THE TAKING INTO ACCOUNT OF DIFFERENT VEHICLE CATEGORIES IN THE OPERATION OF MOTORWAYS

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Traffic flow on motorways and expressways is narrowly associated with several types of factors : some of these factors concern the road and its design, others refer to the road environment and still others characterize the nature of traffic flow. In this last category, traffic composition plays a leading part.

The presence of lorries, recreational vehicles or buses modify very strongly the level of service offered to the road user. It affects speed, increases discomfort and reduces safety on the traffic lanes. It has a direct effect upon traffic flow by a substantial reduction of capacity of different road types.

To meet the increase of traffic of commercial vehicles associated particularly with the development of traffic flow, of goods and the multiplication of great rushes associated with holiday trips, it is important in the field of road operation to examine the aptitude of transport links to absorb the traffic volumes of the different categories of vehicles, especially lorries, recreational vehicles and buses.

The effect of these vehicles on motorway capacity is often quantified in the term "equivalence factor in units of passenger cars", called pce factor. This stands for the number of passenger cars that they represent in given road and traffic conditions. The determination of this factor allows a better relationship between transport supply and demand in a network and can lead to better co-ordination of operating measures.

Without dealing with all the problems raised by these vehicles in traffic, this paper presents three types of analysis of the effects of these vehicles upon traffic on French trunk motorways.

The first method examines the influence of these vehicles under a microscopic angle using descriptive parameters : gaps, time of presence on the detectors, lengths, ...

The two other procedures envisage traffic under a macroscopic angle. This viewpoint leads of course to the concept of fundamental diagram.

- One of the methods consists in comparing the functioning of the road with different traffic compositions.
- The other procedure, in its turn, is based upon the knowledge of the average speeds of each of the categories concerned.

1. THE MICROSCOPIC METHOD OF DETERMINING THE EQUIVALENCE FACTOR

1.1 Introduction

The question of the equivalence of lorries, buses and recreational vehicles with light or passenger cars is dealt with in detail in the Highway Capacity Manual. The criterion used for the assessment of the equivalence factor, here called e, is the relative number of overtakings per unity of distance that would have been accomplished if each vehicle had maintained its normal speed under the given conditions. The basic value given by the HCM on level terrain is 2 for lorries. Other authors have developped (ref. 2 and 3) a method for two-lane roads.

BRANSTON (ref. 4), after GWYNN (ref. 5) and SALTER (ref. 6) determines the equivalence factor by means of the relationships between headways and the categories of vehicles concerned. From these relationships, he deduces directly the capacity of a given road section. The values found vary with the lanes and categories of vehicles : for lorries, they are from 2 to 2.9, for buses from 1.3 to 1.9.

The first studies on motorway capacity undertaken in France on standardized locations have used for e the value 2 frequently admitted on level terrain. Later on, different road types have been studied and a method of assessment of e had to be adapted to each case.

1.2 The principle of the method

You should keep in mind that headways are composed of the times of presence on the detectors and gaps. The gap depends on the nature of the vehicle i and (i-1) but essentially upon the vehicle i.

With this approach, the headway of a vehicle of a given category equals e times the headway of a passenger car.

Formally, e is assessed by means of the relationship :

$$e = \frac{\text{headway of vehicle category}}{\text{headway of a passenger car}} \qquad (1)$$

Let us state that we find again the definition used by BRANSTON (4). However, we determine capacity in a different way.

The procedure used here can be resumed as follows :

- elaboration of the macroscopic parameters - traffic volumes, occupancy - for basic periods of 1, 3 or 6 minutes ;
- conversion of traffic volumes of other vehicles in pce traffic volumes with an approximated e value, usually initialized at 2 ;
- assessment, as a first approximation, of a capacity value given in pce/h and a critical occupancy based on a regression analysis ;
- selection of the 1, 3 or 6 minute-periods whose traffic volume and occupancy values are close to those at capacity, in general at 5 or 10 % ;
- study of the microscopic values of these periods and assessment of e for each lane, on the basis of the given formula ;
- "reinjection" of this e value for the new calculation of traffic volumes given in pce/h and then final assessment of capacity.

