STUDIECENTRUM VOOR ECONOMISCH EN SOCIAAL ONDERZOEK

EXTERNAL DISECONOMIES IN URBAN CAR TRANSPORTATION

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Werknota 7323/851

september 1973

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D/1973/1169/10

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I. Aim of this paper

A city normally provides many functions next to private car transportation, such as the recreational function at several levels, the residential function, the cultural historic function and the public transportation function. It is intuitively clear that the quality of the "other" functions is deteriorated with rising levels of private car-kilometers per unit of time, unless the seperation of car transportation on one hand and the other functions on the other hand would be perfect.

So, in urban areas car transportation may have considerable external diseconomies. The latter equal the lesser of these two amounts:

1. the additional cost of perfect environmental restoration;
2. the total damage that is caused to the users of the other functions.

In this paper, we focus attention on the external diseconomies of private car transportation on public passenger transportation. An attempt has been made to measure a part of the benefits that would accrue to a project to separate private car transportation from the public transportation function in the city of Antwerp. A by-product of these calculations is the establishment of an off-peak and on-peak social tax that should be levied on cars, on account of external diseconomies to the users of the public transportation services

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(1) This paper benefited from the remarks and discussions I had with my colleague, Drs. G. Blauwens. Of course the responsability for any errors or omissions remains entirely mine.

The subject matter is important because it involves space allocation decisions, which are typically long-run decisions. When the quality of the public transportation function, or of the cultural historic or the recreational function (etc.) is deteriorated on account of traffic congestion by private cars, the demand for these functions will fall (people move out e.g.). Then it will be more difficult for politicians to defend preservation, maintenance, and a fortiori, investment. Presumably, the neglect of external diseconomies in car transportation in Antwerp has contributed to

1. fostering a status quo in the scope of the network of public transportation, whereas the market potential shifts gradually from central Antwerp to the outskirts;
2. enforcing the pressure towards decreasing the stock of historic monuments or recreational areas of some value, typically to build parkings instead.

For the purpose of the calculations, data were collected with respect to the city of Antwerp. This city was chosen, for a good deal because the management of both the Antwerp public passenger transportation service, and the traffic Department of the Police in this city, kindly provided us with the available statistics (1). An additional motive was that the data on car transportation in this city cover roughly the same territory as the data on public transportation.

In subsection 2.1 we will discuss these statistics in some detail, whereas subsection 2.2 is devoted to the calculations. In section 3 some conslusions will be presented.

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(1) We are especially indebted to Mr. J. Du Mon of the Maatschappij voor Intercommunaal Vervoer te Antwerpen, and to Mr. L. Koeklenberg, head of the Police Traffic Department.

2. Urban car transportation and the external diseconomy to public passenger transportation

2.1. The data

Two time series were used. In the first place a series on driving times of the public transportation modes for subsequent periods of the day was needed. The time-table of the service could be used for this purpose. One major advantage of using this source instead of (e.g.), direct observation is a markedly lower cost. On the other hand the time schedule of this transportation service is not solely determined by traffic density. Especially in the off-peak period of the day, the schedule is also conditioned by the goal to supply a regularly schemed service.

The second series reflects the number of cars per unit of time, i.e. per hour of the day. The figures that are available are sample results. However the Traffic Department of the Police provides an estimate of the absolute number of car-kilometers per day, so that the distribution of car-kilometers over 24 hours of a day is known in absolute figures.

