

COMPARISON OF KEY FREEWAY CAPACITY PARAMETERS ON NORTH AMERICAN FREEWAYS WITH GERMAN AUTOBAHNS EQUIPPED WITH A VARIABLE SPEED LIMIT SYSTEM

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ABSTRACT

This paper compares key freeway traffic flow parameters for an 18-kilometer segment of a German autobahn with findings from freeways in the U.S. and Canada. The autobahn segment contains a surveillance system and a variable speed limit and congestion level information system using variable message signs located on overhead gantries. This paper includes analysis of the relationships between vehicle flow, density, and speed surrounding an active bottleneck. The relationships between key traffic parameters have been based on reproducible features observed on multiple days. Results are compared with the Highway Capacity Manual (HCM 2000) and the German Handbuch für die Bemessung von Strassenverkehrsanlagen (HBS 2001). Further, the speed/flow relation for various proportions of heavy vehicles is investigated and results are presented that compare field measurements with HBS and HCM guidelines.

1.0 INTRODUCTION

As part of a larger study comparing U.S. and German freeway traffic dynamics, this paper describes an analysis of freeway capacity and level of service parameters on a German Autobahn. This study has identified several recurrent bottlenecks on the A9 motorway near Munich, Germany using archived inductive loop detector data for the days June 24-July 8, 2002 and May 21, 2003. Detector data was provided in 1-minute intervals and segregated by lane and by vehicle type. The construction of transformed curves of cumulative vehicle count and time averaged speed for both autos and trucks provided the resolution necessary to characterize traffic conditions over the freeway segment and facilitated the careful identification of bottleneck activation locations and times (Cassidy and Windover 1995; Cassidy and Bertini 1999). Given the bottleneck's precise activation and deactivation times, its discharge flow (often referred to as capacity) can be measured.

Bottleneck capacities were compared to other measurements conducted on freeways in the U.S., Canada, the U.K. and Germany. For isolated bottleneck activations (preceded by freely flowing traffic) this comparison was directed toward the measurement of flows prior to and during bottleneck activation. For non-isolated bottleneck activations (not preceded by freely flowing traffic), only queue discharge flows are compared. With the segregation of measured traffic parameters by lane and vehicle type (auto versus truck) on the A9, additional insights were revealed that were not possible at other sites. Detailed detector data has allowed for the

exploration of the fundamental relationships for flow, speed, and density in individual lanes and by vehicle type. These relationships are then compared to those provided by the HCM (2000) and HBS (2001) guidelines. Developing an improved understanding of how freeway systems operate in different countries with different control strategies, geometric standards, and driver characteristics requires further empirical analyses using archived sensor data. Brilon and Ponzlet (1996) have noted that average speeds on German Autobahns are highly influenced by traffic volume largely due to the fact that no mandatory speed limit is enforced on many Autobahns.

2.0 STUDY AREA

The A9 study area (between Munich and Nürnberg, Germany) is shown in Figure 1. The analysis considered the north- and southbound directions between kilometers 510.34-528.15. The northbound direction is equipped with 17 inductive loop detector stations (labeled 630-160) and there are 16 southbound detector stations (labeled 25-57). The detector station spacing is provided in meters. Unique to this autobahn section is the use of a variable speed limit (VSL) and traffic information system using variable message signs (VMS) mounted on overhead gantries (shown in Figure 1 as solid lines across the lanes). There are five northbound VMS gantries (labeled AQ 304-312) and ten southbound labeled AQ 201-215a (labels provided by Autobahndirektion Südbayern). The roadway geometry varies between two and three lanes with one lane drop in the southbound direction and one lane addition in the northbound direction.

3.0 BOTTLENECK CAPACITY

Bottleneck activations occurred at reproducible locations on multiple days in the northbound and southbound directions, revealed via analysis of historical inductive loop detector data (Bertini, Hansen and Bogenberger 2004; Bertini, Boice and Bogenberger 2005). A bottleneck arose between northbound stations 390 and 380 a total of 12 times over eight days analyzed for this direction. For the southbound direction, a bottleneck was activated between detectors 57-53 for all three southbound analysis days. Five of the activations in the northbound direction and three in the southbound were isolated bottleneck activations. Table 1 summarizes the bottleneck

characteristics in addition to measured capacities on Autobahn 5 (Lindgren 2005).

