MOTORIST CONQUEST IN BUDAPEST

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Economic growth requires well functioning transport systems. The paper deals with the problems associated with ever-increasing car use and traffic jams in Budapest. Car scarcity was the major problem that impeded car use two decades ago which has transformed into road scarcity since then. Road capacity is limited in the Hungarian capital, only the public transport can help to satisfy medium run travel demand of residents. As motorization and car use grow congestion related time loss, petrol and pollution costs put a heavy burden on Budapest. International experience shows that restrictions on cars can mitigate congestion. In many large cities introduction of road pricing in central areas has become one of the most successful traffic management solutions. Experience in London and Stockholm confirms that citizens support car use restrictions even if they are placed on car use.

Keywords: road pricing, congestion, traffic theory, transport economics, car travel, Budapest

JEL classification index: D62, H23, R11, R14

Running title: Motorist conquest

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INTRODUCTION

Over the last decade the number of cars per capita increased by 22 percent in Budapest, together with a dynamic growth of Hungarian residents' income. Congestion costs are increasing and sooner or later, they will exceed even the initial transport investment expenditures. The average traffic speed has dropped to 15 kilometre/hour, below the speed of a cyclist in central districts. The deceleration of traffic is costly because passengers are idle in traffic jams, hence they can allocate less time to work and spare time activities. Moreover, swelling fuel-consumption and more intensive pollution also add to the costs.

Both theoretical concepts and empirical experiences support the conclusion that the automobile does not provide an efficient mode of metropolitan transport. The load of transport systems is four times larger if travellers choose cars instead of the public bus and there exists a similar size difference between the fuel-consumption of the two modes. The physical dimensions of Budapest constraint the further increase in car use and the development of public transportation is crucial in the medium run.

The share of cars in the modal split jumped and followed international patterns in Budapest 30 years later than in western cities. Therefore, the congestion phenomena and issues of intensive car use also need to be addressed with a lag. As a result, similarly to other challenges of economic emergence, the investigation of international benchmark solutions to congestion can promote a faster economic catch-up process. According to international experience, the development of public transportation services alone is insufficient to curb increasing travel demand from car use. The introduction of road pricing in central areas has become one of the most successful traffic management tools in recent years.

This study comprises four building blocks and is organised as follows: How does the increasing number of cars impact traffic speed and what are the costs of traffic jams? Section 1 discusses fundamental traffic theory and transport economics so as to answer these questions. Section 2 presents the most important determinants of car use in urban regions and compares traffic indicators of Budapest with the indicators of other large cities. Section 3 investigates how the traffic conditions have developed in Budapest since 1990 and presents the main pitfalls of car use. Finally, Section 4 discusses the practical considerations of road pricing, summarises the experiences of four cities and touches upon the possibilities of Hungarian implementation.

CONCEPTUAL BACKGROUND

The research of urban transport is an interdisciplinary field and the boundaries between traffic engineering sciences and transport economics are blurred. The fundamental problems can be linked to traffic engineering; therefore, the following conceptual outline provides first an overview of engineering theories before building the economic concepts on this basis.

Fundamental traffic engineering theories

The most important measures of road traffic are the following:

- traffic speed (V),[1]
- traffic density (K) and
- traffic flow (Q).

While the knowledge of speed is sufficient to describe the motion of individual vehicles, one would require further information regarding traffic density and flow to understand the behaviour of vehicle groups and traffic conditions. Traffic density is measured by the number of vehicles per a unit road (vehicle/km)[2]. For instance, the bigger the number of cars entering Dob street[3], the smaller the available space and safety gap, hence traffic density increases. Traffic flow can be defined as the number of cars passing by a given point (or a set of these points) per a unit of time. (For the sake of simplicity, I will refer to these indicators as density and flow in the following.) The flow can be derived from the product of speed and density, and therefore its measure is vehicle/hour.

$$Q = V \cdot K \qquad (1)$$

Flow and speed can be easily linked on the basis of Equation (1), as well as flow and density. However, one should also understand the relationship between speed and density so as to investigate traffic conditions in more depth. In his pioneering work, Greenshields (1934) used a linear function to explain the relationship of density and speed:

$$V = V_{\max}\left(1 - \frac{K}{K_d}\right) \qquad (2)$$

[1] The definition of speed is the distance traveled per a unit time and it is measured by km/hour.
[2] Because density is influenced by both dimensions of roads, one could measure density with another indicator (vehicles/lane km) more accurately.
[3] Dob street is a busy narrow diagonal street in central Budapest connecting two important major roads.

The theoretical maximum speed (V_{max}) is influenced by many factors: the parameters of vehicles, road conditions and rules of the road (*Figure 1.a*). Traffic speed decreases from this theoretical maximum point as density approaches its maximum value in traffic jams (K_d). If density increases, drivers have to keep an eye on more and more vehicles, they need to brake more frequently and intensively. As a result, traffic speed decreases due to safety reasons.

$$Q = V^{\max}(1 - \frac{K}{K_d}) \cdot K = V^{\max}(K - \frac{K^2}{K_d}) \qquad (3)$$

The relationship between flow and speed follows from the above argumentation, and so does the relationship between flow and density. As density grows, traffic flow increases up to its maximum, while thereafter it begins to decline. This threshold is the *capacity* of the road or road system and is denoted by *c* sub index in the b segment of *Figure 1.*

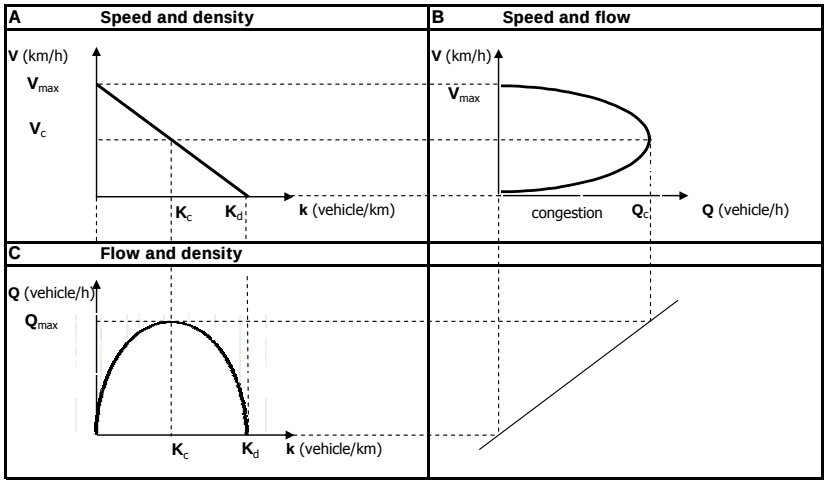


Figure 1. Relationship among traffic speed, density and flow

Traffic flow becomes unstable at the capacity level, and if density grows further, the flow begins to drop at the backward bending side of the curve. Indeed, overload can even clog the road causing gridlock.

