Impact of traffic regulation on lane flow - distribution and capacity of motorways

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Abstract

The distribution of traffic flow in the individual lanes on multilane motorways is an important problem in traffic engineering. The lane flow-distribution directly affects the total capacity of the motorway. Because of different regulations such as “Keep in Lane” which is quiet common in North America and “Commandment of Driving on Right and Prohibition of Overtaking on Right” which applies broadly in Europe, the lane flow-distribution is different from country to country. The regulation regarding speed limits can affect the lane flow-distribution and therefore the capacity. This paper presents a set of representative examples of lane flow-distributions for motorways with two and three lanes in each direction. The results here show significant difference in lane flow-distributions between motorways in Germany and in North America. It also shows that the average capacity of motorways in North America is higher than that in Germany. One of the main reasons for this is the difference in the lane flow-distribution. The investigation shows that the two types of regulations for traffic on motorways have both advantages and disadvantages. The result here can be the basis for a useful recommendation to the Chinese policy makers in setting up regulations for motorway design and operation.

Keywords:

motorway design and operation, lane distribution of traffic flow and capacity, traffic regulation

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Introduction

The distribution of traffic flow in the individual lanes of multilane motorways is an important parameter in traffic engineering. The lane flow-distribution can directly affect the capacity of the motorway section under investigation. Works on this problem have been published by Breuer and Beckmann (1969), Hotop (1975), Sparmann (1978), Leutzbach and Busch (1984), Hall and Lam (1988), as well as by Heidemann (1994). These investigations revealed that in the presence of high volumes, more vehicles tend to travel on the median lane (left-hand lane for the 2-lane right-hand traffic) rather than on the shoulder lane (right-hand lane for the 2-lane right-hand traffic). Thus, it is of interest to develop a method for measuring and improving the capacity of multilane carriageways, and to understand the phenomena of traffic congestion since higher total capacity would be possible if more balanced lane utilization can be established.

Because of the different regulations such as “Keep in Lane” which is quite common in North America and “Commandment of Driving on Right and Prohibition of Overtaking on Right” which applies broadly in Europe, the lane flow-distribution is different from country to country. Also regulations regarding speed limits can significantly affect the lane flow-distribution and therefore the capacity. The present paper presents a set of representative examples of lane flow-distributions for motorways with two and three lanes in each direction. The results of our investigation shows that there is significant difference in the lane flow-distributions between the motorways in Germany (with the regulation “Commandment of Driving on Right” and normally no speed limit) and that in North America (with the regulation “Keep in Lane” and widely used speed limits). The investigation shows that the average capacity of motorways in North America States is higher than that in Germany.

Lane flow-distribution on motorways

Given the total flow rate of a motorway q_{sum}, the relationship between the proportion of traffic flow rates, p_1, p_2,..., on the different traffic lanes 1, 2 ... can be calculated as a function of the total flow rate q_{sum}. Hence, the following relationship always holds:

$$\begin{cases} p_1 = q_1 / q_{sum} \\ p_2 = q_2 / q_{sum} \\ \dots \\ p_1 + p_2 + \dots = 1 \end{cases} \qquad (-) \qquad (1)$$

where p_1, p_2,... are functions of q_{sum}.

In Figures 1 and 2 the measured lane flow-distributions for the sample 2- and 3-lane carriageways in Germany are illustrated.

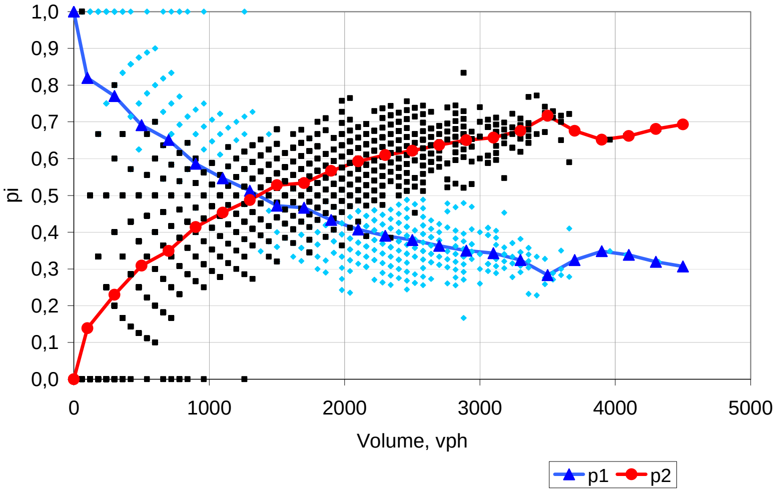


Figure 1 - Lane flow-distribution for a sample two-lane carriageway in Germany (Data: German motorway A44, 1-min intervals, *p*=class means)

