

Determination and Evaluation of Traffic Congestion Costs

Ingo Hansen
Faculty of Civil Engineering and Geosciences
Transportation Planning and Traffic Engineering Section
Delft University of Technology

EJTIR, 1, no.1 (2001), pp. 61 - 72

Received: July 2000

Accepted: August 2000

The current estimation of time loss and costs of traffic congestion is lacking a scientifically valid empirical database concerning the queue speed and time loss, as well as a methodological soundness of the value-of-time of commuting and leisure, and may hence lead to serious errors. In fact, the low willingness-to-pay of commuters for using a toll road indicates that the benefit of traffic time gains is estimated to be much lower than a significant part of the wages

1. Introduction

The trip time reduction impact of new motorways due to higher possible speed and grade separated intersections is one of the major generator of benefits in transport economic evaluations. The growing traffic congestion on motorways, however, is characterized in the public opinion as a waste of time and money that should preferably be eliminated by means of increasing the road capacity. As the construction of new lanes or links in the past seemed to contribute to societal welfare and economic efficiency the political pressure for public investments in this sector is becoming stronger, although there is still much resistance to investments because of the negative environmental impacts. The economic loss by traffic congestion on Dutch motorways e.g. was estimated to be Dfl 1.7 billion in 1997 [AVV, 1998]. Any measure to reduce such an amount of cost is welcome if it wasn't counterbalanced by other negative impacts like accidents or environmental damage.

The time loss of road vehicles because of traffic congestion, in general, is determined on the basis of roughly estimated queue lengths, time periods of congestion and mean queue speed. The registration of queue length and duration is mostly done manually by means of observations of highway policemen and might lead to considerable estimation errors. The queue speed varies a lot by time and location and the use of an average value for a whole network can make the estimation of time loss very hazardous.

The calculation of congestion costs is done by applying different values of time for commuter, business traffic and freight transport. However, the split of the congested vehicles according to trip purposes is based often on traffic inquiries at different road links and other time periods. Furthermore, no difference is made between financial costs of companies and social costs. Thus, the responsibility of the involved parties for the creation of external costs and benefits in the transport sector remains unclear.

The overall cost and benefits of suitable measurements for improvement of the traffic conditions on a regional scale are often determined unsatisfactorily, because of lack of appropriate basic data, weak forecast assumptions, and political preferences. Especially, the long-term investment cost for increasing the capacity of a whole metropolitan network seem to be underestimated systematically, whereas the long-term benefits of new roads are overestimated in order to get the project approved.

The main scientific issues with regard to the costs of traffic congestion and appropriate counter strategies are the following:

- How can the time loss of road users be determined consistently?
- Which external effects are involved by road transport and what is their importance?
- How can the costs of traffic congestion be evaluated methodologically and quantitatively?
- Which are the costs and benefits of different strategies?

The paper will, at first, identify the weaknesses of the actual methods of registration and determination of the congestion time loss. Then, the amount of estimated time loss due to congestion is investigated more in detail. Further on, the method to determine the congestion cost that is actually applied in the Netherlands is discussed and the estimated costs are compared to other external effects of road transport. Finally, the most important measures developed in the last decade aimed to alleviate congestion in metropolitan areas will be described in order to draw some conclusions concerning the effectiveness of countermeasures to fight against traffic congestion. The latter will be referred to their contribution to social welfare maximization.

2. Registration and determination of time loss

The time loss of road users due to traffic congestion is determined, in general, by comparing the average trip time on congested links with the trip time under free-flow conditions corresponding to the design speed of the road. As traffic congestion on urban roads occurs quite frequently, mainly because of the saturation of capacity of the junctions, free-flow traffic does practically not exist within cities. The estimation of time loss due to congestion on urban roads therefore is limited to extraordinary incidents, as accidents or peak traffic volume related to festivities, sport events, fairs etc. It is used only for traffic information purposes in order to promote alternative routes and/or modes. This holds as well for rural road links in case of a temporary closing or very high traffic volumes in the vicinity of shopping centers or leisure parks.

On motorways, which were originally designed for free-flow traffic, congestion is observed and monitored regularly in more and more countries. The easiest manner of registration of congested traffic is used frequently by observing the queue length. The observations were made in the past by police patrols using motorbikes, cars or helicopters. They communicated

the actual queue location and length by radio to the control center where it is registered and transmitted further via traffic message channel or public radio. Although most of the daily traffic queues on motorways are known by experience and reasonably well registered, the incidental queues are detected often not at all or too late. As the police patrols only at a limited frequency the observation intervals are rather long (30 min or longer) and the rate of growth of the queue length cannot be determined reliably.