Many authors have attempted to refine the relationship between density and speed. Greenberg (1959) based his concepts on fluid dynamics theories, and applied logarithmic functions. Lindsey - Verhoef (2002) referred to many factors which influence the relationship including the width of lanes, speed limits, curvature and quality of roads. Goodwin (2002) emphasised the role of weather conditions because these have an indirect impact on the speed-density relationship through visibility conditions, the adhesion coefficient of roads and the

mood of drivers. The monograph by Gartner-Messer-Rathi (1997) provides a comprehensive overview and systematisation of the models.

The relationships discussed above can help to understand traffic conditions on roads without nodes such as motorways. Urban transport systems are more complex because they include junctions, bottlenecks, and are influenced by traffic management. However, the discussed relationships can be used to explain the general urban traffic conditions too. There exist opportunities to refine the relationships further, if one integrates microscopic traffic flow theories, which discuss smaller units of urban traffic (junctions, individual roads), into macroscopic systems. This approach, however, does not alter the general relations. Traffic decelerates if the density increases in urban networks as well, and flow equals the product of speed and density. Simulation results[4] of Mahmassani et al. (1984) and Williams et al. (1987) also supports this argumentation.

The economics of urban traffic

The use of automobiles became common in the developed countries in the late 1950ies and the analysis of traffic also emerged as an important research field in economics by this time. Walters (1961) was one of the first authors who managed to successfully merge traffic theories with economics. In his microeconomic framework the price of travelling is linked to travel time. Travel time (t/s = 1/V, t – *time*, s – *distance*) changes in invert proportion to speed. If speed declines then travel time lengthens, and as a consequence, the *average social cost (ASC)* of travelling also increases. For the sake of simplicity, let us assume here that drivers form a homogenous group and face similar costs.

Lengthening travel time implies costs of shrinking working- and spare time which are denoted by *b* in Equation (4). Moreover, fuel consumption, environmental and other costs (*d*) also rise when travelling speed declines. Further costs, which are independent from the travel speed (maintenance costs, insurances, taxes), are denoted by *a*.

$$ASC = a + \frac{(b+d)}{V} \qquad (4)$$

The ASC curve (*Figure 2*) has a backward bending shape because it is derived from the flow curve (*Figure 1.b*). For example, a given traffic flow (Q_A) can be achieved with lower cost (C_A) or higher cost ($C_{A'}$). As speed declines travelling time and hence also costs go

[4] The author of this study conducted simulation with the Netlogo 3.1.3 software and arrived at similar results. The simulations can be accessed at http://www.erhartsz.extra.hu/traffic_en.html.

to infinity. The *marginal social cost* (*MSC*) represents how much extra cost is caused by an additional driver. The marginal social cost goes to infinity already as the traffic flow approaches the capacity level.

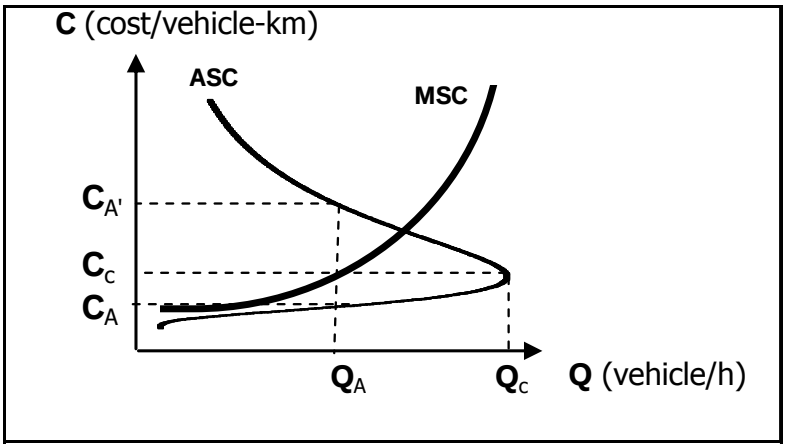
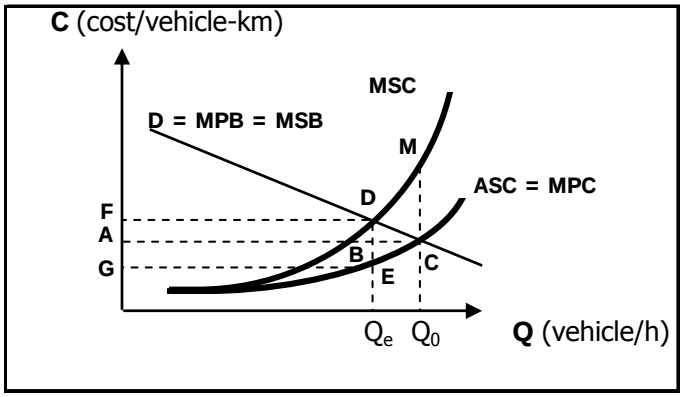


Figure 2. The cost curves of road transport

Travel demand can be also expressed as a function of travel time. Rising traffic density has an increasing impact on travel time and its price, therefore the demand curve (D) is downward sloping. For simplicity's sake, let us assume in the following that the demand curve equals individual drivers' *marginal private benefit* (*MPB*) and also the *marginal social benefit* (*MSB*).



Source: Button (2004)
Figure 3. The simple diagram of road pricing

According to microeconomic concepts, traffic flow is optimal if the marginal social benefit is equal to the marginal social cost (*Figure 3*). Drivers take into account their own expenses, which is equal to the *average social cost* (*ASC*) in case the drivers form a homogenous group. However, drivers ignore the indirect cost of their car use imposed on drivers in other vehicles, which is the *marginal social cost* (*MSC*). Consequently, the traffic

flow is above the optimal level ($Q_0 > Q_e$), and travellers face the well-known problem of microeconomics, the *tragedy of the commons* and the consequences of excessive individual consumption. The dead-weight loss of congestion can be calculated from the difference of the marginal social cost and average social cost (triangular DMC on *Figure 3*).

There are several ways to cope with congestion and minimise the dead-weight loss but one particular solution, road pricing is an especially efficient tool and became very popular in practice (see this study's last section). The major goal of road pricing is to reduce congestion and confront drivers with the externalities of car use. The optimal toll imposed on drivers can be calculated from the difference of marginal social benefit and marginal social cost. The imposition of the optimal toll (DE in *Figure 3*) ensures that the marginal social benefit is equal to the marginal social cost. The toll revenues (GEDF rectangular in *Figure 3*) stem partly from the shrinkage of consumer surplus, which should be returned to road users, for example in the form of infrastructure development.

URBANISATION AND MOTORIZATION

What are the most important factors influencing car use in urban areas? I discuss this question in two strands. The first strand concerns the general aspects of urban motorization, and the second compares traffic indicators of emerging East European cities with those of other European cities.