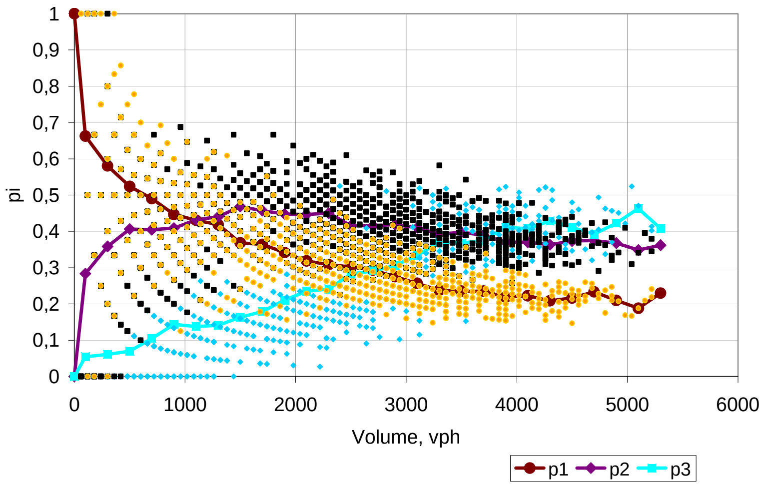


Figure 2 - Lane flow-distribution for a sample three-lane carriageway in Germany (Data: German motorway A1, 1-min intervals, *p*=class means)

The lane flow-distributions illustrated in Figures 1 and 2 represent average traffic conditions on German motorways. In other European countries, the lane volume distribution on motorways is comparable to those in Germany. We can recognize in these figures, that under heavy traffic conditions (near capacity) only 35% (compared to 50% for a uniform distribution) of the total traffic flow is traveling on the first (rightmost) lane of a two-lane carriageway (Figure 1). For a three-lane carriageway, it is even below 25% (Figure 2, compared to 33% for a uniform distribution).

Assuming a maximum lane capacity for the most occupied lane, the total capacity of a carriageway can be estimated from the lane flow-distribution at capacity. For example, for the lane flow-distributions from Figure 1 and Figure 2, the total and average lane capacities for carriageways with 2 and 3 lanes can be estimated, as shown in Table 1 (with $C_{max,ln}$ = 2400 veh/h). It can be recognized here that the average lane capacity increases with increasing number of lanes (cf. FGSV, 2001).

Table 1- Capacity estimation from the lane flow-distribution for German motorways (cf. Figure 1 and Figure 2).

		Distribution of lane flow (%)			Average capacity	
n	lane C_{max}	*j*=1	*j*=2	*j*=3	C_{total}	C_{ln}
2	2400	32	68	-	3535	1768
3	2400	21	35	44	5510	1837

The lane flow-distribution is of course different from country to country because of the different traffic behaviours and regulations. The characteristic profile of the lane flow-distribution on German motorways is a consequence of the strict regulations of "Commandment of Driving on Right" and "Prohibition of Overtaking on Right". In general, country-related lane flow-distributions should be used for the calculations.

In North America, where the regulation of "Keep in Lane" is common, the lane volume distribution should be more balanced than in European countries.

In Figure 3 and Figure 4 the measured lane flow-distributions for the sample 2- and 3-lane carriageway in North America are illustrated.

We see that for motorways in North America, the lane flow-distributions are more balanced compared to that for German motorways (cf. Figure 1 and Figure with Figure 3 and Figure 4).