The manual registration of the duration of congestion and of the queue length becomes more and more time consuming, inefficient and imprecise when congestion is spreading. That is why the detection of traffic congestion was automated in the last decade by computing the flow and speed data, which are collected continuously by induction loops. As the older induction loops only count the number of vehicles, they cannot not be used for detailed analysis of congestion and have partly been replaced by devices that can measure also the speed of the vehicles on each lane. This is, of course, quite costly in case of bigger networks. In recent years more and more optic sensors are used for measuring traffic flow and speed. They can be fixed easily at passing bridges and are fed by sun collectors. The traffic data is transmitted by radio to traffic information centers.

The continuous automatic detection of actual flow and speed data per lane by means of induction loops or optic sensors is an absolute prerequisite of reliable traffic congestion analysis. As it will not be feasible to equip a whole motorway network by such measure devices, it is sufficient to install the measure equipment at the heavier loaded links, preferably at distances of 500 m to 1 km. The traffic flow at sections upstream of interchanges, discontinuities (reduction of number of lanes) and heavy loaded on-ramps should be measured and monitored with special diligence.

Even if traffic flow and speed data are available the calculation of the incurred congestion time loss for motorway traffic on a bigger (national) scale is done systematically and regularly, as far as known, only in the Netherlands. Since 1986 the number of time loss measured in vehicle-hours per year e.g. has increased from 11 million up to 19 million in 1997 [AVV, 1998]. This amount contains the registered traffic queues with a length of at least 2 km (at well-known bottlenecks minimal 3 km). The time loss due to congestion is calculated in that study on the basis of the overall assumption that the trip time of every vehicle is increased by 4 min per km of queue length [AVV, 1998 p. 12]. This value corresponds to the difference between a queue speed of 13 km/h and a free-flow speed of 90 to 120 km/h. The computed duration of each queue is then increased by 2.5 min per km of maximal length in order to account for its growth and disappearance respectively.

Table 1. Variation of calculated congestion time loss per queue km

Reference speed [km/h]	Queue speed [km/h]	Volume [pcuplph]	Density [pcuplkm]		Time loss/km [min]
			Upstream	Downstream	
120	14	1200	10	86	3.8
120	13	1500	12.5	115	4.1
120	22.5	1500	12.5	67	2.2
120	60	1500	12.5	25	0.5
90	22.5	1500	12.5	67	2.0
90	13	1500	12.5	115	3.9
90	32	1800	15	56	1.2
90	55	2100	20	38	0.4
60	22.5	1500	12.5	67	1.7
60	13	1500	12.5	115	3.6
60	32	1800	15	56	0.9
60	55	2100	20	38	0.1
60	32	2100	20	67	0.8

The estimated loss of time during traffic congestion is, however, very sensitive to the difference in volume and speed realized (table 1). Both depend on the queue density that, so far, is not sufficiently validated by field measures. Therefore, the upstream and downstream densities at bottlenecks have been derived from a simplified fundamental diagram being applied actually for traffic on Dutch motorways [Hansen and Westland, 1998]. If the maximum speed at capacity (90 km/h) and a queue speed of about 30 km/h was used as reference, the time loss would be only about 1.4 min per km of queue length. Assuming an upstream speed of 60 km/h and a queue speed of 20 km/h the time loss would be about 2 min per queue km. At such a speed level the risk of accidents would be much lower due to the much shorter and less different braking distances of the cars approaching to the tail of the queue and those being already queued. The big difference of preliminary estimation results emphasizes the importance of a more thorough theoretical and empirical basis for the determination of realistic congestion time losses [Bovy and Salomon, 1998].

Moreover, a common definition of the start and the end of a congested traffic flow is still pending. A clear start of congestion on motorways can be observed after exceeding the rate of flow at capacity on at least one lane. On Dutch motorways congested traffic typically starts at a rate of flow of about 2000 vehicles per hour on at least one lane when a sudden decrease of speed has happened and a density of about 20 passenger car units per km is exceeded. For reasons of simplicity, congestion on urban and rural feeder roads that are part of the trips are not considered here.

If time loss due to traffic congestion was assessed technically the question still remains which level of congestion would be optimal from an economic perspective, i.e. referring to allocative efficiency of resources.