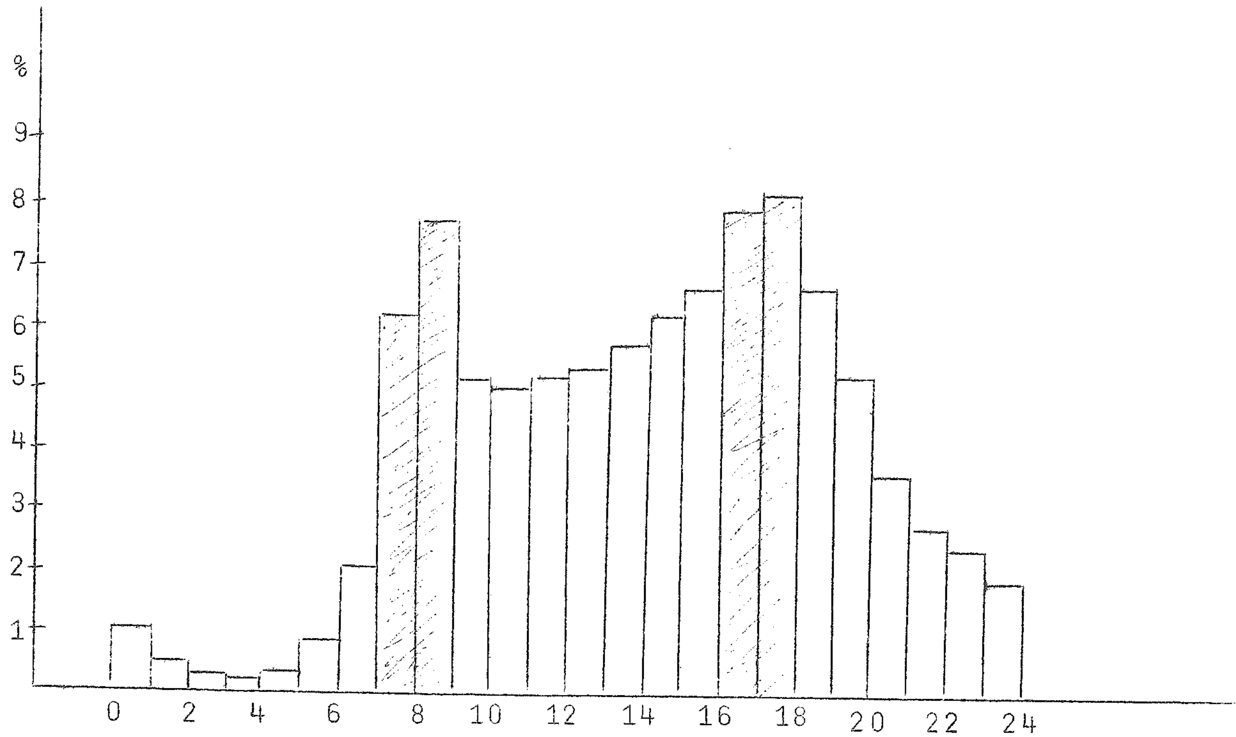
All data refer to the year 1972.

Figure 1 presents the procentual distribution of the number of cars over the hours of a day.

In accordance with the picture of this distribution it seems plausible to divide the day into five subperiods:

- I : 0 a.m. to 7 a.m.
- II : 7 a.m. to 9 a.m.
- III: 9 a.m. to 16 a.m.
- IV : 16 a.m. to 18 a.m.
- V : 18 a.m. to 24 a.m.

Fig. 1. Number of cars per hour - procentual distribution



Consequently we obtain a simplified distribution, which is given in table 1.

Table 1. Distribution of car-kilometers in % and in absolute figures per hour

Period	(in %)	(in car-km) per hour
I	3,0	15.911
V	15,1	80.091
III	22,5	118.970
II	28,4	150.247
IV	31,0	173.205
	100,0	

What mainly interests us is the joint distribution of car-kilometers and average driving times per kilometer in each of the five periods. The frequency of this distribution is the number of tramway or bus lines. Table 2 reveals the fact that there is a marked dependency between the two variates. Besides a χ^2-test was executed. With n = 32 and χ^2 = 93.1 the deviations from expectation are significant at a level between 0,01 and 0,001.

Table 2. Joint distribution of driving times in public transportation and relative density in private car transportation

car-km per hour \ driving time	180-199	200-219	220-239	240-259	260-279	280-299	300-319	320-339	340-359	Marginal distribut.
3,0	8	6	8	-	1	-	-	-	-	23
15,1	4	3	10	5	-	1	-	-	-	23
22,5	-	3	6	8	4	1	1	-	-	23
28,4	-	1	4	3	9	5	-	1	-	23
31,4	-	-	5	2	7	6	2	-	1	23
Marginal distribution	12	13	33	18	21	13	3	1	1	115

2.2. Calculation of external costs

In order to calculate the external costs, the conversion of driving times into cost of driving time is required. The cost of time can essentially differ from individual to individual. For convenience sake, we grouped the individual passengers into one out of three broad classes: the "school" class, "working" class and "miscellaneous" class. The cost of time for each individual was taken to be zero for the school class. The displacements for work were supposed to have a cost of time equal to the average industry wages per unit of time (0,0325 BF per second in 1972). The third class, we reckoned, evaluates the cost of time to be half the industry wages.

In the next table one observes that the distribution of passenger kilometers over those three classes differs from period to period. For example, in periods I and IV (morning and evening peak) the relative share of the second class (workers) is much greater than in the remaining periods, etc. This means, that the cost of time is relatively high when driving time (or the traffic load factor) itself is high, and consequently one may expect a sharply rising marginal cost.

Table 3. Distribution of the daily average number of passenger kilometers in public transportation

subperiod (1)	school (2)	working (3)	misc. (4)	total (5)	total per hour (6)
I	2.802	15.554	7.830	26.186	13.093
V	9.831	60.040	23.649	93.520	18.704
III	17.012	94.437	47.537	158.986	22.712
II	7.631	54.018	13.168	74.817	37.409
IV	7.155	50.641	12.345	70.141	35.070
Total	44.431	274.690	104.529	423.650	

Source: Maatschappij voor Intercommunaal Vervoer Antwerpen

In table 4 the weighted cost of 1 second of time for passengers of the public mode is presented for the five subperiods that were distinguished.