Why (not) drive in cities?

From an economic point of view, transport is a special good. Its demand is determined by the needs of economic agents to change place or transport other goods, while its supply is influenced by infrastructure and the transportation fleet. The agents seek the optimal solution taking into account their physical and budget constraints. The following section deals with factors playing a key role in determining car use in urban areas (*Figure 4*).

The growing demand for transport is an obvious consequence of economic growth because the main driver of growth is the transport of resources and trade. Consequently, transport and travel demand shifts upwards due to economic growth. The car fleet has been almost doubled in the EU-15 countries since the beginning of the 1970ies, and more than 170 million cars ran on European roads in 2000.

Although travelling by car is by far not the optimal travel mode, it is indisputable that cars have several advantages. First and foremost, cars provide freedom to their passengers. The range of cars is almost unlimited, drivers can time the ride, and the speed can be flexibly adjusted. Finally, the role of prestige can not be overestimated; the automobile is still a status symbol in many countries.

Concentration is the very essence of urbanisation. Townspeople live in crowded small places, hence information spreads faster, and residents can enter into transactions from job search to shopping more easily. Hence, it is not surprising that areas with the highest per capita income often overlap with places where the population density is the highest.[5]

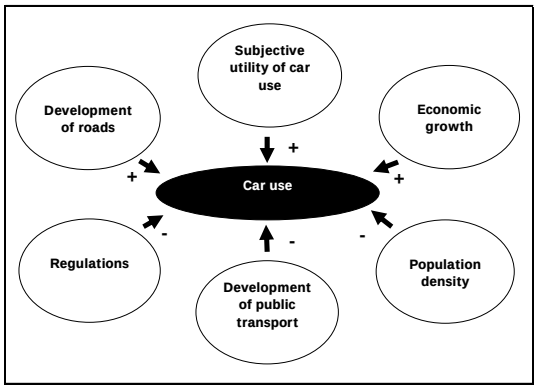


Figure 4. The main drivers of car use in urban areas

However, frictions are inevitable in crowded cities because the space per capita is scarce. Travelling by car becomes more expensive in cities since the car is not among the most efficient travel modes. The automobile looses many of its advantages in urban areas. During rush hours, the freedom cars may give ceases to exist, and it is not the driver who determines travelling speed and the journey is constrained by traffic conditions.

The choice between travelling options is also influenced by the features of other travelling modes. The more reliable the public transport network and the higher its quality, the more travellers choose the bus, tram or subway instead of the car. However, international experiences show that the development of public transport itself has modest effect on travelling customs. Car use reacts more sensitively to rising costs such as waiting time, maintenance costs, tolls (Facts and Results (2006)).

Rules and regulations of traffic are also among the key drivers of traffic conditions. As a matter of fact, conditions can worsen even if individuals strive for optimal solutions. The

[5] Fujita (2004) gives a comprehensive overview of urban and spatial economics.

authorities have many tools at their disposal to influence the modal split and cope with externalities (bus lanes, tolls, parking fees, urban design, etc.).

The load of roads and congestion can lessen if travellers change from cars to other transport modes. A smaller car occupies five times bigger area of the road network and consumes five times more energy per traveller than a bus, assuming average passenger numbers for both travelling modes. Riding a bicycle is one of the most efficient ways of urban transport for shorter distances. Its energy consumption is the tenth of the car's and it uses scarce roads more economically. The emission of transport means is approximately proportional to their energy consumption. Therefore, the bus and the bicycle are not only space and energy efficient but they are also environment friendly compared to the car.

Table 1
The road use and energy consumption of travelling means

	ABSOLUTE MEASURES			RELATIVE MEASURES	
	A. Car*	**B. Bus****	**C. Bicycle*****	**Car / Bus**	**Car / Bicycle**
1. Length (m)	3.7	12.0	1.6	0.3	2.3
2. Width (m)	1.7	2.6	0.6	0.7	2.8
3. Number of passengers					
seats (number, maximum)	5	30	1	0.2	5.0
average (number)	1.5	34	1	0.1	1.5
total capacity (number, max)	5	100	1	0.1	5.0
5. Road use (m^2)					
total	6	31	1	0.2	6.6
per seated passengers	1.26	1.02	0.96	1.2	1.3
per average passenger	4.19	0.90	0.96	4.7	4.4
per maximum passenger number	1.26	0.31	0.96	4.1	1.3
5. Energy consumption (kJ/passengerkm)					
per seated passengers	413	450	159	0.9	2.6
per average passenger	1376	397	159	3.5	8.6
per maximum passenger number	413	135	159	3.1	2.6

* Suzuki Swift
** Volvo 7700
*** 70 kg male

Source: Volvo, Suzuki

International outlook

Practical experiences of European cities confirm the theoretical hypothesis that cars can not satisfy transport needs in urban areas (*Table 2*). This fact was recognised by East Europeans only in the recent past because the number of cars per capita increased immensely in the previous 15 years and in some cases also exceeded West European standards. The convergence of car fleet can be considered as very dynamic as the income of East European cities is still around 30-50 percent of West European citizens. If incomes were compared on the basis of purchasing power, the gap would obviously close somewhat but the latest developments might reflect that East Europeans value cars more than West Europeans.

Table 2
Infrastructural and transport indicators across European cities (2005)

	Vienna	Cologne	Prague	Copenhagen	Lyon	Warsaw	Bucharest	Rotterdam	Budapest	**Budapest / sample average**
Size										
Population (1000 residents)	1550	1021	1166	500	580	1688	1960	600	1705	**1.5**
Population density (1000 residents/km^2)	3.7	2.5	2.4	5.6	9.4	3.3	8.2	2.9	3.2	**0.7**
GDP/capita (euro)	26853	17854	12266	54000	30204	13315	4237	26455	13760	**0.6**
Infrastructure										
Bus network (m/1000 residents)	408	461				565	512	705	818	**1.5**
Metro network (m/1000 residents)	39			22	100	9	63	87	36	**0.7**
Bus lanes (m/1000 residents)	35		9	60	116	6			28	**0.6**
Ciclyng roads (m/1000 residents)			51	710	283	113	3	500	60	**0.2**
Roads (km/1000 residents)			3	1	7	2	1	3	3	**0.9**
Vehicle fleet										
Cars (number/1000 residents)	421	404	556	208		466	194	300	357	**1.0**
Motorcycles (number/1000 residents)	5	3	50	17	177	37	8	97	9	**0.2**
Traffic										
Speed of public busses (peak-hour, km/h)	16.0	21.0	26.3	14.0	17.0	17.2	16.0	16.0	21.5	**1.2**
Speed of cars (peak-hour, km/h)	22.0	40.0		28.0		20.0	32.6	26.0	22.3	**0.8**
Number of road injuries (number/year/ 1000 residents)	4.4	4.4	3.4	0.9	19.5	1.3	0.3	2.7	3.1	**0.7**

Source: European Commission, Urban Transport Benchmarking Initiative

Quantitative infrastructural indicators show that the difference between East and West European cities is not significant. The least developed element of Budapest's infrastructure is the bicycle road network. We do not have indicators to measure the quality of public transport (hours of operation, frequency of service, punctuality, cleanness), although these effect the modal split too. It seems that the wider comfort gap between cars and public transportation also contributes to the East European popularity of cars.