The table includes a comparison of these flows to A5 near Frankfurt am Main, Germany to determine if pre-queue and queue discharge flows were similar. As indicated, these peak flows appear to be consistent. On A9, average pre-queue flows ranged between 1440-2430 vehicles per hour

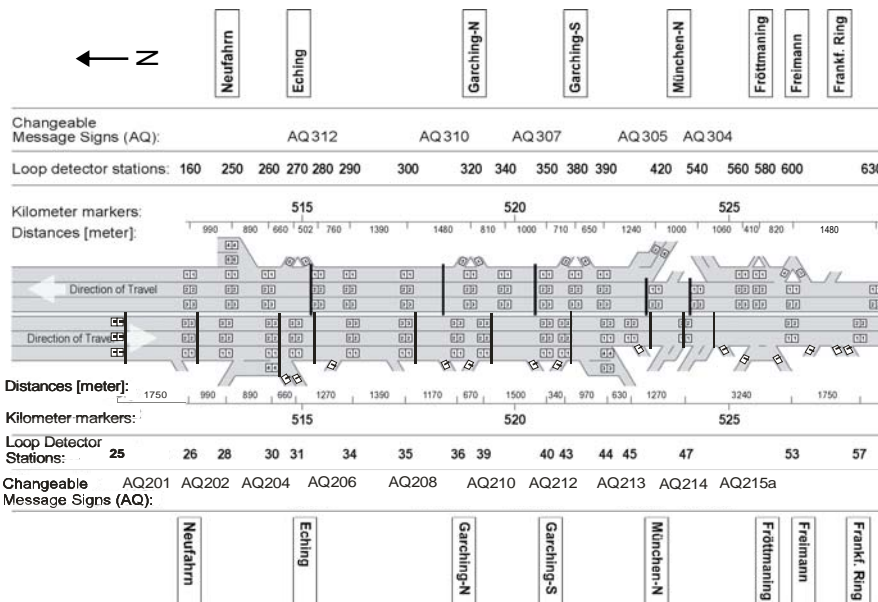


Figure 1: Study Area

per lane (vphpl) in the northbound direction and 1810-2250 vphpl southbound. The A9 consists of 3 lanes between detector stations 390-380 in the northbound direction and 2 lanes in the southbound direction between detector stations 53-57 where bottleneck activations occurred. The difference in capacities between two and three lane autobahns will be discussed in sections that follow. A9 queue discharge flows ranged between 1490-2030 vphpl northbound and 1860-2080 vphpl in the southbound direction. Average pre-queue flows across lanes were 1910 and 2030 vphpl for northbound and southbound A9 respectively while average queue discharge flows were 1800 and 1970 vphpl for northbound and southbound. Average pre-queue and queue discharge flows observed on A5 were 1730 and 1600 vphpl respectively. Backward propagating shock velocities ranging between 6-20 km/hr were measured on A9 in both directions. Further comparisons were made with freeway sections analyzed in the U.S., U.K., and Canada. These comparisons are presented in Table 2. As shown both pre-queue and queue discharge flows measured on Canadian and U.S. freeways are notably higher than those measured on A9 while measurements from the U.K. are similar.

Table 1: Isolated Bottleneck Activations (A9 and A5 in Germany)

Date	Pre-Queue Flow by Lane (vph)				Discharge Flow by Lane (vph)				Flow Change by Lane (%)			
	All	Median	Middle	Shoulder	All	Median	Middle	Shoulder	All	Median	Middle	Shoulder
A9N 6/27/02	5510	2410	1760	1340	5370	2140	1790	1440	-2.5	-11.2	1.7	7.5
A9N 6/28/02	5800	2490	1910	1400	5550	1890	2190	1470	-4.3	-24.1	14.7	5.0
A9N 7/2/02	5980	2340	1920	1720	5190	1960	1690	1540	-13.2	-16.2	-12.0	-10.5
A9N 7/3/02	5840	2360	1940	1540	5490	2040	1900	1550	-6.0	-13.6	-2.1	0.6
A9N 7/5/02	5530	2530	1770	1220	5430	2120	1850	1460	-1.8	-16.2	4.5	19.7
<i>Mean A9 N</i>	<i>5730</i>	<i>2430</i>	<i>1860</i>	<i>1440</i>	<i>5410</i>	<i>2030</i>	<i>1880</i>	<i>1490</i>	<i>-5.6</i>	<i>-19.8</i>	<i>1.1</i>	<i>3.5</i>
A9S 5/21/03	4350	2430	-	1920	4330	2260	-	2070	-0.5	-7.0	-	7.8
A9S 6/24/02	3780	2070	-	1710	3550	1900	-	1650	-6.1	-8.2	-	-3.5
A9S 6/26/02	5300	-	-	-	4770	-	-	-	-10.0	-	-	-
<i>Mean A9 S</i>	<i>4480</i>	<i>2250</i>	<i>-</i>	<i>1810</i>	<i>4220</i>	<i>2080</i>	<i>-</i>	<i>1860</i>	<i>-5.8</i>	<i>-7.6</i>	<i>-</i>	<i>2.8</i>
A5 N 9/14/01	5190	2270	1860	1060	4630	1840	1640	1150	-10.8	-18.9	-11.8	8.5
A5 N 9/14/01	5090	2190	1880	1020	5170	2190	1810	1170	1.6	0.00	-3.7	14.7
A5 N 9/14/01	5380	2450	1930	1000	5220	2090	1840	1290	-3.0	-14.7	-4.7	29.0
A5 N 9/14/01	5170	2100	1700	1370	5100	2010	1750	1340	-1.4	-4.3	2.9	-2.2
A5 N 12/4/01	4770	1820	1800	1150	4260	1690	1500	1070	-10.7	-7.1	-16.7	-7.0
A5 N 12/4/01	4950	2030	1700	1220	4710	1860	1710	1140	-4.8	-8.4	0.6	-6.6
A5 N 9/19/01	5760	2470	1970	1320	5320	2120	1930	1270	-7.6	-14.2	-2.0	-3.8
A5 N 8/17/01	5300	2300	1940	1060	5100	2200	1850	1050	-3.8	-4.2	-4.6	-0.9
A5 N 9/20/01	5220	2200	1890	1130	5150	2240	1830	1080	-1.3	1.8	-3.2	-4.4
<i>Mean A5</i>	<i>5203</i>	<i>2200</i>	<i>1850</i>	<i>1150</i>	<i>4960</i>	<i>2030</i>	<i>1760</i>	<i>1170</i>	<i>-4.7</i>	<i>-7.7</i>	<i>-4.9</i>	<i>1.7</i>