Table 4. The cost of time per subperiod

period (1)	cost per passenger-km (in BF per sec.) (2)	cost for total passenger-km in one hour (in BF per sec.) (3)(*)
I	0.0241	316
V	0.0240	449
III	0.0244	554
II	0.0262	935
IV	0.0264	988

(*) column 3 = column 2 x column 6 of table 3.

From table 2 the average driving time can be calculated per subperiod. When we assume that the part of driving time, attributable to congestion by car transportation is zero in period I, one can determine for each of the subsequent periods, the part of driving time due to congestion. These figures are given in columns 2 and 3 of the next table (table 5) Multiplication of the cost for total passenger kilometers per hour (see column 3 of table 4) with the driving time due to congestion yields the per hour cost of driving time that is due to congestion. The result is given in column 4 of table 5. Column 5 of that table presents the average of column 4 per car-kilometer. The marginal cost is given in column 6. It was derived in the following manner: the cost for all passenger-kilometers (column 3 of table 4) in period t is multiplied by the difference: driving time due to congestion in period t minus driving time due to congestion in period t-1. When this product is divided by the difference: number of car-km per hour in period t minus number of car-km per hour in period t-1, we obtain the marginal cost in period t. The calculation can be written in a more concise way as follows:

$$MC_t \quad \frac{C_t(T_t - T_{t-1})}{X_t - X_{t-1}}$$

where MC = marginal cost of driving time due to congestion

C = cost for all passengers per second

T = driving time due to congestion

X = number of car-km per hour

t(=1...5) = index referring to periods in the order I,V,III,II,IV.

<u>Table 5. Marginal and average external cost per car kilometer in various periods of the day</u>

period (1)	average driving time (sec.per km) (2)	driving time due to congestion (sec.per km) (3)	cost of driving time per hour, due to congestion (4)	average cost per car km (BF) (5)	marginal cost per car-km (BF) (6)
I	220	0	0	0	0
V	229	9	4.041	0,050	0,06
III	248	28	15.512	0,130	0,27
II	263	43	40.205	0,267	0,45
IV	278	58	57.304	0,331	0,65

Legend: column 4 = column 3 x column 3 of table 4
column 5 = column 4 / column 3 of table 1
column 6 = (Δcolumn 3 x column 3 of table 4) / Δcolumn 3 of table 1.

Practically, these results mean, that on account of damage to public transportation no tax should be levied on private cars before 7 a.m. and after 18 p.m. On the other hand a considerable tax of 0,45 to 0,65 BF per car-km should be charged during peak hours, and a much smaller tax is appropriate (about 0,27 BF per car kilometer) between the peak hours, i.e. from 9 a.m. to 16 p.m.

The total daily external cost can very easily be derived from the fourth column of table 5. Each figure should be multiplied by the legnth (in hours) of the period. Summation of these products yields the required figure. In matrix notation, this reads

$$\begin{bmatrix} 0 \\ 4.041 \\ 15.512 \\ 40.205 \\ 57.304 \end{bmatrix}' \begin{bmatrix} 7 \\ 6 \\ 7 \\ 2 \\ 2 \end{bmatrix} = 327.848 \text{ BF}$$

The per annum external cost amounts roughly to 113,3 million BF.

The present value of the stream of such costs, which are in fact benefits that would accrue to a project, depends upon the economic life of the project and upon the time preference. Table 6 shows the present value for some alternative combinations of length of life and rate of interest.

Table 6. Present value of benefits to users of public transportation, resulting from separating car traffic from public transportation in Antwerp

rate of interest \ length of life	perpetual	20 years	15 years	10 years
	(in million BF)			
0,01	11.333	2.045	1.571	1.073
0;04	2.833	1.540	1.259	919
0,05	2.266	1.410	1.170	872
0;06	1.889	1.300	1.100	834
0,07	1.619	1.200	1.032	796
0,08	1.417	1.112	970	760

As a perpetual lifetime seems a good approximation for most investments in transport facilities, and a time preference of about 5 % is a reasonable one in social cost benefit analysis, one could conclude that the present value of benefits amounts to approximately 2.266 million BF. This outcome, as the table shows, is rather sensitive to the period of analysis and the discount rate but in a large number of cases the benefits exceed the considerable amount of 1.000 million BF.

3. Some conclusions

A first attempt was made to measure the volume of the damage of private car transportation to passengers of the public transportation modes.

It was found that benefits to a project to separate the private from the public transportation service would convey an annual stream of external benefits to the amount of 113,3 million BF. The present value of this benefits would be some 2.266 BF.

If no project were executed, a tax on account of damage to public transportation service of 0,45 to 0,65 BF per car-km would be appropriate in on-peak periods, whereas 0,27 BF should be charged between the two peaks. Before 7 a.m. and after 18 p.m. no (or a neglectable) tax should be levied on account of damage to public transportation.