3. Assessment of congestion costs

Congestion costs are part of the external costs of road transport, like the costs of accidents, noise, pollution, space consumption and physical or visual barriers. Their significance is to a large extent time and location sensitive. Improved vehicle technology, higher safety standard

of roads, more environmentally-friendly accommodation of road infrastructure, as well as dynamic traffic management may contribute to a reduction of external costs, but the continued growth of car ownership and mobility is likely to outweigh the favorable impacts. Investments in road transport increase net social welfare only if the total social benefits exceed social costs (Verhoef, 1996, p.17). Thus, potential benefits of lower production costs and consumer prices, greater variety in product choice, faster delivery, and spin-off effects such as value-adding or employment in related economic sectors, due to improved accessibility should be higher than the total costs of investment, operation, maintenance, and external effects.

The valuation of external effects, i.e. by putting a monetary value on the effects which are by definition not priced, enables a quantitative comparison of the magnitude of different external effects, as well as an evaluation of economic and social costs and benefits. However, as Verhoef emphasizes, the interpretation of the validated externalities should be done very carefully, because the absolute values are very sensitive to the methods used. The estimated total external costs of transport in different OECD countries may range up to over ten percent of GDP with road transport causing by far the largest share. Estimations of the external costs of road transport in The Netherlands range from Dfl 3 to 25 billion (see table 2), depending especially on whether they include the greenhouse gas emissions and the valuation of air pollution effects.

The congestion costs are estimated at Dfl 300 to 700 million per year, representing only up to 10% of the total external costs of road transport. By comparison, the accident costs are estimated to be about four to seven times higher than the direct congestion costs!

Table 2. Estimates of external costs of road transport in The Netherlands

	Bleijenberg et al. (1994)			Bonenschansker et al (1995)	CvE (1988)	AVV (1998)
	Low	Mid	High			
Air pollution	1.68	7.02	17.67	0.9 - 1.2	1.2 - 1.7	
Noise	0.2	0.64	1.09	0.5 - 1.1	0.3 - 0.8 ¹	
Accidents	1.21	3.67	6.35	2.3 - 3.8	2.0 - 2.2	
Congestion				0.3 - 0.6	0.4 - 0.6 ²	0.7 ³ - 1.7 ⁴
Space occupation					0.3 - 0.9	
Total	3.09	11.32	25.09	4.0 - 6.6	4.2 - 6.2	

¹ incl. soil pollution

² business and freight traffic only

³ queues only

⁴ incl. secondary delays, detours etc.

Sources: Verhoef, 1996 p. 25; CvE, 1988; AVV, 1998

The assessment of congestion costs is mainly based on the estimated amount of time loss of road users due to congested traffic conditions corresponding to HCM levels-of-service D, E or F. The impact of additional gas consumption costs due to congestion is very small [AVV, 1998 p. 12]. The time loss is determined on the basis of automatic traffic count data and manual observations of maximum queue length and duration. The estimated congestion time loss is broken down into commuter, business, freight and other traffic and validated by specific values-of-time. These values are derived as a percentage of the actual gross wages

per hour of different road users (see table 3). The impact of five scenarios with different percentages of gross wage/h per user group on congestion costs has been tested.

Table 3. Value-of-time of road transport in the Netherlands in 1997 per trip purpose

Purpose of trip	Gross wage/h [DFI]	Value-of-time per scenario									
		% of gross wage/h					[DFI/h]				
		1	2	3	4	5	1	2	3	4	5
Commuting	32.18	30	27	20	45	45	9.65	8.69	6.44	14.5	14.5
Business	62.92	100	50	80	130	77	62.9	31.5	50.3	81.8	48.5
Freight	36.94	100	50	80	130	196	36.9	18.5	29.6	48.0	72.4
Other	32.18	25	25	25	80	36	8.05	8.05	8.05	25.7	11.6

Source: AVV, 1998 p. 14

The application of a value-of-time for commuter traffic is based on the assumption that travel time gains of commuters have a certain value and would be allocated to increase social welfare. However, studies concerning the willingness to pay of commuters for the extra time e.g. by the use of toll roads might include hidden benefits and seem to depend a lot on local factors [Amelsfort and Bovy, 2000]. The strong opposition against the introduction of road pricing indicates at least that most of the individual car users, in general, don't appreciate much the monetary value of the gained time.