North European cities can provide a benchmark to emerging urban areas. Copenhagen and Rotterdam have the highest GDP per capita. Despite their wealth and richness, car use is moderate due to high population density and the environment friendly attitude of citizens. The number of cars per capita is only 208 in the Danish capital and 300 in Rotterdam.

The bicycle is much more dominant in the modal split of the two Northern cities. Their bicycle road network is the longest among the analysed cities and consequently, the number of road injuries is smaller in relative terms.

The motorcycle provides a private way of travelling similar to the car, but it puts a smaller burden on the road network and it can help to get over congested areas more easily. In most East European cities the motorcycle is less popular than in Western Europe. While 1000 residents own 177 motorcycles in Rotterdam and 99 in Lyon, in Budapest and Warsaw these figures are 9 and 37, respectively.

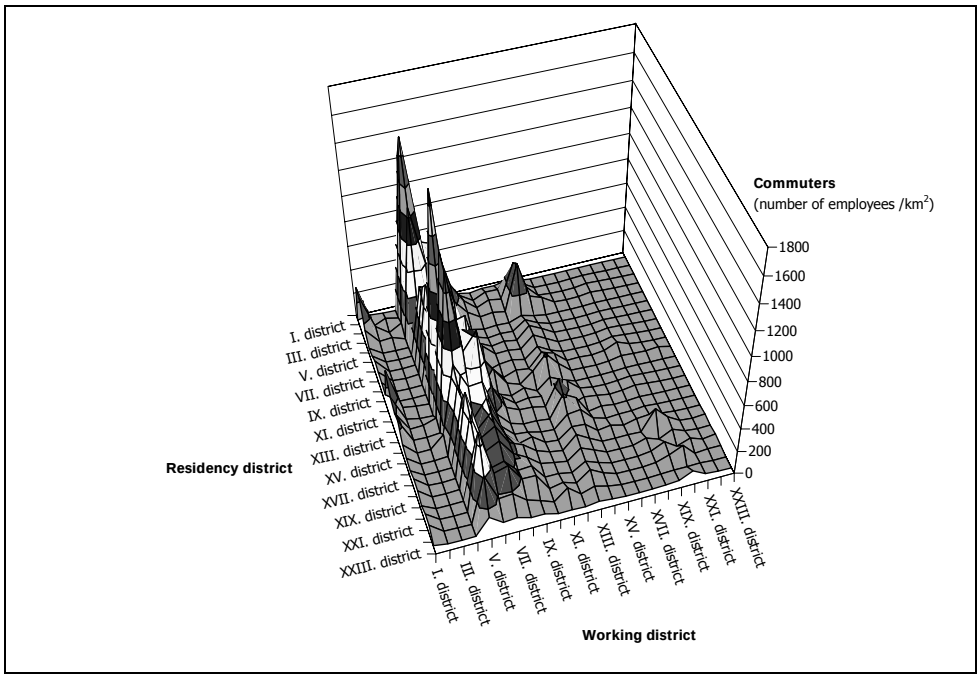
BUDAPEST GRIDLOCK

Does anybody remember how many cars Hungarian families owned at the beginning of the political reforms? And how many cars do they have today? The major problem was car

scarcity that impeded car use two decades ago. However, car scarcity has transformed into road scarcity since then. This section presents a time series analysis and its results. First, the issue of urban spatial structure is addressed before traffic patterns are analysed. Second, the shift in modal share toward car use will be discussed. Finally, consequences and costs of traffic congestion will be investigated.

Urban spatial structure and transport

Similarly to most other European cities, Budapest is a monocentric city. Economic activity is concentrated in the city centre while outer districts serve as residential areas. While in 2001 only 9 percent of the population lived in central districts (district V., VI., VII.), 21 percent of the employees commuted to these districts to work. Plotted on a surface diagram, employment activity is clearly the highest in the city centre (*Figure 5*).



Source: Hungarian Statistical Office (KSH), 2001 Census data
Figure 5. Distribution of employees among living and working districts

There is a shortage of information concerning recent trends because only domicile's geographic distribution has been available since the census in 2001. Residents continued to migrate to outer districts and the share of residents in districts V.,VI.,VII. dropped to 7 percent, while the number of residents in outer districts remained unchanged.

Despite more pleasant living conditions that outer urban areas provide, commuting becomes longer and more complex if residents settle farther from central areas. Moreover, car driving gets more attractive because travelling by public transport need more effors for longer distances. The effect of intra-city migration on modal share is reflected by the drastic, more than 20 percent drop of passengers on suburban rails (HÉV), which transports commuters to inner districts (*Table 3*).

Table 3
The key transport indicators in Budapest (1994-2005)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Change (%) (1994-2005)
Size													
Population (million)	1.91	1.89	1.87	1.84	1.82	1.76	1.74	1.72	1.70	1.68	1.67	1.67	-12%
Vehicle fleet													
All vehicles (number, 1000)	637	657	656	673	627	620	645	651	668	680	678	680	7%
Car (number, 1000)	556	570	568	581	540	536	559	579	594	605	602	596	7%
Motorcycle* (number, 1000)							11	12	14	15	18	19	
Car (number per 1000 residents)	292	302	305	315	297	304	321	337	350	360	359	357	22%
Infrastructure													
Length of road network (km)	4244	4253	4257	4256	4256	4264	4270	4269	4289	4283	4301	4312	2%
Length of covered roads (km)	3261	3279	3292	3296	3317	3339	3353	3387	3451	3465	3282	3312	2%
Public transport (billion passenger-km)													
Tram + trolley	1.20	1.17	1.30	1.18	1.22	1.22	1.24	1.24	1.23	1.22	1.18	1.15	-4%
Bus (D_t^{AB})	3.64	3.68	2.97	2.70	2.83	2.86	2.92	2.93	2.88	2.86	2.80	2.72	-25%
Suburban rails	0.63	0.60	0.61	0.55	0.57	0.56	0.57	0.56	0.55	0.55	0.52	0.50	-21%
Metro + cog railway	1.20	1.15	1.36	1.22	1.30	1.33	1.36	1.36	1.34	1.32	1.25	1.21	1%

Source: Budapest Bulleting of the Budapest Municipal (Budapest Kézikönyv), BKV
** In case of motorcycles the base year is 2000.*

The evolution of car use in Budapest and its consequences

The number of registered vehicles grew by 7 percent between the mid 1990ies and 2005, when the total fleet consisted of almost 600 thousand cars. The fleet swelled even though the population dropped by 12 percent due to demographic changes and the migration wave to agglomeration areas. As a result, the number of cars per capita had risen dynamically and at the end of the analysed period 1000 residents owned 357 cars.