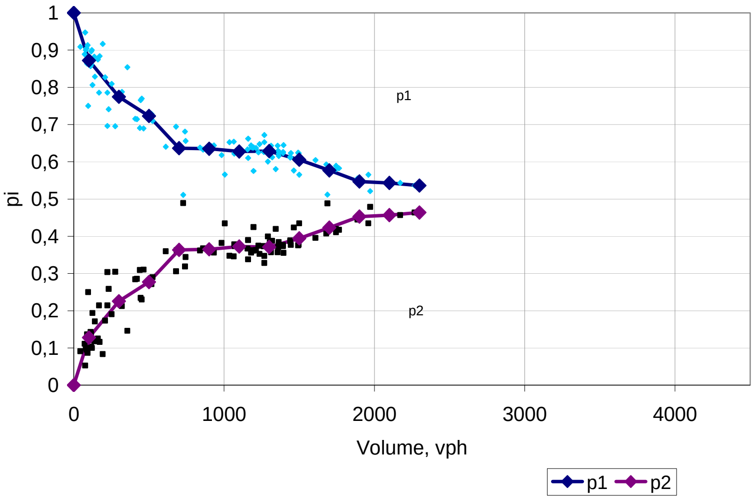


Figure 3 - Lane flow-distribution for a sample two-lane carriageway in North America. (Data: Texas, Highway 6, 15-min intervals, *p*=class means.)

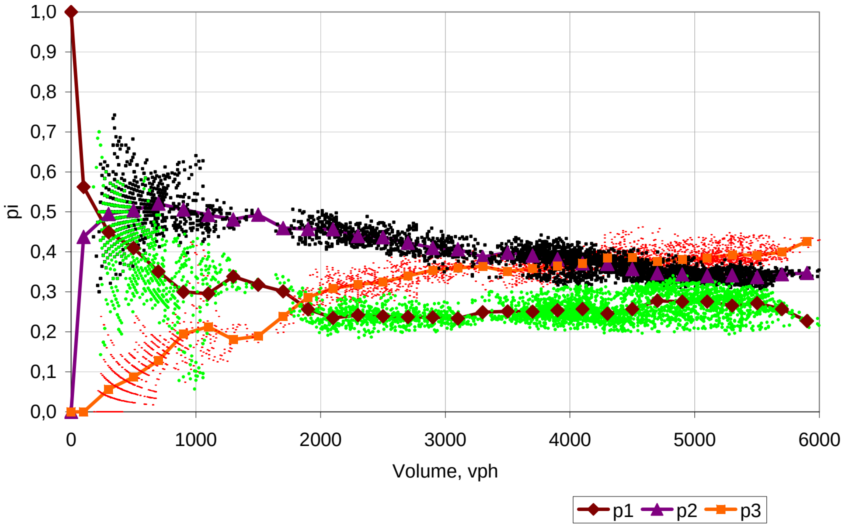


Figure 4 - Lane flow-distribution for a sample three-lane carriageway in North America. (Data: Canada (QEWDE0500DES), 1-min intervals, *p*=class means.)

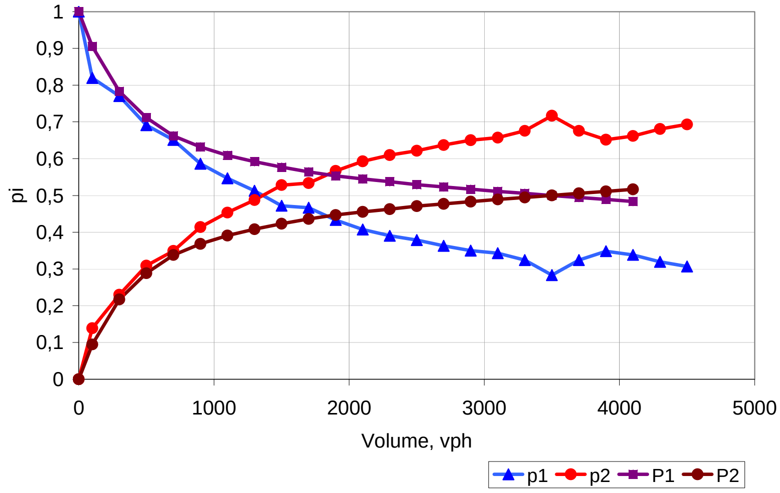
Table 2- Capacity estimation from the lane flow-distribution for motorways in North America (cf. Figure 3 and Figure 4).