This method can of course be expanded to other levels of service.

1.3 Results obtained

This method was applied to 4 different locations whose characteristics can be seen in Table 1.

1.3.1 2 and 3 Lane-carriageways

The 4 locations were on 2 or 3-lane carriageways and at first we will give the results on this type of road, assessed at capacity level for the different lanes with long vehicles (Table 1). As a matter of fact, lorries and passenger cars are vehicles or vehicle combinations of a length superior or inferior to 7 m. Table 2 gives an extract of the number one-lane record of location number 2 with separated values for recreational vehicles ($L < 11$ m) and real lorries ($L > 11$ m). These values suggest the following comments :

- the e values are superior on the number one-lane, though relatively low : 1.92 in normal traffic flow, 1.8 with a great number of lorries and up to 1.48 with recreational vehicles. The e value on a 2 % upgrade (with 200 m of 4 %) is also very low (2.14) ; recent american studies (ref. 1) give e = 5 on an upgrade of 2 % on 1200 m ;
- recreational vehicles have the same gaps as lorries but their lengths are inferior ;
- at capacity level, the necessary passing time of a vehicle is composed of the time of presence at 10-20 % and of the gap at 80-90 %. The time of presence is essentially defined by the lengths of the vehicles for speeds are practically identic.

It is the gap that has the greatest influence upon the equivalence factor. So capacity depends wholly upon the gaps.

The equivalence factor is determined for each lane. In the calculations of traffic volumes, one can use an average value weigthed by the traffic volume of lorries in each lane. This supposes that the passenger cars which change lanes as a function of the percentage of lorries have a behaviour (gaps) that varies with the lane used.

One could also imagine that vehicles have their own gaps independent of the lane used; in this case, each vehicle "rejected" into lane 2 by a lorry occupies the space of a car with the shortest gap. Then it would be justified to calculate e on the basis of the headways of all the passenger cars and lorries on the carriageway. Thus we obtain superior e values : 2.86 for location 3 and 2.07 for location 4 (instead of 2.14 and 1.92 on lane 1).

1.3.2 One-lane roads : the case of work zones

On work zones, traffic often goes on just one lane either on the carriageway where the roadworks are carried on or on a lane operated in the wrong direction of the other carriageway. In the two cases, there is no possibility of overtaking on several kilometers. This was the case of sites 1 and 4. The following results refer indiffently to one or the other type of one-lane roads, because no difference between them has been stated.

For location number 4, the equivalence factors have been determined for 4 types of traffic flow, or for traffic volumes of 50 %, 75 % and 100 % of capacity value, then in congestion : Table 3.

At capacity level, the e value is 2.2. Figure 2 shows the variations of a certain number of variables of Table 3 ; there we see :

- the regular decrease of e and of the relationships betweens the gaps ;
- that the gaps of lorries and passenger cars have their minimum values at capacity level ;
- the very rapid variations of the gaps of lorries.

Physically, we can state that, because of the impossibility of overtaking, the cars cluster behind the slowest vehicles, most often lorries. These leave a big space before them, so much the bigger as traffic volumes are low.

1.3.3 Variations of equivalence factors on 2 and 3-lane carriageways

A priori, two parameters can affect the equivalence factor : traffic volumes and percentage of lorries.

With the definition adopted for e, as the traffic volume goes down starting at capacity level, the gap increases and, moreover, the time of presence decreases. At very low traffic volumes, all the vehicles have the same gaps and e tends towards 1.

Indeed we have been able to state the following facts :

on location n° 2, at capacity level, e = 1.53 ; at 45 % of capacity level, e = 1.15

on location n° 4, at capacity level, e = 1.92 ; at 80 % of capacity level, e = 1.77

On location n° 3 (upgrade), we determined e at capacity level for two very different percentages of lorries : 20 and 47 % ; compared to the average percentage of 28 %, there was no change neither in microscopic values nor in the e value.

1.3.4 Variations of the e value on a single lane

Fig. 2 showed the decrease of the equivalence factor with the increase of occupancy.