The other side of the coin is that the demand for public transport services dropped sharply in the same period (*Table 3*). The distance travelled by bus and suburban rail passengers (passenger kilometre) dropped by more than 20 percent and the group of tram passengers shrank too. Metro and subway traffic stagnated in the period.

The load of public roads in Budapest depends on the development of road network and the evolution of traffic flows. The road network grew by merely 2 percent because there exist strict physical constraints, while intensive growth of car use implied that the burden on roads became much heavier. In order to estimate the change in road use I relied on the passenger kilometres of public buses operated by BKV (Budapesti Közlekedési Vállalat, Budapest Transport Company). As a matter of fact, one can generate a measure to quantify the travel

demand for public roads in year t (D_t) by adding the kilometres travelled by car (D_t^c) and bus passengers (D_t^b).

$$D_t = D_t^c + D_t^b \tag{6}$$

The information about kilometres driven by cars was not available. Hence, it was assumed that travel demand increases in line with economic growth but the growth rate is smaller (g – yearly growth rate of travel demand) and the basic year demand is D_0.

$$D_t = D_0 (1+g)^t \tag{7}$$

It follows from the previous argumentation that one can obtain the total mileage of cars by subtracting the total mileage of buses from the estimated travel demand.

$$D_t^c = D_t - D_t^b = D_0 (1+g)^t - D_t^b \tag{8}$$

It was assumed that the yearly average mileage of cars was 10,000 km in the base year and also that they ran 50 percent of the distance within the city boundaries. The passenger kilometres were converted to vehicle kilometres both in case of buses (d_t^b) and cars (d_t^c) so as to calculate the growth of road traffic.

$$d_t^b = \frac{D_t^b}{U_t^b}, \tag{9.a}$$

$$d_t^c = \frac{D_t^c}{U_t^c}, \tag{9.b}$$

where U_t^b and U_t^c are the average passenger number of buses and cars. There are differences as to how intensively the different vehicle types utilise road infrastructure. Therefore, the general practice was followed and different multipliers were applied in case of cars and buses ($M_c = 1,\ M_b = 2{,}1$) to gain a "passenger car equivalent" (Badalay et al. 2003). Finally, the traffic expressed in passenger car equivalent for a given year is:

$$d_t = M_b \cdot d_t^b + M_c \cdot d_t^c \tag{10}$$

Since the distance travelled by buses declined significantly in recent years, the increasing travelling demand should have resulted in increasing car use (*Table 4*). Assuming three different scenarios for economic growth (g = {**A:** 1%; **B:** 2%, or **C:** 3%}, the traffic increased by 39%, 61% and 86 %, respectively. In order to double-check the results one can use the traffic data of Budapest's Danube bridges (Monigl 2001). In a shorter period (1994-2001) the traffic increased by 34 percent on Danube bridges, which implies a traffic growth consistent with scenarios *A* and *B*.

Table 4
Estimated traffic in Budapest - three scenarios

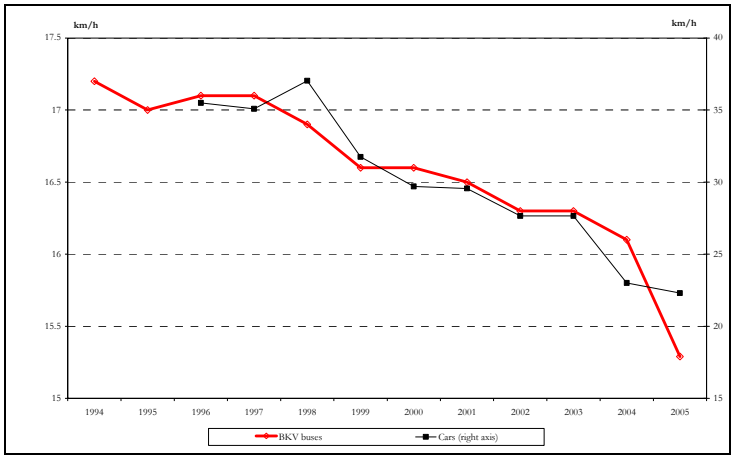
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Scenario (A) (g=1%)												
Estimated road traffic growth (d_t/d_0)	100%	100%	117%	125%	124%	125%	125%	127%	129%	132%	135%	139%
Estimated car mileage in the city (d_t^c, 1000 km/year)	5.0	4.9	5.9	6.1	6.5	6.7	6.4	6.3	6.3	6.3	6.5	6.7
Scenario (B) (g=2%)												
Estimated road traffic growth (d_t/d_0)	100%	102%	121%	130%	131%	134%	136%	140%	145%	149%	155%	161%
Estimated car mileage in the city (d_t^c, 1000 km/year)	5.0	5.0	6.1	6.4	6.9	7.2	7.0	7.0	7.0	7.1	7.4	7.8
Scenario (C) (g=3%)												
Estimated road traffic growth (d_t/d_0)	100%	104%	124%	136%	138%	144%	148%	154%	161%	168%	177%	186%
Estimated car mileage in the city (d_t^c, 1000 km/year)	5.0	5.1	6.2	6.7	7.4	7.7	7.6	7.7	7.9	8.1	8.5	9.1
Memo items												
Average number of bus passengers (U_t^b)	34	37	32	30	32	32	34	35	34	34	32	31
Average number of car passengers (U_t^c)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Traffic growth on Danube bridges (dt/d0)	100%	95%	93%	104%	95%	107%	128%	134%				

Source: Budapest Kézikönyv, BKV, Transman Kft.

On the backward bending side: declining traffic speed and dropping flow

How does travel time react to the dynamic growth of car use and growing traffic? Theoretical considerations help to find the straightforward answer. If traffic density increases, drivers have to react to the manoeuvres of an increasing number of vehicles, they have to decrease travel speed and so travel time grows proportionally (*Figure 1*). Consequently, it is not surprising that the expanding share of cars in the modal split brought about the deceleration of traffic in Budapest.

COWI Consulting and Planning Kft. (COWI Kft.) conducted traffic surveys concerning average peak-hour speed of vehicles. Their surveys show that the peak-hour speed dropped from 35.5 km/hours in 1996 to 27.6 in 2003.



Source: BKV, COWI Kft., European Commission.

