the information technology helps here, because it is possible to work and arrange some services regardless of place and time.

**Measure 5: apply congestion pricing but only when the technology needed can be used also for other ITS location-based services which mitigate congestion and make the traffic flow more fluent.** The costs of congestion pricing technology are very high – at least for time being - compared to the use of fuel tax which is almost free of price. The advantage of congestion pricing is that it can be differentiated by area, which is not possible in the case of fuel tax.

In case of developed countries, one can emphasize again and again the role of public sector in transportation. The governments of all countries (together with the United Nations) could consider more radical measures and require vehicle manufacturers to develop and produce intelligent and safe vehicles. The intelligent vehicles are the key for the developing countries when reducing traffic accidents. They are not able to build their road infrastructure like the developed countries can. The drivers in developing countries should have vehicles which are safe in poor road and traffic conditions.

5.2 Improvements for bus transportation – beneficial and cheap

The possibilities of bus transportation should be studied and applied more thoroughly in cities in order to utilize its many beneficial features compared to rail transportation.

To improve the traffic flows on main radial routes of cities and, especially, to improve them so that bus and coach traffic flows better is very important. If the width of main radial routes is enough, the improvements (lane reservations, bus stops and intersection arrangements) are not expensive. Simultaneously it is important to utilize intelligent transport systems (telematics), and try to arrange green waves for main radial routes.

If the cities are ready to change the city image, the changing of main radial routes into boulevards and of significant four-way level intersections into grade separations and interchanges could make the main radial routes into “bus expressways”. In this way it is possible to avoid or postpone expensive rail transport investments.

Improve of main radial routes of cities into “boulevards” and, especially, for bus transportation in order to utilize its positive features will mean among others the following measures:

- separated lanes for different vehicle groups: 1) buses and coaches, 2) cars, vans and small trucks, 3) bicyclists, and 4) pedestrians
- significant four-way level intersections into grade separations and interchanges
arrange intelligent transport systems to support bus and coach transportation

The necessary improvement investments in infrastructure for bus transportation include:
- lane reservation and necessary arrangements incl. stops for buses and coaches
- changing significant four-way level intersections into grade separations and interchanges
- arrange intelligent transport systems to support bus and coach transportation

The results of this kind of measures will be:
- relatively low infrastructure investments
- flexible and fluent bus and coach traffic flows on principal radial routes which means significant reductions of their fuel consumption, pollutant emissions, driving times and driving costs
- more passengers to buses and coaches, which means better profitability for bus and coach companies and thus less subsidies from tax payers
- less car traffic and congestion (and less fuel consumption and pollutant emissions caused by cars)
- more fluent goods transportation by vans and small trucks and less fuel consumption and pollutant emissions

The case study in Helsinki indicates that the increase of average speed by 5 km/h could reduce the congestion impacts 20 to 40 percent depending on the impact category, see figure 5. It can be mentioned as a positive example in Helsinki. This year (2010) a significant four-way level intersection on one main radial route in Helsinki area (Mannerheimintie and Hakamäentie) was changed into grade separations so that the main crossing traffic flows can flow freely.

Figure 7 indicates the most efficient utilization areas of different transport modes in passenger transportation in Finland. It shows that bus and coach transportation is very efficient from the point of view of energy, when passenger amount per vehicle is from 15 to 60. The reason to the efficiency of buses and coaches is indicated in the legend part of figure 7.

Figure 7. The energy consumption of vehicles in different passenger transport modes in Finland according to passenger volume per vehicle

It is important to remember, that the amount of physical work of moving a vehicle depends linearly on the vehicle mass, and that energy equals work. That is why the mass of vehicles has a major
affect on energy consumption.

**Some examples:** Nowadays some cities have started to utilize this idea, in other words to improve radial routes for buses and coaches. E.g. the South-American cities, Curitiba in southern Brazil, Bogota in Colombia and Mexico City in Mexico, have used this policy and succeeded well without congestion pricing [15]. “Insurgents artery of Mexico City runs in dedicated lanes, avoiding traffic and attracting new riders. This line saves 18 million litres (4.8 million gallons) of diesel fuel per year, one-third from the replacement of small buses with larger ones, one-third from reduction in travel time for all vehicles and one-third from riders switching from cars to the bus. The bus line serves more than 300,000 people per day and saves each rider about 10 minutes in travel time” [15].