In one case, we found that e decreased while the percentage of lorries increased. However, this could not be considered as an established fact, because of the small number of vehicles. This decrease could be due to the presence of lorries in the queues of vehicles, which would reduce the average gap of this category.

2. THE MACROSCOPIC APPROACH BY COMPARISON OF TRAFFIC FLOW LAWS

2.1 Principle of the method

The equivalence factor e indicate the number of passenger cars represented by each lorry in given traffic flow conditions. It allows the definition of the traffic volume in pce by unit of time according to the relationship :

$$Q_{pce} = Q_{PC} + e\, Q_{lorries} \quad (2)$$

Then the method adopted consists in comparing the relationships traffic volume/occupancy for the different groups of percentages of lorries. The comparison of the capacity values obtained in each group allows the estimation of the equivalence factor lorries/passenger cars.

In fact, let us keep in mind that we have the following relationship :

$$Q_{pce} = Q\ [\ 1 + (e - 1)\ p\,] \quad (3)$$

where Q_{pce}, Q and p represent the total traffic volume in pce/h, the total traffic volume in veh/h and the percentage of lorries.

So if we have available 2 estimations $\hat{C}_1$ and $\hat{C}_2$ of capacity levels corresponding to the average percentages of lorries $\bar{p}_1$ and $\bar{p}_2$ in traffic, we can deduce :

$$\hat{C}_1\ [\,1 + (e - 1)\,\bar{p}_1\,] = \hat{C}_2\ [\,1 + (e - 1)\ \bar{p}_2\,] \quad (4)$$

and then the assessment of the factor e at capacity level, factor supposed independent of p :

$$e = 1 + \frac{\hat{C}_1 - \hat{C}_2}{\bar{p}_2\,\hat{C}_2 - \bar{p}_1\,\hat{C}_1} \quad (5)$$

With e given, it will then be easy to estimate the capacity of the motorway strucure in pce per unit of time.

2.2 Application

Forthe application, the preceding method needs the availability of 2 or more given capacity values for different traffic compositions. These values result from the adjustment of the fundamental diagrams. The obtained maximum traffic volumes are sensitive, on given motorway structures, to :

. operating conditions and traffic control ;
. environmental factors ;
. traffic composition, according to the different categories of vehicles envisaged.

We must also mention the significant influence of the choice of the basic interval of traffic counts and that of the a priori selected function of adjustment. These different remarks underline the importance of a judicious selection of data before calibrating the traffic flow laws. So the successive steps of the procedure are precised as follows.

a. Have available traffic count values for the traffic volumes of each vehicle group and the occupancy (or density) during a given basic period.

b. Cross the two variables occupancy τ and percentage of lorries p in order to select 2 or more traffic areas of the type :

$$[\tau_{min}, \tau_{max}] \times [p_1, p_2]$$

where $[p_1, p_2]$ standsfor a homogeneous group of percentages of lorries. In practice, we can, for instance, take groups of a width of 5 % if the collected data allow this.

c. Adjust the fundamental diagram in each of the traffic areas defined above.

d. Then apply the formula given for the assessment of the equivalence factor lorries/ passenger cars at capacity level.

2.3 The application of the study of the effect of lorries on an upgrade motorway section

The analyzed data correspond to values recorded on workday mornings on location 3 already mentioned. The clustering of points associated with 2 groups of percentages of lorries (0, 5) and (5, 10) is represented in Fig. 3. There we can see a clear variation of traffic flow conditions according to the traffic composition.

The statistical analysis gives a good equivalency with the "generalized power model". Tables 4 and 5 resume the principal results.

The value $e = 2.1$ confirms the results of the microscopic analysis. Compared to value 2 frequently admitted on level terrain, it appears rather small for a 4 % upgrade.

3. MACROSCOPIC APPROACH FOUNDED ON THE AVERAGE SPEEDS OF EACH CATEGORY

3.1 Description of the procedure adopted

In this paragraph, index 1 (or 2 respectively) is relative to passenger cars (or lorries respectively).

