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ECONOMIC INVESTIGATION OF A PUBLIC TRANSPORT SUPPORT POLICY: A CASE STUDY AT BUDAPEST

ABSTRACT

This paper analyses the effect of supporting the public transport policy based on intersection controlling with the aim of tram priority in Budapest, as a case study. The hypothesis related to this study was that the support of public transport is only viable when the marginal benefit of public transport is higher than the marginal cost of individual transport. Therefore, the real costs of this support for the society were estimated. This study revealed that by applying this policy, the waiting time at intersections and CO_2 emission-related costs have increased by about 13.7% and 14.2%, respectively. Besides, the estimated monetary gain of tram users would be 17,800 euro on a daily level total by applying the mentioned policy.

KEY WORDS

public transport support policy; social costs; intersection controlling; CO_2 emission cost;

1. INTRODUCTION

The transport policy in most of the countries states that the transport system should be designed in order to contribute to a shift towards sustainable society. An important part of the official policy is that pricing in the transport sector should be efficient, i.e. prices should equal the marginal costs (including environmental costs caused by transportation) and that changes in the transport system (including investments) should be appraised through the use of cost-benefit analysis [1]. Policy interventions in the transport sector are accompanied by risks and uncertainties, which become visible in the form of unintended effects [2]. These effects can lead to a deviation from the initial policy objective or even be counter-intentional [3]. Single policies or entire policy packages are often assessed using different methods aiming at a quantification of effects as well as the detection of undesired outcomes. The knowledge of potential impacts is essential to take informed policy actions [3]. There are a number of studies in the literature that assessed the impact of transport policies. For instance, Tobollik et al. studied the impact of transport policies and mostly its related air pollution on health using particulate matter (<2.5 μm in aerodynamic diameter $PM_{2.5}$) and elemental carbon (EC) [4]. Verma et al. assessed the sustainability impact of transportation policies in Bangalore city [5]. Sun et al. evaluated the low-carbon transport policies based on multi-actor multi-criteria analysis (MAMCA) in Tianjin [6]. Crisalli et al. presented a methodology to evaluate rail-road freight policies such as new services and/or incentives for long-distance freight transport by using a mixed what-if/what-to approach. It uses a specific mode-service choice model to share the freight demand among alternatives (rail-road combined transport, maritime Ro-Ro and road transport) and a service network design model to identify new rail-road freight services [7]. Wang et al. assessed transport policies implementation using two accessibility indicators (i.e., potential and adaptive accessibility) in land use and the transport interaction (LUTI) model [8]. The European Commission white paper (2011) proposed that congestion in the European Union (EU) is often located in and around urban areas and costs nearly 100 billion euro (or 1% of the EU's GDP) annually [9]. Public transport support policies will be mostly done in order to reduce congestion and subsequently decrease the social costs of transportation by increasing the efficiency of public transportation and shifting commuters from private cars to public transport. In this paper, the effect of supporting public transport policy based on intersection controlling with the aim of tram priority has been analysed in order to investigate whether this public transport support policy really decreased the social costs of transportation or not. The research area was Budapest. The hypothesis related to this study was: the support of public transport is only viable when the marginal benefit of public transport supporting policy is higher than the marginal cost of individual transport punishment. Wei et al. research proposed a methodology to assess the urban carrying capacity [10]. In this paper, the authors focused only the urban transportation and the balance between public transportation and private cars. Nowadays, intersection controlling is not only a tool for lower emission level but also a tool for promoting sustainable mobility inside the city. Cerny et al. showed suitable theoretical findings as a support for decision-making on economic sustainability and accessibility of public transport [11]. Tosa et al. in their publications, investigated the occurrence of the vehicle engine pollution appearance taking into account velocity and street loading [12].

Modal shift [13] from private car use to public transport is not only important for EU [14, 15] but on a smaller scale as a city, it is very important for building a liveable city [16]. There are known policy tools for public transport support strategies [17] or advanced information services for public passengers [18]. In this paper, a case study was analysed in Budapest. The results could be interesting not only for Hungary but worldwide as well.