In principle, the valuation of time losses should be based on opportunity costs of foregone benefits. In case the time loss due to congestion does not change the contracted amount of work time, but reduces the free time of the individuals its value, in general, is correspondingly low and might be neglected in first instance. Only occasionally, e.g. at the start or end of holiday and vacation travel, its value would increase. In case the congestion time loss reduces the available work time and consequently the production volume the time valuation related to the wage level is a good indication. However, it is arguable whether this is really the case, as in actual work conditions and increasing flexibility of working hours the traffic delays are mostly compensated by later end of work or occasionally more intensive work. Thus, in periods of relatively small individual time losses in traffic the economic impact on commuters seems to be almost negligible.

The values-of-time of business and freight trips are based on the estimated wages of employees and lorry drivers respectively. In fact, they vary a lot according to the type of business done and good transported. As empirical studies concerning the composition of daily business trips and the value of cargo transported on roads are specific by region and time, standard values for the estimation of opportunity costs are difficult to obtain. Besides, the official statistics of freight transport are insufficient because of the lack of detailed classification of consumer goods. The estimation of congestion costs of freight transport, therefore, is still hazardous.

Nevertheless, for the year 1997 a total congestion time loss of 19 million vehicle-hours on Dutch motorways and principal highways has been officially estimated. The distribution of the estimated congestion time loss is split according to well-known bottlenecks, other locations, trip purpose, and cause of congestion (see table 4).

Table 4. Congestion time loss of vehicles in 1997 on Dutch motorways and principal highways

Purpose of trip	Time loss by cause of congestion [1000 veh.-h]				Total time loss [1000 veh.-h]	Time loss [%]
	Bottleneck	Accident	Works	Other		
Commuting	5771	818	238	623	7449	38.6
Business	3827	719	284	593	5421	28.2
Freight	1104	218	99	191	1661	8.6
Other	2625	688	475	969	4757	24.6
Total	13325	2444	1095	2376	19237	100.0
Total in %	69.3	12.7	5.7	12.3	100.0	

Source: AVV, 1998 p.16

The big majority of congestion time loss occurs at daily bottlenecks. About 40 % of the congestion time loss affects commuters, whereas business and freight traffic take about 35 % into account. Infrastructure bottlenecks are by far the most important reason of congestion time loss, accidents contribute only 13 % and road works 6 %. About 75 % of congestion time loss occurs during the morning and afternoon peak periods from 7 to 9 a.m. and 4 to 6 p.m. and 91.5 % of the estimated vehicle time loss concerns passenger cars. It is obvious that most of the actual daily road congestion time loss is created by commuters and business traffic.

The estimated congestion time loss measured in vehicle-hours is subsequently converted into person-hours by applying specific average vehicle occupations per time period, type of vehicle and trip purpose based on empirical data of the national traffic model. The average passenger occupation of cars varies between 1.18 for commuters and 2.04 for leisure trips during the week end and holidays.

The total time loss due to congestion on Dutch motorways and principal highways is consequently estimated at about 27 million hours in 1997. The rate of growth of the congestion time loss is about 2 % compared to 1996 being about half of that of the traffic volume. The direct costs of road congestion are assessed to be Dfl 706 million in 1997 according to the value-of-time scenario 1 [AVV, 1998 p. 19]. Furthermore the time loss due to slowed down traffic is estimated at additional 40 % leading to an overall congestion cost amount of Dfl 1.7 million in 1997 [AVV, 1998 p. 21].

This means that the time loss of Dutch road users has been validated on the average at Dfl 38 per hour of congestion. This corresponds more or less to the value-of-time of freight transport in the same scenario and can be explained only by the impact of the much higher value-of-time of business traffic, as both have only a share of 35 % of the total congestion time loss. Minor differences with regard to the estimated percentage of business and freight traffic in vehicle queues on motorways, as well as the really experienced time loss and other values-of-time would lead to significant changes of the congestion cost estimate. Taking alone the possible error of estimate with regard to the queue speed in mind it is quite questionable whether the existing congestion cost estimate on Dutch motorways can be used as a sound basis for developing suitable transport policy strategies.

Especially, the reasoning of the estimated additional costs of delayed traffic, introduced by McKinsey [1986] and applied since in official reports is lacking of theoretical and empirical evidence because the proposed additional amount of costs for further delays (at least 40 %) is only a personal suggestion of the advisor. Neither the reported amount of congestion costs,

nor the additional costs of delayed traffic are proven by a thorough scientific research of the social optimum of costs and benefits of road transport.