		Proportion of lane flow at capacity (%)			Average capacity	
Number of lanes, *n*	lane C_{max} (veh/h)	*j*=1	*j*=2	*j*=3	C_{total} (veh/h)	C_{ln} (veh/h)
2	2400	48	52	-	4646	2323
3	2400	27	34	39	6109	2036

The total and average lane capacities of the sample carriageways with 2 through 3 lanes in North America can be estimated as shown in Table 2 (with $C_{max,ln}$ = 2400 veh/h). It can be recognized that the average lane capacities are higher than those in Germany. From these data, it seems the lane capacity of the two-lane carriageway is higher than the lane capacity of the three-lane carriageway. This does not agree with the statement in HCM 2000 (TRB, 2000) that the lane capacity of a two-lane carriageway is lower than the lane capacity of a three-lane carriageway. However, this discrepancy cannot be considered as representative because the sample field data of the two-lane carriageway was of poor quality. In the range of the capacity we have no data points at all (cf. Figure 3). The extrapolation of the model function into this range is not very reliable. Thus, more data are needed in order to get a more accurate conclusion. Furthermore, heavy vehicles have not been taken into account in this investigation, so that comparison with the values given in HCM 2000 may not be appropriate.

To demonstrate the differences between the lane flow-distributions in Germany and North America, the lane flow-distributions for both areas are illustrated together in

Figure 5. We can see clearly the more balanced lane flow-distribution in North America both for the sample two-lane carriageway and for the sample three-lane carriageway. This is a consequence of the traffic regulations. The major differences in traffic regulations in both areas are presented in Table 3 together.



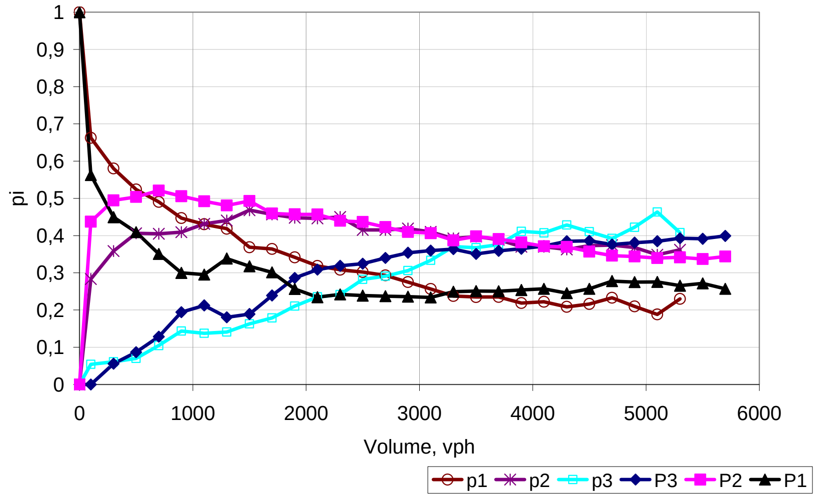


Figure 5 – Comparison of lane flow-distributions for motorways in Germany and North America (p for Germany, P for North America).

Table 3- Major differences in traffic regulations in Germany and North America

	Germany	North America
overtaking	only on left	no restriction
speed for Heavy traffic	80 km/h	no restriction
general speed limit	no restriction	up to 120 km/h

If the traffic flow rate of the different lanes, q_1, q_2, ..., can be obtained directly from measurements, they should be used directly for further calculations.

In additions to the theoretical approaches for representing the lane flow-distribution (cf. Heidemann, 1994, Wu, 2005 and 2001), a generalized regression function (2) is established here for a carriageway with n lanes. This regression function is

$$\begin{cases} p_i = a(1 - b \cdot e^{-c \cdot q_{sum}{}^{d}}) q_{sum}{}^{-e} & for \quad i \neq 1 \\ p_1 = 1 - \sum_{i=2}^{n} p_i & for \quad i = 1 \end{cases} \qquad (-) \qquad (2)$$

q_{sum} is the total flow rate in veh/s. The parameter a, b, c, d, and e for sample motorways are given in Table 4.