Figure 1 shows a ring in Budapest with two lanes in the opposite direction and two opposite lanes for tram service. There are different intersection control possibilities [19]. Until 2012, there was a synchronised green-wave through the ring with the periodicity of 90 seconds that gave advantages to private car users as a green wave with the designed speed of 50 km/h. In 2012, the synchronisation controlling policy changed to 60 seconds of periodicity. Since then a new controlling policy has been used that supports the trams instead of private cars. To gain more advantages for tram priority, the synchronisation of intersections was based on the tram schedule. The phases of individual intersections were synchronised in order to develop intersection optimum to reach the network optimum [20] in travel time minimization on the tram. Therefore, the travel time was shortened by 2-3 minutes. The total project cost 176,000 euro of which 160,000 euro were funded by the European Union [21]. To the best of the authors' knowledge, the related international literature has not been taking into account the cross-effect of support of public transport. The competition of individual private cars and public transport has some negative effects on the private car usage in the case of urban environment [22]. But yet, no one has estimated the real costs of this support to society. In this paper, the social costs of public transport support in Budapest were estimated. Our hypothesis is that the support of public transport is viable only when the marginal benefit of public transport is higher than the marginal cost of individual transport.

2. METHODOLOGY

The full costs of transportation are usually categorized as direct and indirect costs. Direct costs (sometimes also called private or internal costs) include the costs that car users directly consider in making a trip, such as vehicle operating cost, car depreciation, cost

Figure 1 – Area of investigation in Budapest

of fuel consumption, time lost in traffic, tolls and other parking fees, etc. Indirect costs (also called social or external costs), on the other hand, refer to the costs that car users are not held accountable for. These include the congestion costs that every user imposes on the rest of the traffic, costs of accidents, and costs of air pollution and noise [23]. Among these so-called external costs in this paper the cost of fuel consumption (cost of related CO_2 emission) and cost of time lost were respectively calculated and compared before and after applying the previously mentioned public transport support policy. In this paper, the marginal costs/benefits of individual/public transport is considered as the change in the entire average perceived costs plus external costs of individual/public transport. Since the average perceived costs will not be significantly changed (if not unchanged), due to a tiny increase in the average intersection waiting time, the modal change from private to public transport is basically included in this assumption considering the change in external costs/benefits of individual/public transport. In this study, a detailed traffic counting was done on an hourly basis on the tram line and in each lane before and after the change of synchronisation method of signals.

Based on this hourly counting (*Table 1*) the hourly social costs (based on the emissions and value of travel time and changes in travel time) of private cars [24] and tram users (based on the value of travel time and changes in travel time) can be estimated [25]. The tram users were also surveyed. The result of surveying was that the tram users travel average 6 stops and the average flow was 8,000 persons/h/direction. Private cost surplus based on fuel consumption:

$$C_{fuel} = \left(\sum_{i=1}^{m} c_i \cdot t\right) \cdot v_j \qquad (1)$$

where:

C_{fuel} – private cost of fuel consumption surplus [€/h];

c_i – idle fuel consumption of vehicle i [litre/h] based on the statistical value of Hungarian vehicle fleet consumption analysis [26];

t – sum of red times in one hour [h/h];

v_j - cost factor of fuel j [€/litre].

From the elapsed time in the intersection where the engine is in idle mode, the CO_2 emission can be calculated based on the fuel consumption.

Emission-based hourly social cost estimation:

$$C_{CO_2} = \left(\sum_{i=1}^{m} e_i \cdot t\right) \cdot v \qquad (2)$$

Table 1 – Result of traffic counting [PCU/h] for individual road transport

Blaha Lujza tér northwards [PCU/h]									
6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00
774	1,222	1,280	1,365	1,321	1,309	1,372	1,450	1,353	1,268
Blaha Lujza tér southwards [PCU/h]									
6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00
816	1,396	1,382	1,205	1,264	1,270	1,352	1,908	2,347	2,089
Boráros tér northwards [PCU/h]									
6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00
756	1,191	1,120	1,117	869	1,009	1,223	1,164	1,120	895
Boráros tér southwards [PCU/h]									
6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00
1,341	2,409	2,315	2,176	1,730	1,848	1,739	1,725	1,758	1,706
Széll Kálmán tér northwards [PCU/h]									
6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00
1,058	1,725	1,728	1,681	1,688	1,824	1,758	1,704	1,701	1,567
Széll Kálmán tér southwards [PCU/h]									
6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00
465	953	976	921	916	1,014	1,078	896	677	715
Budafoki-Október 23. utca northwards [PCU/h]									
6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00
1,074	1,795	1,936	1,751	1,663	1,739	1,592	1,512	1,752	1,503
Budafoki-Október 23. utca southwards [PCU/h]									
6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00
758	1,282	1,278	1,276	1,315	1,359	1,223	1,315	1,226	1,084

where:

C_{CO_2} – emission-based hourly social cost estimation [€/h];

e_i – idle CO_2 emission of vehicle *i* [tCO_2/h] based on the statistical value of Hungarian vehicle fleet consumption analysis [26];

t – sum of red times in one hour [h/h];

v – cost factor of CO_2 [€/tCO_2].