In the public opinion, news concerning traffic congestion and estimates of its costs are often used as a means to promote road investment programs. The news and comments create the impression that congestion costs is 'lost money' and public spending in road capacity extension 'saves money'. It is, however, rarely mentioned that other external effects of road transport have much higher external costs than congestion. And it is often neglected that the stimulation of road transport by public investments in upgrading the road capacity might lead for a while to less congestion costs, but involves on the long term even higher other external costs as air pollution, accidents and space occupation.

Furthermore, no distinction is made in many documents between the need of real public expenditure for upgrading the bottlenecks and the 'virtual' private and social costs of external effects which, so far, are not taxed. The claim for reducing private (variable) transport costs through public investments in the road sector does not reflect the extra high construction costs of road extension in densely settled areas. The estimated costs for building of the new motorway link A4 between Den Hague and Rotterdam according to a sustainable (partly underground) design would be about Dfl 250 million/km compared to Dfl 50 million at-grade [Min.VenW, 1996].

Assuming an average of 50,000 vehicles/day, a yearly volume of 15 million vehicles and an economic period of operation of 50 years, the costs for depreciation of the sustainable option would be f 2,5 per trip instead of f 0.5 in case of the cheapest, but environmentally damaging option. The costs of air pollution, accidents or loss of natural space are still not considered. This example shows that the social optimum of internal and external costs of road transport in densely populated areas is quite different from that of less frequently used links in rural areas.

Furthermore, if it was assumed that the average time loss per queue km was only 2 minutes instead of 4 minutes the total amount of estimated congestion costs on the Dutch motorways would be reduced to about Dfl 350 million a year! The existing methodological and quantitative uncertainties indicate the importance of more thorough and diligent research on the economics of road transport in order to develop a scientifically consistent approach for road investment and regulation in saturated networks.

4. Countermeasures in metropolitan areas

As it is very doubtful that traffic congestion costs are as high as stated in Dutch governmental reports the question raises whether strategies to fight traffic congestion are urgent and efficient from a societal perspective. At first, the economic evaluation has shown that the private welfare optimization with regard to traffic congestion is not optimal from the social point of view. Secondly, social welfare maximization in the road transport sector would need to concentrate activities on the minimization of external costs in the most important areas, i.e. air pollution and accidents, in order to secure allocative efficiency. Optimal Pigouvian taxation on car ownership, level of toxic emissions and speed regulation therefore should merit priority in any transport strategy. Thirdly, if traffic congestion is considered as a relevant source of external costs its social costs would be minimal when taxation of road use was focused on business and freight traffic, assuring reasonably low

emission levels, high traffic safety and reliable travel times by regulating all kinds of road vehicles.

In practice, the following measures to fight traffic congestion on motorways and to create benefits in terms of time savings or other social benefits are available:

- Upgrading of capacity
- Demand management
- Traffic management.

The increase of road capacity consists of building new motorways and junctions, adding lanes to existing links and junctions, increasing the lane width of sections with less-than-standard cross section and upgrading the alignment, length and width of slip roads. On a regional motorway network level, these measures need long design and construction periods with in general 5 to 10 years. As the traffic volume and vehicle-kilometers actually grow at a rate of 2 to 3 % per year, the increase of capacity at the critical links and bottlenecks would have to be significantly faster. This would require a doubling of capacity of the most heavily loaded sections in about 15 years.

In densely settled metropolitan areas, as between the four bigger cities of the Randstad, this would mean the construction of some additional 50 % within the next 10 years. This is politically, economically and socially completely unrealistic. Even if sufficient private capital funds were raised for the building of new links and operation as toll-roads, the limited engineering and legal manpower would probably not allow to plan and build successfully more than some 20 new motorway-kilometers in the next 10 years in this area. Assuming unit costs of DfI 250 million per km the total amount of capital needed would be about DfI 7.5 billion including financing costs.

After put into operation the new links would have to generate a yearly revenue of some DfI 500 million which corresponds to an average of some 200 million trips paying each f 2.5/car in order to equal its construction costs. Even if a mean trip length of only 10 km was assumed the 20 km new toll roads could not produce reasonably more than 30 million trips per year. This means that a pure private capital funded Design-Build-Operate toll road project is unfeasible for financing an environmentally sustainable design of a motorway in the Randstad. A charging of the marginal social costs of the toll roads alone would need to be assessed more in detail. In fact, the private capital needs the public partnership in order to finance the majority of capital funds for the upgrading of the motorway network.