Figure 6. Traffic speed evolution in Budapest (1994-2003)*

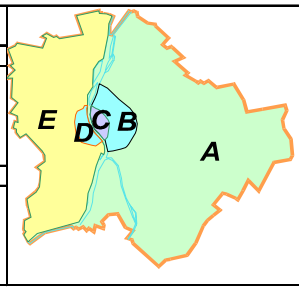
* The red line for buses shows the average speed for the operating hours, while in case of cars the peak-hour speed is plotted. There is a discrepancy between the data of the European Commission (*Table 2*) and BKV for 2005 (EU Commission 21.48 km/hours during peak-hours, BKV: 15 km/h during operating hours).

COWI Kft. has not carried out surveys in the last years, though the database of the European Commission shows that deceleration of traffic has continued, and the average speed was merely 22.3 km/h in 2005. The traffic data of the BKV confirm the existence of the decreasing trend. The average speed of buses declined to 15.2 km/h in 2005 from 17.2 in 1994. Deceleration was especially drastic in 2005, when the yearly decline in speed was 1 km/h or 5 percent in relative terms.

The traffic deceleration was particularly sharp in central districts (*Table 5*). The speed dropped by 40 percent in the 1995-2003 period in the area within the Nagykörút (Grande Boulevard, one of the arteries of the city) which forms a natural boundary of central districts. As a matter of fact, the average speed was 13 km/h in this zone, while rush hour speed in London and Stockholm central areas was higher, around 14 km/h and 20 km/h, respectively, when these cities decided to introduce road pricing arrangements (Transport for London 2006; Facts and Results 2006). Though implying a less sharp decline than in central districts, traffic deceleration was also radical, 20-30 percent, in outer districts.

Table 5.
Traffic speed across zones (km/h)

		1998	1999	2000	2001	2002	2003	Change (1998-2003, %)
zone		morning						
A	Pest side, between the city boundary and the Hungaria street	39	35	31.5	33	28.9	29.8	-24%
B	Pest side, between the Hungaria street and the Big ring	30.8	26.8	26	25.8	23.2	25	-19%
C	Pest side, inside the Big ring (city center)	26.2	24.7	22.1	22.7	17.1	16.3	-38%
D	Buda side, inside the Buda-ring (city center)	27.9	23.1	19.9	20.4	18	20.3	-27%
E	Buda side, between the city boundary and the Big ring	44.6	37.1	35.3	34.2	33.7	32.6	-27%
		afternoon						
A	Pest side, between the city boundary and the Hungaria street	40.9	36.1	33.2	34	32.8	32.9	-20%
B	Pest side, between the Hungaria street and the Big ring	30.3	23.8	22.3	22	21	22	-27%
C	Pest side, inside the Big ring (city center)	21.9	16.4	16.5	13.5	15.3	12.8	-42%
D	Buda side, inside the Buda-ring (city center)	26.6	20.6	19.6	20.2	15.9	18.3	-31%
E	Buda side, between the city boundary and the Big ring	42.6	37.7	37.1	36.4	36.7	33.1	-22%



Source: COWI Magyarország Tanácsadó és Tervező Kft.

While growing traffic density causes lower speed, it is ambiguous how traffic flow reacts to density. The impact of growing density on traffic flow is positive and exceeds the impact of decreasing speed up to the capacity level of roads (see the Figure 1.c in the theoretical introduction). Declining speed together with decreasing traffic flow, however, is a clear signal of severe traffic problems. It indicates that the density increased above the capacity level, the marginal social cost goes to infinite and further growth in traffic flow can be achieved only with more efficient transport means.

Table 6
Changes of the peak-hour traffic flow (2001-2003, %)

	morning hours		afternoon hours	
Diagonal roads to/from the city center	lanes from the city center	**lanes towards the center**	**lanes from the city center**	lanes towards the center
Andrássy út - Kós Károly sétány - 3. sz. városi főforgalmú út	-9.1	**-13.4**	**-8.9**	-1.2
Attila út - Szilágyi E. fasor - Hűvösvölgyi út - Hidegkúti út	-7.0	**5.1**	**0.0**	14.4
Bajcsy Zs. út - Váci út	3.2	**-14.0**	**-8.8**	-5.6
Bécsi út	22.7	**-5.5**	**-3.8**	18.2
Gróza P. rakpart - Árpád fejedelem útja - Pacsirtamező út - Szentendrei út	7.3	**-25.6**	**-18.1**	1.0
Közraktár utca - Soroksári út - Haraszti út	0.6	**-10.1**	**-15.7**	-9.1
Rákóczi út - Kerepesi út - Veres P. út - Szabadföld út	1.8	**-11.9**	**-8.3**	7.7
Szt. Gellért rakpart - Budafoki út - Nagytétényi út	-10.6	**-0.3**	**-10.9**	3.0
Thököly út - Csömöri út - Drégelyvár út - Nyírpalota út	-1.5	**-12.7**	**6.1**	-2.3
Üllői út	11.0	**25.4**	**18.0**	2.5
Total flow (all streets including non-diagonal streets)	-2.9%		-3.3%	

Source: COWI Magyarország Tanácsadó és Tervező Kft.

Budapest's traffic flow dropped by 3 percent over the period 2001-2003 (*Table 6*). This suggests that the traffic load increased above capacity level, and Budapest is at the backward bending side of the fundamental flow curve (see *Figure 1.b* in the theoretical part). This tendency is unambiguous in case of diagonal roads linking inner and outer districts. The load of diagonal roads is particularly heavy on the lanes towards the centre of Budapest during the morning peak-hours and towards the outer districts during the afternoon peak-hours due to the concentration of offices in the centre (cf. middle columns in *Table 6*)[6]. The traffic flow has decreased in almost all of these directions. Although there are no data available since 2003, the deceleration implies that the flow must have declined too. As a consequence, traffic volumes in Budapest could increase only if cars were replaced with other, more efficient transport modes.

How much does congestion cost?

There exist many costs that are related to congestion (*Figure 7*). First and foremost, available time budget for work and leisure activities becomes scarce if travelling time increases. Furthermore, energy consumption of vehicles increases as speed falls, and hence the fuel bill, environmental costs and health risks (diseases of the lung, heart- and vascular systems, etc.) rise. In the following part of the study, Budapest's congestion costs are estimated from the current costs of cars and buses. The estimation exercise covers exclusively fuel and time costs because the estimation of environmental and health expenditure factors requires special expertise and knowledge.

[6] See the surface diagram (*Figure 5*) about the working activity in Budapest.