The value of travel time and changes in travel time were estimated for both tram users and car users as follows:

$$TTC = \left(\sum_{j=1}^{n} N_j \cdot \Delta TT \right) \cdot \tau \qquad (3)$$

where:

TTC – social cost of travel time change [€/h];

N_j – number of passengers;

ΔTT – change in travel time in one hour [h/h] please note that it can be positive or negative, depends on tram or private car usage in this case;

τ – monetary value of travel time [€/h] [26].

It should be mentioned that the red times of intersections were known from the phase-plane of the intersection before and after the change.

3. RESULTS

In *Table 2* the intersections were investigated based on their red times by the new and old controlling policies.

Taking *Table 1* into account, the average increase of intersection waiting time is less than four seconds. In fact, the costs that travellers will consider in their own travels (the so-called perceived average generalized costs) will not change since this time increment is insignificant for travellers. The thing which is of great importance here is the increase of external costs. Therefore, as people just consider their own costs and not the costs they will impose on the rest of the society, the modal split will not be changed.

Based on [26] and *Equation 1* that considers waiting in intersection with idle engine, the cost of fuel consumption surplus can be estimated (*Table 3*).

Based on [26] and *Equation 2* that considers waiting in intersection with idle engine, the cost of CO_2 emission and resulting social costs can be estimated (*Table 4*).

Based on [26] and *Equation 3* that considers waiting in intersection, the cost of change in travel time can be estimated (*Table 5*).

4. ANALYSIS AND DISCUSSION

As it can be seen from *Table 2*, the waiting time in intersections was increased from total 431 sec. to total 490 sec. This is an increase of 59 sec which is 13.7%. In a real condition, the increase is higher because of the more stop-and-go situation.

From *Table 3* it can be stated that the CO_2 related social costs were increased by the newly implemented controlling policy. In the investigated period in the peak hour with the old strategy, the average social costs were approximately 4.5 €/hour in each direction for petrol driven cars and were approximately 1.7 €/hour in each direction for diesel oil driven cars. With the new public transport supporting policy, the average approximated social cost in peak hour was increased to 5.2 €/hour in each direction for petrol driven cars and 2€/hour in each direction for diesel oil driven cars. In total, this is about 14 €/peak hour CO_2

Table 2 – Length of red times [s]

No. of intersection	Old controlling policy	New controlling policy	Description
1	20	5	II. Margaret bridge Buda side
2	12	23	XIII. Margaret Island
3	17	26	XIII. Jászai Mari sqr
4	35	34	VI, Nyugati Railwaystation
5	64	35	VI. Oktogon sqr
6	17	39	VI. Wesselényi str
7	15	34	VII. Király str
8	35	24	VII. Blaha Lujza sqr
9	15	50	VIII. Rákóczi sqr
10	44	26	VIII. Baross str
11	61	25	VIII. Corvin sqr
12	32	33	IX. Mester str
13	20	48	IX. Boráros sqr
14	12	33	XI. Petőfi bridge, Buda side
15	32	20	XI. Budafoki str
16	-	35	XI. Fehérvári str - Not existed in the old controlling policy

Source: BKK Centre for Budapest Transport related social cost caused only by private cars in the investigated area (see *Table 4*).

Although the potential energy saving in Europe in the transportation sector is about 26% reduction in energy consumption [27], by applying this policy not only more fuel consumption has negative effects on the social level through more CO_2 emissions, but also on the private level a surplus in fuel consumption. An average 30 €/h surplus of consumption-related private costs has been caused by changing the control policy (based on *Table 3*). According to the Hungarian tax regulation on fuel consumption, this could cause approximately 12 €/h more tax based on the fuel consumption surplus.