Furthermore, the paradox is well known that creating additional capacity by new links or lanes will attract even more traffic to the route that offers the least trip time or travel cost [Arnott and Small, 1994], because the temporarily lower traffic density allows for a higher speed. This leads to a redistribution of traffic flows in the whole network and encourages a 'back to the peak' behavior. Thus, limited extension of the capacity is no remedy against traffic congestion. The queue length upstream of bottlenecks might even grow after extending the number of lanes by one or two, while the travel time remains unchanged. If car ownership and use continues to grow harder than the increase of network capacity in future and no other measures are taken, then the periods of traffic congestion and the number of affected road users will grow automatically.

The main tools of demand management are stimulating the use of other than congested road links, encouraging the use of heavily loaded links at off-peak periods, introduction of road pricing and supporting the construction and use of other modes of transport. Alternative, less

loaded links with competitive travel times in peak periods usually don't exist anymore in metropolitan motorway networks. Actual traffic information by radio or variable message signs in order to navigate the traffic demand which exceeds the capacity of some links along less or still not congested routes can relief congestion only in off-peak periods when there is still spare network capacity. However, the dynamic modeling and redistribution in practice of traffic flows in networks assuring a significant shorter trip time via a detour is quite complicate, not mentioning the impact of different user's reaction on the recommended detour. In case a network is saturated for a longer time period and no alternative routes exist, the dynamic traffic information cannot reduce traffic congestion.

The introduction of road pricing can help to reduce traffic congestion significantly by charging the road users with the marginal social costs of transport. Its impact seems to be greater if the pricing was different during peak and off-peak periods in order to stimulate the use of spare capacity in off-peak periods, but rarely any modal shift to public transport can be expected [Pepping *et al.*, 1997]. This is due to the fact that for most of the car users the height of the assumed user charge (DFI 4.5/trip) or the reduction of train tariff (10 %) still does not compensate for the perceived additional private cost of inconvenience, waiting and longer trip time by public transport.

In practice, the introduction of congestion pricing is much more difficult than the opening of a new toll road where the user charge may be equal. In the first case, the road users perceive the pricing as extra cost and will oppose to it as against a new tax, whereas the toll road creates a new (time saving) travel opportunity that might be worth to pay for. The recently modified plans of the Dutch government to test road pricing on the motorway network in Amsterdam, Rotterdam and eventually Den Hague still create much criticism because the cities are afraid that it will worsen its accessibility and they might not participate sufficiently at the revenue.

Finally, congestion can be limited or even avoided by means of influencing the traffic flow on site. The 'soft' traffic management option is restricted to the application of continuous registration of the volume and speed of traffic flows and the use of dynamic traffic information via RDS/TMC, variable message signs and rapid incident intervention. It believes in the capability of self-organizing of the ensemble of road users, road infrastructure and monitoring equipment [Kerner *et al.*, 1996] and it is estimated that the use of optimal monitoring and traffic control equipment on heavily loaded links could lead to a 50 % increase of capacity [Kerner, 1998]. This expectation, however, is based on short time intervals with a very high flow rate that necessarily leads to congestion [Hansen and Westland, 1998a].

The 'harder' option of traffic management is characterized by the control of access to the network, speed control, and by the creation of dedicated lanes for trucks, buses or high occupancy vehicles. It is based on the conviction that the individual road user is unable to estimate the impact of his own behavior on the stability of the traffic flow in the network or to react adequately upon downstream incidents. The application of broad-scale regulatory measurements, as ramp-metering and buffers at important on-ramps and upstream of junctions [Broeren and Westland, 1999] and the obliged standard use of intelligent speed control devices in every motor vehicle would reduce the queue length at bottlenecks and improve the traffic safety significantly. It allows for splitting of the approaching vehicles into different market segments (e.g. trucks, buses, business cars, other cars) and processing them according to urgency, economic importance or readiness to pay [Hansen and Westland,

1998b]. At the same time the dynamic control of volume and speed of the traffic flows on a network level can assure a high degree of occupation of the network at predetermined maximum travel times.