Table 4- Parameters of the regression function (2) for the sample motorways in Germany and North America

	Germany			North America		
Parameter	A44	A1		HWY6	DET500	
	n=2	n=3		n=2	n=3	
	i=2	i=2	i=3	i=2	i=2	i=3
a	1,41	0,41	1,67	5,59	0,41	0,57
b	1,00	1,53	1,00	1,00	0,98	1,01
c	0,65	3,87	0,25	0,10	2,88	1,04
d	1,59	0,44	3,35	1,60	0,71	1,40
e	1,02	0,20	2,35	1,32	0,44	0,54

Figure 6 through Figure 9 show the shape of the lane flow-distribution from equation (2) for motorways under consideration together with the class means of the field data. We can see here that the generalized regression function (2) fits the field data perfectly. Thus, this function can be recommended for fitting real lane flow-distributions under arbitrary traffic conditions.

Once the proportion of the traffic flow rates, p_1, p_2,..., are given, the traffic flow rate of the different lanes, q_1, q_2, ..., can be calculated from the function

$$\begin{cases} q_1 = p_1 \cdot q_{sum} \\ q_2 = p_2 \cdot q_{sum} \\ \ldots \\ \ldots \end{cases} \qquad (veh/s) \qquad (3)$$

Obviously, the lane flow-distribution can only be calculated up to a certain maximum of the traffic flow rate. Normally, this limit is the capacity of the motorway. Beyond this limit all functions derived above are not defined because the flow rate q_{sum}

is no longer defined. Thus, the lane distribution of flow rates in congested conditions cannot be obtained from this proposed model. For the lane flow distribution in congested conditions, a theoretical solution is given elsewhere by the author (Wu, 2005).

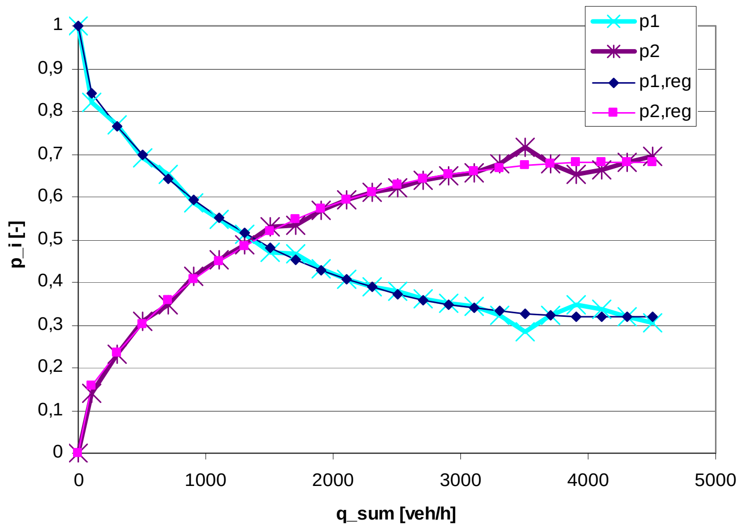


Figure 6 – Regression function (eq.(2)) of the lane flow-distribution for the sample two-lane motorway in Germany (p=class means of field data, p_{reg}=regression)

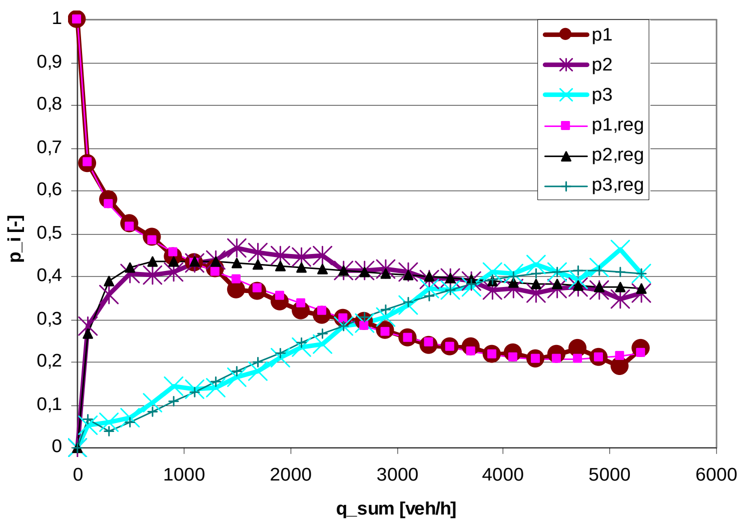


Figure 7 - Regression function (eq.(2)) of the lane flow-distribution for the sample three-lane motorway in Germany (*p*=class means of field data, p_{reg}=regression)