It can be stated from *Table 5* that the total social cost for private car users based on monetary value of

Table 3 – Private cost of fuel consumption in red time in idle mode [€/h]

Gasoline		6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00	Sum
Old	to North	97	160	171	169	158	167	171	166	169	153	1,581
	to South	92	167	180	169	159	166	165	174	174	161	1,607
Sum		189	327	351	338	318	333	336	341	343	313	3,188
New	to North	111	183	196	193	181	190	195	190	193	174	1,806
	to South	105	191	205	193	182	189	189	199	198	184	1,836
Sum		216	374	401	386	363	380	384	389	391	358	3,642
Diesel oil		6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00	Sum
Old	to North	33	54	58	57	54	56	58	56	57	52	536
	to South	31	57	61	57	54	56	56	59	59	54	545
Sum		64	111	119	114	108	113	114	116	116	106	1,080
New	to North	38	62	66	65	61	64	66	64	65	59	612
	to South	36	65	70	65	62	64	64	67	67	62	622
Sum		73	127	136	131	123	129	130	132	133	121	1,234

Table 4 – Sum of CO_2 emission-related costs/hour in red [€/h] (calculation was done on 20 EUR/tCO_2)

Gasoline		6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00	Sum
Old	to North	2.58	4.25	4.54	4.47	4.21	4.42	4.53	4.42	4.48	4.05	41.95
	to South	2.45	4.43	4.77	4.49	4.23	4.40	4.39	4.63	4.61	4.26	42.65
Sum		5.03	8.68	9.31	8.96	8.43	8.82	8.92	9.04	9.09	8.31	84.60
New	to North	2.95	4.85	5.19	5.11	4.80	5.05	5.17	5.05	5.12	4.63	47.91
	to South	2.79	5.06	5.45	5.13	4.83	5.03	5.01	5.28	5.27	4.87	48.71
Sum		5.74	9.91	10.64	10.23	9.63	10.08	10.18	10.33	10.39	9.50	96.63
Diesel oil		6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00	Sum
Old	to North	0.96	1.57	1.68	1.66	1.56	1.64	1.68	1.64	1.66	1.50	15.54
	to South	0.91	1.64	1.77	1.66	1.57	1.63	1.62	1.71	1.71	1.58	15.80
Sum		1.86	3.21	3.45	3.32	3.12	3.27	3.30	3.35	3.37	3.08	31.33
New	to North	1.09	1.80	1.92	1.89	1.78	1.87	1.92	1.87	1.90	1.71	17.75
	to South	1.03	1.87	2.02	1.90	1.79	1.86	1.86	1.96	1.95	1.80	18.04
Sum		2.13	3.67	3.94	3.79	3.57	3.73	3.77	3.83	3.85	3.52	35.79

Table 5 – Monetary value of travel time for private cars [€/h]

		6:00	7:00	8:00	9:00	14:00	15:00	16:00	17:00	18:00	19:00	Sum
Old	to North	673	1,108	1,185	1,167	1,097	1,153	1,182	1,153	1,169	1,057	10,944
	to South	638	1,156	1,244	1,171	1,103	1,148	1,144	1,207	1,203	1,112	11,126
Sum		1,311	2,264	2,429	2,338	2,200	2,302	2,326	2,360	2,372	2,169	22,071
New	to North	769	1,266	1,354	1,333	1,253	1,317	1,350	1,316	1,336	1,207	12,500
	to South	729	1,320	1,421	1,337	1,260	1,312	1,307	1,379	1,374	1,270	12,708
Sum		1,498	2,586	2,775	2,670	2,513	2,629	2,657	2,695	2,709	2,477	25,209

travel time was 22,071 € on the daily basis but with new controlling policy it was 25,209 € on the daily basis.

The new approach has caused 3 minutes of travel time savings for the tram users. The estimated monetary gain would be 17,800 € on the daily level total based on the number of commuters and their value of travel time. The estimated costs are summarized in *Figure 2*.

Sensitivity analysis has been conducted (*Table 6*) in order to reveal the effect of input parameters such as cost factor of fuel [€/litre] (v_j), cost factor of CO_2[€/tCO_2] (v), monetary value of travel time [€/h] (τ)

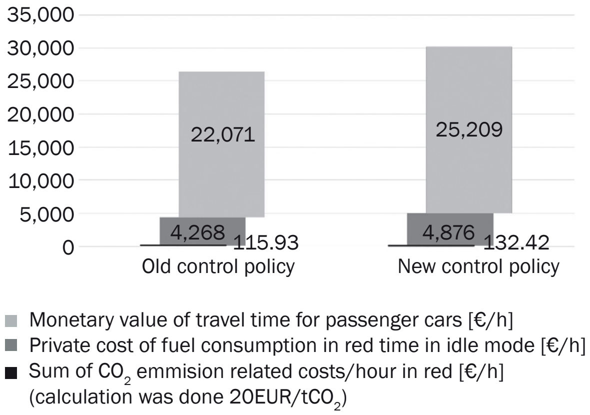

Figure 2 – Estimated social costs

5. CONCLUSION

In this paper, the social costs of public transport supporting in Budapest were estimated. By applying the new policy of intersection controlling, travel time related costs for passenger cars, private cost of fuel consumption in red time in idle mode and CO_2 emission related costs have been all increased by 3,138 euro, 608 euro and 16.49 euro per hour, respectively.