Let us adopt the hypothesis that the average speed of each category is explained SIMULTANEOUSLY by the density of all vehicle categories. So, for passenger cars and lorries, this gives the linear formulation :

$$V_1 = a_1 k_1 + b_1 k_2 + c_1 \quad (6)$$

$$V_2 = a_2 k_1 + b_2 k_2 + c_2 \quad (7)$$

V and k stand for the speed and density variables.

The traffic volumes of each vehicle category can be easily deduced. In fact, we have

$$Q_1 = k_1 V_1 = a_1 k_1^2 + b_1 k_1 k_2 + c_1 k_1 \quad (8)$$

$$Q_2 = k_2 V_2 = a_2 k_1 k_2 + b_2 k_2^2 + c_2 k_2 \quad (9)$$

and consequently $Q = Q_1 + Q_2$ for the total traffic volume.

The preceding formulations having been accepted, we suggest to characterize the set of all the density pairs (k_1, k_2) for which

. the motorway structures are at capacity level
. the composition of traffic is fixed.

Formally this set H can be defined as follows :

$$H = \left\{ (k_1, k_2) \,/\, Q \text{ maximum and } p = \text{constant} \right\}$$

These two conditions will be expressed by $dQ = 0$ and $dp = 0$.

We show (ref. 8) that in the present case, the density pairs searched for belong to the conic :

$$2(a_1 a_2 k_1^2 + b_1 b_2 k_2^2) + 4a_1 b_2 k_1 k_2 + (2a_1 c_2 + c_1 a_2)k_1 + (b_1 c_2 + 2c_1 b_2)k_2 + c_1 c_2 = 0 \quad (10)$$

The above relationship is useful for the analysis of the effects of each vehicle category on the traffic volume at capacity level.

So in the total absence of lorries - that is for $k_2 = 0$ - the critical density of passenger cars $\hat{k}_1$ can easily be calculated, as well as the capacity level $\hat{C}_o$ of the motorway structures in pce/h.

More generally, for each density value of a vehicle category, the relationship (10) determines the value of the other category at capacity traffic volume. The traffic volumes for passenger cars and lorries are then specified, as well as the total traffic volume corresponding to capacity value C (in veh/h) and the percentage of lorries p. Then the equivalence factor e is assessed by the expression :

$$e = 1 + \frac{C_o - C}{pC} \quad (11)$$

3.2 Numerical results on an upgrade motorway section

Table 6 indicates the coefficients of the models (6) and (7) on location 3. On the other hand, the relationship (10) corresponds to the equation of the following hyperbola :

$$0.265 k_1^2 + 2.679 k_1 k_2 - 1.821 k_2^2 - 117.768 k_1 - 367.399 k_2 + 10041.591 = 0 \quad (12)$$

We deduce $\hat{k}_1 = 115$ veh/km and $\hat{C}_o = 6520$ pce/h

The Table 7 indicates the different e values thus obtained according to traffic compositions at capacity level.

We note that e increases with the percentage of lorries. This results infirms the hypothesis of the preceding method, in which e was supposed to be independent of the percentage of lorries in traffic.

However, it should be stated that the 2 macroscopic approaches lead to very close capacity values.

3. CONCLUSION

The values of e found by these methods are relatively small, because, on level terrain, they are about 2.1 for lorries and 1.5 for recreational vehicles.

In this research, which is not terminated, we have been able to indicate clearly the fluctuations of the equivalence factor, which are sometimes to be verified or further explored.

In the framework of the microscopic method, there seem to be two principal questions to be raised :

. the question of calculations per lane or carriageway on the whole. In order better to motivate this choice, we should know if and how variations of the percentages of lorries, thus the numbers of passenger cars per lane, modify the gaps of passenger cars in each lane ;

. the importance of the equivalence factor in other fields than capacity and the use of a variable value. As the basic value for traffic volumes is capacity level, we will take for the e value for drafting a traffic volume - density curve, for instance, the e value at capacity level.

However, if we fix a maximum traffic volume, A or B for instance, it may be interesting to use the corresponding e value in order to take into account the discomfort caused by the different categories of vehicles.

Finally, it should be stated that the microscopic approach and the macroscopic one based on the comparison of flow-occupancy relations, lead to similar results.