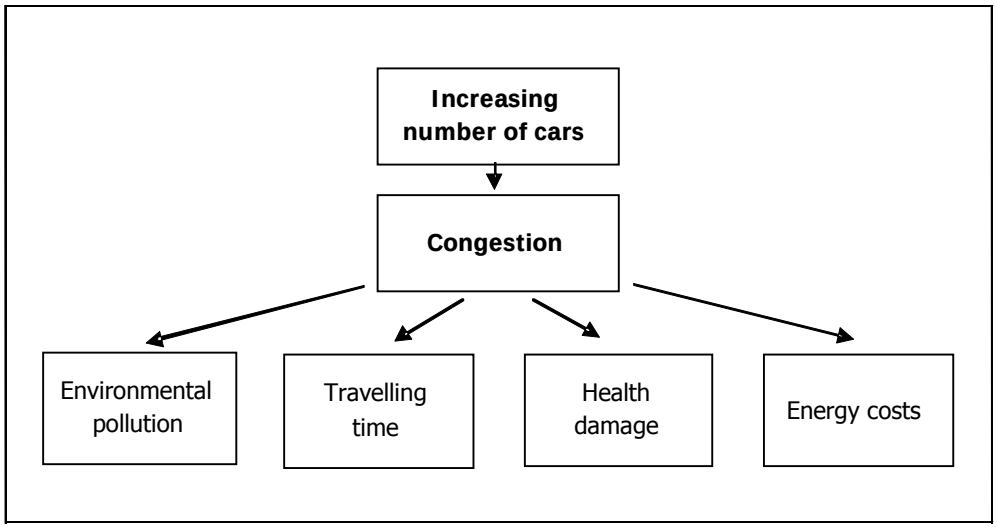


Figure 7. The costs of congestion

The estimation results show that passengers travelled 10 billion kilometres in Budapest and fuel costs amounted to HUF 100 billion in 2005. The car is less energy efficient, thus, the fuel cost of buses was only a fraction of cars' fuel bill. Residents' age structure and income level have been taken into account when calculating the costs of travelling time. Travelling time is worth less than the wage rate of travellers, hence, it was assumed that passengers value a unit travelling time at 50 percent of their unit wage rate[7]. Travelling time of bus and car passengers amounted to 190 billion HUF in 2005.

Fuel and travelling time costs in total amounted to 3.8 percent of Budapest's GDP in 2005. Because the relationship between travelling speed and travelling costs can be approximated by linear relationship both in case of travelling time and fuel costs[8], a provisional estimate is also provided on how traffic deceleration changes expenditures. If travelling speed drops by 1 kilometre/hour then car and bus passengers' travelling time cost increases by an annual sum of HUF 10-15 billion.

Table 7
Travelling time and fuel costs of bus and car passengers in Budapest (2005)

[7] The main reason why travelling time is relatively undervalued is that residents spend only a fraction of their time with work activities and employment. Litman (2002) and the ODT (2004) studies gave empirical evidence that passengers value their travelling time at 35-60 percent of their wages in case of private travelling and 80-120 percent in case of business travelling.

[8] Although vehicles consume more fuel in urban traffic, the reason for this can be the rhythmic motion, frequent deceleration and acceleration of vehicles, rather than speed as such.

	Passenger-kilometre (million km)	Average speed (km/h)	Travelling time (million hours)	Cost of travelling time (bn HUF)	Fuel-consumption (l/km)	Fuel costs (mrd Ft)	Total costs in % of the GDP*
Bus	2717	15.3	177.7	68.4	43.8	9	1.0%
Car	6995	22.3	313.7	120.8	7.3	92	2.8%
Total	9712		491.4	189.2		101	3.8%
Memo items:							
Share of pensioners:		30%		Share of students in public education			17%
Average pension as a % of wages		37%		Average wages (1000 HUF/year)			2412
Value of travelling time as a % of wages		50%		Average travelling time of employees (in minutes)			62
Average mileage of cars (1000 km)		7.8		Budapest's GDP (bn HUF)			7600

** As a % in Budapest's GDP*
Source: BKV Rt., COWI Magyarország Tanácsadó és Tervező Kft., KSH, UTBI, author's calculations

Monigl et al. (1999) estimated the total costs of transport services in Budapest including the internal (paid by travellers) and external (not paid by travellers) costs. The total cost was 532 billion HUF in 1999 prices (approximately 13 percent of Budapest's GDP). In case of cars, external costs per travel amounted to 168 in 1999, while in case of public transport this figure was only 71 HUF.

THE SUCCESS OF ROAD PRICING IN PRACTICAL TRAFFIC MANAGEMENT[9]

There are many cities that raised the costs of car use in order to remedy congestion problems in recent years. Local authorities can choose from many traffic management options such as the introduction of traffic restrictions or the development of transport network and parking conditions. This section presents road pricing, a new practical traffic management tool in central city areas. Although road pricing arrangements have been introduced only in few cities, the first practical experiences show that it can effectively mitigate congestion.

Goals and implementation of road pricing

In general, worsening traffic conditions and congestion poses serious problems for central city areas. The ultimate goal of road pricing is to improve road use, ease congestion and finance infrastructural investment. Singapore was the first city that introduced road pricing in its downtown in 1975. Although congestion was a challenge faced by almost every developed city by this time, there existed technological obstacles to the practical implementation of road pricing. The pioneering system in Singapore was paper-based and the first digital systems were launched more than a decade later. The introduction of road pricing in two European capitals attracted wide interest. London introduced congestion charging in 2003, while Stockholm launched its system in 2005.

In general, cameras are employed to identify vehicles as they pass the cordons of the charging zone. The size of the zone varies from city to city, the biggest one is in Oslo (64 km^2). The smallest system operates in Singapore on 7.25 km^2, which is approximately the same size as the area of districts V., VI. and VII. of Budapest (see also pp 10-11 about the spatial design of Budapest).

Table 8
Features of urban road pricing arrangements

	Singapore	Oslo	London	Stockholm
Goal	optimisation of road use	finance road- and public transport development	reduce congestion costs, finance transport development	reduce congestion and environmental pollution, finance public transport development
Fee	0-2 €	1.5 €	10 €	1-2 €
Operating hours	Mo-Fr, 8:00 - 19:00	Mo-Su, 0:00 - 24:00	Mo-Fr, 7:00 - 18:30	Mo-Fr, 6:30 - 18:30
Revenue (yearly)	40 million €	130 million €	415 million €	85 million €
Charging zone (km^2)	7,25	64	21	29,5
Exemptions	scheduled busses, emergency services	scheduled busses, emergency services, motorcycles, disabled people	scheduled busses, emergency and military services, motorcycles, taxis, busses, disabled people, alternative fuel and electronic propelled vehicles, 90% discount for residents	scheduled busses, emergency and military services, motorcycles, taxis, busses, environment friendly vehicles
Year of introduction	1975	1990	2003	2006

Source: Transport for London, Stockholmsförsöket, Singapore Land Transport Authority, IEROMONACHOU-POTTER-WARREN[2006]

The systems usually operate during weekdays and only daytime. The charge is around €1-2 per entry in Oslo, Singapore and Stockholm, while the daily charge is £8 in London irrespective of the number of entries. Taking into account the dynamics of traffic demand the charge varies with time in Singapore. Drivers can choose from various payment methods: sending an SMS from their mobile phones, internet banking or buying pre-paid cards are all accepted. The cities typically cover infrastructural development projects from the revenues.