Although the investigated public transport support policy seems to be perfect at first glance, the derived results show the disagreement. In order to shift people toward public transportation, the "human-oriented transportation" policies might be an idea worth considering. In achieving this, the city leverages on the use of intelligent transportation systems (ITS) so as to provide high-quality transport infrastructure and improve services. The plan is to build a sustainable transportation system that centres on pedestrians. This entails providing safe, convenient transportation for the disabled, a pedestrian-oriented transportation environment, and low-cost, high-efficiency operation systems.

Although the costs were increased for private car users the cost structure did not change significantly due to the change of policy. Still, the emission-related estimated social costs are approximately 0.5% of the total, 16% of private costs surpluses due to increased fuel consumption and 83.5% of travel time and waiting-related estimated social costs. Besides, the estimated monetary gain of tram users would be 17,800 euro on a daily level. As previously mentioned, the costs of fuel consumption, travel time delay and CO_2 emission all related to the increment of waiting time at intersections due to applying a public transport support policy were analysed in this paper. Considering the entire air pollution costs, the scope for the future research of the authors is adopting a fuel consumption function F(V) where V is the traffic speed in order to estimate the quantities of not just CO_2 but the entire pollutants (e.g. VOC, CO, NO_X, and PM_{10}) which are generated by motor vehicles due to the waiting time increment at intersections. Besides, increased noise

Table 6 – Result of sensitivity analysis [€/h]

	Old Controlling Policy [€/h]	New Controlling Policy [€/h]
Sum of CO_2 emission related costs/hour in red, [€/h] (calculation was done on 20 EUR/tCO_2)	116	132
Sum of CO_2 emission related costs/hour in red, [€/h] (calculation was done on 10 EUR/tCO_2)	58	66
Sum of CO_2 emission related costs/hour in red, [€/h] (calculation was done on 5 EUR/tCO_2)	29	33
Private costs of fuel cosumption in red time in idle mode [€/h] 1 litre Gasoline: 300 Ft; 1 liter disel oil: 300 Ft	2,999	3,426
Private costs of fuel cosumption in red time in idle mode [€/h] 1 litre Gasoline: 424 Ft; 1 liter disel oil: 431 Ft	4,268	4,876
Private costs of fuel cosumption in red time in idle mode [€/h] 1 litre Gasoline: 500Ft; 1 liter disel oil: 500 Ft	4,998	5,710
Monetary value of travel time for Passenger cars [€/h] (VTT: 6 €/h)	22,071	25,209
Monetary value of travel time for Passenger cars [€/h] (VTT: 8 €/h)	29,428	33,612
Monetary value of travel time for Passenger cars [€/h] (VTT: 10 €/h)	36,785	42,015

costs by calculating the reduction in the value of residential units alongside the investigation area which tend to abate with distance can be incorporated in further analysis to see whether this 13.7% waiting time increase has any effect on noise costs or not. Also, the impact of the so-called local pollutants on human health both in terms of mortality (i.e. reducing life expectancy) and morbidity (i.e. affecting the quality of life) can be analysed further.

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KÖZFORGALMI KÖZÖSSÉGI KÖZLEKEDÉS ELŐNYBE RÉSZÉSEÍTÉSÉNEK GAZDASÁGI ELEMZÉSE: BUDAPESTI ESETTANULMÁNY

ABSZTRAKT

Ebben a cikkben a szerzők a budapesti körúti villamos előyberészesítésének társadalmi-gazdasági vizsgálatát végezték el. Cikkükben a szerzők rávilágítanak, hogy a közforglmú közösségi közlekedés prioritása némely esetben megkérdőjelezhető. Az elemzés rámutatott, hogy az egyéni személygépjárművek CO_2 kibocsátása 14.2 %-kal a várakozásból származó társadalmi kiadások pedig 13.7 %-kal növekedtek. Ezzel szemben a villamoshaszhnálók napi nyeresége 17 800 €, ami az utazási idő rövidüléséből származik.

KULCSSZAVAK

Közforgalmú közösségi közlekedés előnybe részesítése; társadalmi költség; csomópont irányítás; CO_2 kibocsátási költség;

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