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Location		Frequency	Speed km/h	Lenght m	Occupation time s	Gap s	Headway s	Caracteristics
N° 1	Lorry	56	80,3	11,9	0,54	3,43	3,97	A6 NEMOURS Workzone
Right	Car	446	78,3	3,9	0,2	2,02	2,22	Downgrade
Lane	Ratio	0,11	1,02	3,05	2,7	1,7	e = 1,8	- 0,8 %
N° 2	Lorry	665	65	10,41	0,61	3,42	4,03	A6 VALENCE
Right	Car	2175	65	4,25	0,26	2,37	2,63	2 Lanes
Lane	Ratio	0,24	1	2,45	2,35	1,44	e = 1,53	
N° 2	Lorry	70	66,6	10,3	0,68	2,08	2,76	Holiday
Left	Car	1503	68,7	4,2	0,24	1,62	1,85	Departures
Lane	Ratio	0,05	0,97	2,45	2,83	1,28	e = 1,49	
N° 3	Lorry	415	49,7	12,3	0,92	3,59	4,5	A6 SAVIGNY
Right	Car	1079	54	4,27	0,3	1,8	2,1	Outskirts of Paris
Lane	Ratio	0,28	0,92	2,88	3,02	2	e = 2,14	upgrade
N° 3	Lorry	18	56,6	12	0,77	1,67	2,44	2 %
Center	Car	1060	57,9	4,06	0,26	2,23	1,49	(1400 m) and 4 %
Lane	Ratio	0,02	0,98	2,95	2,96	1,36	e = 1,64	(200 m)
N° 4	Lorry	114	57	12,4	0,79	3,6	4,38	
Right	Car	882	57	4	0,26	2,03	2,28	A6
Lane	Ratio	0,11	1	3,1	3,04	1,77	e = 1,92	Outskirts of Paris
N° 4	Lorry	18	68,7	9,12	0,5	1,84	2,34	
Left	Car	1387	59,9	4,78	0,29	1,49	1,70	Workzone
Lane	Ratio	0,02	1,15	1,91	1,72	1,23	e = 1,31	

TABLE 1 : 2 and 3 lanes carriage-ways. Microscopic variables.

	Frequency	Speed	Lenght	Occupation time	Gap	Headway
Car	726	69,6	4,24	0,23	2,34	2,57
(1) Lorries L > 11 m	69	65	14,6	0,91	3,34	4,25
Ratio (1)/Car		0,97	3,42	3,95	1,43	e = 1,65
(2) Rec. Veh. (L < 11 m)	207	67,2	9,2	0,51	3,3	3,8
Ratio (2)/Car		1	2,15	2,21	1,41	e = 1,48
(3) Rec. Veh. + Lorries	276	66,7	10,6	0,61	3,31	3,92
Ratio (3)/Car		0,96	2,47	2,65	1,41	e = 1,52

TABLE 2 : Location n° 2 - Right lane - Microscopic variables for lorries and recreationnal vehicules (Rec. Veh.)

	50 % capacity			75 % capacity			Capacity			Congestion		
% Lorries	21			23			31			24		
Speed km/h	59			64			52			27		
	Car	Lorries	Ratio	Car	Lorries	Ratio	Car	Lorries	Ratio	Car	Lorries	Ratio
Occupation time s	0,25	0,73	2,93	0,28	0,8	3,36	0,33	0,96	2,8	0,76	1,98	2,8
Gap s	2,5	8,9	3,56	1,86	5,05	2,71	1,55	3,13	2,02	2,15	3,45	1,58
Headway s	2,76	9,61	e=3,48	2,13	5,35	e=2,75	1,87	4,1	e=2,2	2,93	5,43	e=1,85

TABLE 3 : Location n° 4 - One lane carriage-way. Microscopic values at various regimes. Cars and lorries have same speed at all regimes.