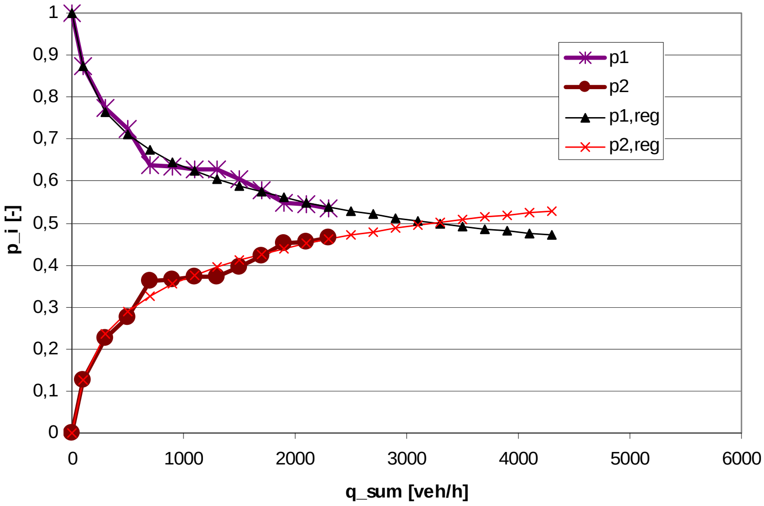


Figure 8 - Regression function (eq.(2)) of the lane flow-distribution for the sample two-lane motorway in North America (p=class means of field data, p_{reg}=regression).

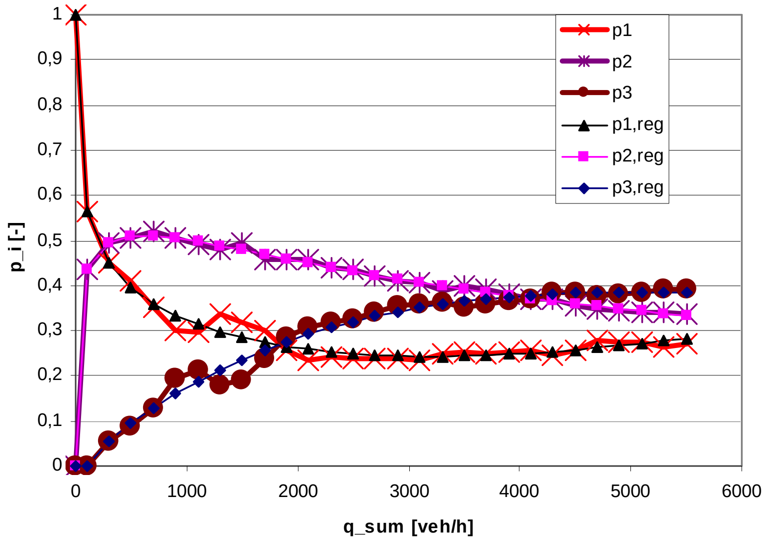


Figure 9 - Regression function (eq.(2)) of the lane flow-distribution for the sample three-lane motorway in North America (p=class means of field data, p_{reg}=regression).

Conclusions and outlook

In this paper a set of representative examples of lane flow-distributions for motorways with two and three lanes in each direction is introduced and. The results here show that there are significant differences in the lane flow-distributions between the motorways in Germany (with the regulation "Commandment of Driving on Right" and normally no speed limit for passenger cars and strict speed limits for heavy vehicles) and that in North America (with the regulation "Keep in Lane" and widely used speed limits for both passenger cars and heavy vehicles). Our study also shows that the average capacity of motorways in North America is higher than that in Germany. One of the main reasons is the difference in the lane flow-distribution. The investigation demonstrates that there are both advantages and disadvantages in the two types of regulation for traffic on motorways.

For practical applications, a generalized regression function is introduced to represent the real lane flow-distributions under the traffic conditions being investigated.

The results here can be useful to Chinese policy makers in setting up traffic regulations in motorway design and operation.

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