5. Conclusions

The amount of congestion costs seems to be systematically overestimated, especially when compared to other external effects, like air pollution costs or accident costs. Essential for any successful strategy to maximize the social benefits of transport and to minimize the costs of traffic congestion is a combination of efficient transport economy measures, sustainable road design, and intelligent traffic control. Technical means may achieve a homogenous flow of traffic at a high, but limited level of capacity, speed and safety. However, the road users are human beings who follow their own interests and often do not know or disregard the social impacts of their behavior. The best way to avoid as much as possible unforeseen delays and accident risks due to traffic congestion is to verify a more even distribution of the traffic volume over daytime and over the network. This can be achieved by a continuous control of traffic volume on the main roadway and its entries/exits, the control of vehicle speed and by charging the road users with the marginal social costs of road transport, especially during peak periods.

As much opposition against raising road user fees is to be expected, it is very important to leave the free choice for/against using congested road links or toll roads and to create sensible social benefits by improving the overall quality and safety of living and transport for the people. In order to avoid a social segregation and polarization into classes of rich and poor road users, a partly compensation of low- income people for the extra cost of road use via tax reductions should be considered. This requires a radical change of the conventional paradigm of free-flow road traffic in favor of economic regulation and effective control of traffic flows. A smooth traffic flow in motorway networks at reduced speed and maximum capacity that recovers its marginal social costs and contributes to a higher level of safety and quality of living should be part of a comprehensive strategy for the optimal use of transport facilities.

References

- Amelsfort, D.H. van, Bovy, P.H.L. (2000) 'Mode choice behaviour at the San Diego value pricing project', in: Bovy, P.H.L., Thijs, R. (eds.) *Estimators of travel time for road networks*, Delft University Press, p. 321-340
- Arnott, R., Small, K. (1994) 'The economics of traffic congestion', *American Scientist* 82, Sept./Oct., p. 446-455
- AVV Adviesdienst Verkeer en Vervoer (1998) *Filekosten op het Nederlandse hoofdwegenet in 1997* (in Dutch), Rotterdam
- Bovy, P.H.L., Salomon, I. (1998) 'The spread of congestion in Europe', CEMT/RE/TR (98) 1, Paris

- Broeren, P.T.W., Westland, D. (1999) 'Traffic flow in congested motorway networks using buffers', TRB 1612, p. 34-41
- CBS Centraal Bureau voor Statistiek (1998) *Kerncijfers verkeer en vervoer 1998*
- CvE Centrum voor energiebesparing en schone technologie (1988) *Waardering van negatieve externe effecten van het autoverkeer* (in Dutch), PB IVVS report 88.09.19
- Hansen, I., Westland, D. (1998a) 'Stauentwicklung richtig deuten' (in German), *Int. Verkehrswesen* 50 (7+8), p. 345-347
- Hansen, I., Westland, D. (1998b) 'Verkehrsstaus rational betrachtet' (in German), *Straßenverkehrstechnik* 42 (11), p. 586-592
- McKinsey & Company (1986) *Afrekenen met files* (in Dutch), Min.Verkeer en Waterstaat, Den Haag
- Kerner, B.S., Konhäuser, P., Schilke, M. (1996) 'A new approach to problems of traffic flow theory', in: *Transportation and Traffic Theory*, Proc. 13th Int. Symp. on Transp. and Traffic Theory Lyon, France, 24-26 July, p.119-145
- Kerner, B.S. (1998) 'A theory of congested traffic flow', paper 3rd Int. Symp. on Highway Capacity, Copenhagen, Denmark, 22-27 June
- Pepping, G.C., Rietveld, P., Verhoef, E.T., Vleugel, J.M. (1997) 'Effecten van prijsmaatregelen in het personenverkeer' (in Dutch), *Tijdschrift vervoerswetenschap* 33 (4), p. 345-361
- Min.VenW Ministerie van Verkeer en Waterstaat (1996) *Trajectnota/MER Rijksweg 4, Delft-Schiedam* (in Dutch), p. 221
- Verhoef, E.T. (1996) *Economic efficiency and social feasibility in the regulation of road transport externalities*, PhD thesis, Vrije Universiteit Amsterdam
- Vonk, T., Westerman, M., van der Vlist, M. (1999) 'Dynamisch verkeersmanagement op niveau', *Verkeerskunde* 50, March, p. 20-25
- Vlist, A.J. van der, Verhoef, E.T., Rietveld, P. (1998) 'Rekeningrijden: spitsvondigheid aan de stadsrand?', *Verkeerskunde* 49, September, p. 14-18
- Transportation Research Board (1994) 'Highway Capacity Manual', *Special Report 209*, Washington DC