Simultaneous measures

Road pricing has an impact on the relative price of travelling modes: car use becomes more expensive compared to public transport. Therefore, it is of key importance that the increasing

[9] This section is the detailed version of the article that the author published in the economic weekly *Heti*

demand for public transport is being satisfied because otherwise the quality of public transport would decline, impeding the achievement of the original goal to change the modal split. The capacity of buses has been increased substantially, by 14,500 seats in the peak-hours in London, and 2 percent extra money was poured into the tube network's budget. In Stockholm, 197 additional buses started to run, 16 new bus lines were established and the bus network provided increased travelling frequency. In addition, new parking areas were built close to the cordon around the charging zone. In Singapore, new parking houses opened with reduced fee.

Almost every city exempted disabled people and emergency services from the charge. To encourage the use of other transport modes, scheduled buses, coaches and motorcycles are also exempted in most cases. However, until the system in Singapore was reformed, motorcycle traffic had increased so fast that this vehicle was also classified as chargeable. In London, residents in the charging zone can register for a 90 percent discount.

Results

Experiences are pleasant almost everywhere. In Singapore, the initial decline in car use was 44 percent (Keong 2002) due to decreasing transit traffic. Furthermore, travellers started to time their journeys before and after the charging hours which resulted in smoother traffic load.

In London, the number of drivers entering the central zone declined by 12 percent, while the number of cars dropped by 33 percent each year after the introduction of the measures in 2003. As a result, traffic speed increased: the typical delay values were 1.6 minutes per kilometre compared with 2.3 minutes per kilometres before the introduction of charging. The reliability of bus service improved; the number of delays declined by 50 percent and the number of bus passengers increased by 37 percent in the first year.

Table 9
Vehicle-kilometres driven within the charging zone during charging hours*

Világgazdaság (Erhart 2006).

	2002		2003		2004		2005	
	million vehicle kilometers	%	million vehicle kilometers	%	million vehicle kilometers	%	million vehicle kilometers	%
All vehicles	1.64	100	1.45	100	1.38	100	1.40	100
Four or more wheels	1.44	88	1.23	84	1.16	84	1.16	83
Potentially chargeable	1.13	69	0.85	58	0.80	58	0.79	56
- Cars and minicabs	0.77	47	0.51	35	0.47	34	0.47	33
- Vans	0.29	18	0.27	19	0.26	19	0.25	18
- Lorries and other	0.07	4	0.07	5	0.06	5	0.07	5
Non chargeable	0.51	31	0.60	42	0.58	43	0.61	44
- Licensed taxis	0.26	16	0.31	21	0.29	21	0.30	22
- Buses and coaches	0.05	3	0.07	5	0.07	5	0.07	5
- Powered two-wheelers	0.13	8	0.14	9	0.13	10	0.13	10
- Pedal cycles	0.07	4	0.09	6	0.09	7	0.10	7

Source: Transport for London, Fourth Annual Report pp. 27
**Annualised weekdays*

In Stockholm, traffic volume was 20-26 percent lower during the probationary period, well above the targeted 10-15 percent. Also, delay time declined by 30-50 percent. Pollution decreased by 14 percent in the charging zone and by 2.5 percent in the greater Stockholm area. The change in fatal injuries was 5-10 percent according to the first estimates.

Political economy of road pricing

The surveys showed that the deterioration of traffic conditions became a major issue faced by metropolises all over the world. However, introducing a charge interferes with many interests and municipal politicians have to consider political risks before embarking on road pricing. The burden of the charge varies with class and only those who can not afford the payment for the car's comfort are forced to change travel mode. In fact, the introduction of charging requires local authorities' commitment and social consensus. However, the re-election of Ken Livingstone, London's Mayor, and the residents' positive reactions to charging confirm the success of the measures.

The Stockholm City Council decided in June 2003 to launch a trial period for congestion tax. The Swedish Parliament, the Riksdag passed the law on congestion tax one year later, in June 2004, and the system has been introduced gradually since August 2005. The residents of Stockholm municipality voted yes in the referendum scheduled at the time of the general elections, 17 September 2006. The Swedish government introduced the Stockholm congestion tax permanently in October 2006.

Briefly about the possible implementation in Budapest

It is very important to investigate whether road pricing could ease congestion in the central districts of Budapest. This study attempts to address this issue, though the aim here is not to

find ultimate answers but to give a brief overview of the key points and conclusions of previous works.

Traffic speed decreased below the critical level in Budapest. In fact, speed is now lower than it used to be in cities with road pricing arrangements at the time when they decided to implement the reforms. Hence, it is very likely that road pricing would have a positive impact on Budapest's traffic conditions. The application of tested technologies is less costly than their development; therefore Budapest can expect lower implementation expenditures.

Of course, success of the measures is conditional on many factors. The major knots of both the national and capital road network are in the central zone of Budapest. Therefore, it is of key importance to develop the circular elements of the network and establish alternative routes. The introduction of road pricing will be less problematic soon after the finalisation of the eastern phase of the M0 highway ring because it will lessen the transit traffic burden on internal circular roads and offer an alternative.

The development of public transport is inevitable, which increases public spending temporarily. International practices show that road pricing can be introduced without executing general reforms of the public transport network and it is sufficient to substitute car traffic with buses and extend parking areas.

There are two detailed studies that discuss the practical issues of road pricing reforms in Budapest. Pápay et al. (1992) addressed the issue when the London charging system was planned. In line with other foreign studies, the authors argued that car use had to be restricted and road pricing could be a useful tool to reduce congestion and improve urban environment. The authors noted several economic, social and traffic management conditions for practical implementation including development of urban infrastructure and public transport.

The Transman Kft. conducted a research in 1999 on how road pricing would have effect the modal split in central Budapest (see Monigl-Berki 2001). The authors assumed that the border of the charging zone would be Budapest's Nagykörút (Grande Boulevard). The results showed that the total entry traffic flow would drop by 4 percent. Car flow would drop by 40 percent, similar to the observed sharp decline in Singapore (44 percent) and London (33 percent). Conversely, the decline in car use would be offset by increasing traffic of other modes: public transport (8 percent), walking (2 percent), bicycle (3 percent). Charging would result in a revenue of HUF 7 billion (1999 prices). The study emphasises the key role of developing alternative roads in the non-charging zone before road pricing is introduced.

The reform requires the support from residents and traffic management decision makers in Budapest. International experience shows that the popularity of road pricing

improves continuously over time, though public consultation and a well prepared campaign can contribute to the success.

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