% Lorries	Mean	Equation	Capacity (veh/h)
0 - 5	3.5	$Q/\tau = [illegible]87 - 362\,\tau^{0.293}$	6440
5 - 10	7.1	$Q/\tau = 624 - 25\,\tau^{0.344}$	6203
10 - 15	11.8	$Q/\tau = 552 - 19\,\tau^{0.873}$	5906

TABLE 4

Comparison of different zones of % Lorries	Values of e	Capacity in pce/h
(0,5) and (5,10)	2.09	6685
(0,5) and (10,15)	2.13	6704
(5,10) and (10,15)	2.16	6716

TABLE 5

Speed model	Equation	R^2	Linear Correlation With k_1	Linear Correlation With k_2
Cars	$V_1 = -0.4932k_1 - 0.6704k_2 + 113.4288$	0.88	- 0.9163	- 0.3690
Lorries	$V_2 = -0.2684k_1 - 1.3579k_2 + 88.5277$	0.65	- 0.6577	- 0.5797

TABLE 6

% Lorries	Method 2 Comparison of flow-occupancy relations		Method 3 Mean speed of each category of vehicules	
	Capacity in veh/h	Values of e	Capacity in veh/h	Values of e
3.5	6440	2.09	6437	1.42
6.5	6225	2.10	6290	1.55
7.1	6203	2.13	6265	1.58
11.8	5906	2.16	5909	1.88

TABLE 7

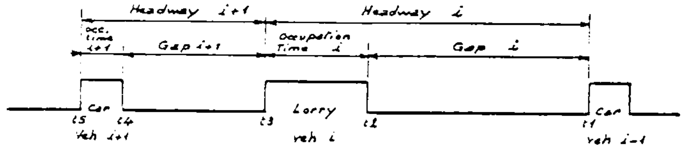

Fig. 1 - Signal output from detectors

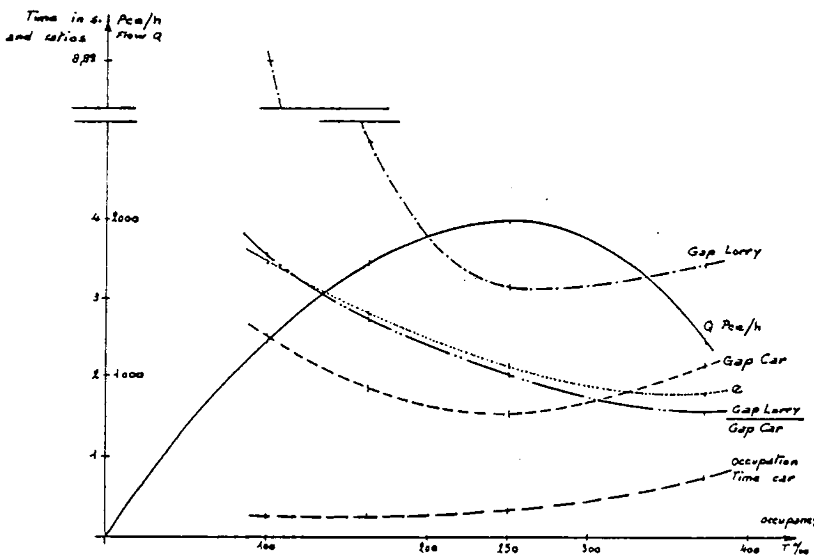

Fig. 2 - One lane carriage-way. Flow and microscopic variables versus occupancy.

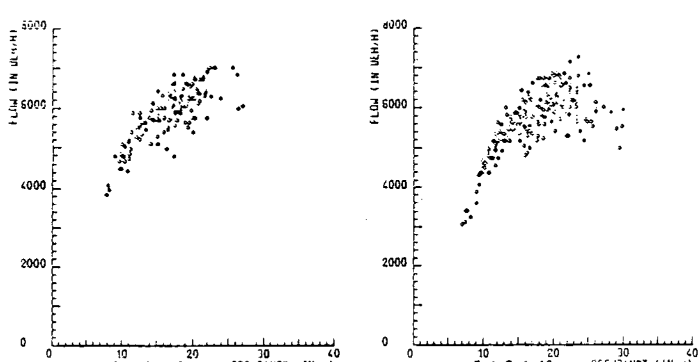

Fig. 3 - Evolution of traffic flow conditions for different percentages of lorries.