### 5.3 Some thoughts about congestion pricing

Neither congestion pricing nor the electric vehicles will solve transportation problems in big cities. Congestion pricing will oblige the car drivers to re-consider their car usage, and if public transport is a real alternative, they might use it. This means less car traffic. On the other hand, the electric vehicles – if battery development will be successful – may increase car use in cities. That is why the improvement ideas mentioned earlier (chapter 5.1) will be valid in the future.

The current policy in many countries is to develop congestion pricing systems. However, it is good to take into account that 1) the car drivers as well as owners and drivers of other vehicle already pay the congestion costs, 2) in the case of car traffic the pollutant emission costs are less than 2 percent of driving costs, and 3) pollutant emission costs are less than 15 percent of fuel tax (in other words the fuel tax is about seven (7) times the amount of pollutant emission costs), as seen in figure 8. The following questions emerge: “Shall the cars drivers as well as the drivers and owners of other vehicles which already pay the congestion costs, additionally, pay extra congestion price meanwhile the public sector fails to do its duties, but collects fuel tax and congestion prices, and uses the fuel tax for other purposes than transportation improvements?”

**Figure 8.** Driving costs with their components and pollutant emission costs related to driving costs and fuel tax
6 Conclusions and recommendations

6.1 Conclusions

- There is a need for numeric information about the impacts of traffic disturbances and congestion, especially, in city area where the impacts are significant.
- The disturbance/congestion impact analysis discovers the consequences of traffic disturbances and congestion in measurable quantities, numerically in quantitative and in monetary terms.
- The impact analysis means a step further to solve the congestion problems, because “when the consequences of a problem can be measured, then it is possible to realize the scale of the problem widely, to discuss the problem and to find solutions to it.
- The traffic disturbance/congestion causes significantly
  - extra driving costs to different vehicle categories, and thus economic losses to the society
  - extra emissions causing health problems and increased climate change
  - loss of productivity of the transport sector and indirectly of the whole society
  - extra fuel taxes to the taxation authority (the state government), especially when the fuel tax is high as it is in Finland and also in the other EU countries.
- The case study in Helsinki indicated that
  - the costs of pollutant emissions are negligible compared to the time costs and variable vehicle costs (at least according to those unit values given by the Finnish transport authorities).
  - the transport power, which is the basis of income for transport enterprises, decreases but transport costs increase drastically in congestion
  - the marginal impacts change fast when the average speed of disturbed/congested traffic changes, and they change exponentially if the average speed decreases
  - the rush hours (high traffic volumes) have minor effect on congestion impacts because during the mid-day hours the traffic speeds are at the same level as during the rush hours, and consequently the congestion unit impacts are at same level, too
- The road/street users pay themselves the disturbance/congestion costs, the taxation authority gets the extra fuel taxes and the society as whole gets pollutant emissions. The congestion pricing may change modal split to the benefit of public transportation, but it will not solve the transport problems in cities.
- The method developed and based on vehicle dynamics is suitable for estimating the main direct impacts of traffic congestion as well as for quantifying the marginal impacts when the speed of traffic flow increases or decreases by small amount (e.g. 1, 5 or 10 km/h).

6.2 Recommendations

The public sector which has monopolized the urban and land use planning, and planning of transport routes and network, should

- control and steer the growth of cities so that they grow in sustainable way and so that the transportation system can be developed corresponding to the growth
- improve main radial routes of cities into “boulevards”, especially, for bus transportation in order to utilize its positive features; the measures are:
  - separated lanes for different vehicle groups: 1) buses and coaches, 2) cars, vans and small trucks, 3) bicyclists, and 4) pedestrians
  - significant four-way level intersections into grade separations and interchanges
  - arrange intelligent transport systems to support bus and coach transportation
- use transport telematics in intelligent way (e.g. green waves) to mitigate traffic congestion and disturbances
- introduce more flexibility into working hours, especially when the continuously developing information technology provides wider possibilities to work independently from place and...
time, and thus reduce peak-hour traffic

- apply congestion pricing together with other ITS services in order to share its high costs

7 References

[9] KOSKINEN Olavi H. (2008), Environmental impacts vs. traffic congestion, Dependence of fuel consumption and emissions of different vehicle categories on congestion degree at different target speed levels. 18th CRC on-road vehicle emissions workshop, San Diego, California, March 31 – April 2, 2008.