4.0 FUNDAMENTAL RELATIONSHIPS

It has been shown that the traffic flow variables speed, volume, and density are dependent on one another as illustrated by the fundamental relationship diagrams presented in many of today's transportation planning and design manuals. Although these relationships are typically agreed upon, the formation or exact dependency of the relationship is often a topic of debate. Thus, an attempt to better understand the relationship between these parameters was made for this study segment of A9 with the assistance of historical inductive loop detector data. Aided by transformed curves of cumulative count and time averaged speed, periods exhibiting "nearly stationary" traffic states were identified, consisting of nearly constant flow and speed over a sustained period. The mean values measured during the nearly stationary periods were then

Table 2: U.S., Canada, and U.K. Bottleneck Activations

Date	Country	Roadway	Pre Queue	Discharge Lane Flow (vph)				% Δ Flow
				All	Median	Mid	Should	
10/10/02	Canada	Gardiner W	-	5770	2270	1890	1610	-
10/10/02	Canada	Gardiner W	-	5990	2290	1960	1740	-
10/10/02	Canada	Gardiner W	-	5820	2200	1840	1780	-
10/10/02	Canada	Gardiner W	-	5970	2220	1900	1850	-
3/5/97	Canada	Gardiner W	6490	5980	2340	1920	1720	-7.9
2/20/97	Canada	Gardiner W	6620	5890	2290	1910	1690	-11.0
7/21/97	Canada	Gardiner W	6120	5970	2330	1950	1690	-2.5
2/11/97	Canada	Gardiner W	6270	5800	2290	1890	1620	-7.5
3/12/97	Canada	Gardiner W	-	5830	2320	1900	1610	-
1/17/97	Canada	Gardiner W	-	5860	2390	1910	1560	-
10/8/97	Canada	Gardiner W	-	6070	2350	1990	1730	-
11/26/98	Canada	Gardiner W	-	5940	2290	1920	1730	-
5/3/95	Canada	QEW E	7000	6420	-	-	-	-8.3
5/1/95	Canada	QEW E	6890	6420	-	-	-	-6.8
5/12/95	Canada	QEW E	7120	6500	-	-	-	-8.7
11/16/98	U.K.	M4	3690	3300	-	-	-	-10.6
11/18/98	U.K.	M5	3690	3300	-	-	-	-10.6
11/30/98	U.K.	M6	3840	3430	-	-	-	-10.7
12/2/98	U.K.	M7	3750	3500	-	-	-	-6.7
12/3/98	U.K.	M8	3510	3150	-	-	-	-10.3
3/20/00	U.S.	Minn I-494	4475	4250	-	-	-	-5.0
3/21/00	U.S.	Minn I-495	4440	4230	-	-	-	-4.7
3/23/00	U.S.	Minn I-496	4340	4260	-	-	-	-1.8
3/24/00	U.S.	Minn I-497	4530	4290	-	-	-	-5.3

plotted. The methodology used here follows that presented in Cassidy (1998) in which nearly stationary traffic states tended to generate well defined reproducible continuous relationships and targets the reduction of the noise in these measured relations. For this paper, nearly steady states of flow and speed were considered only when the duration was 5 minutes or greater and when average flows and speed did not fluctuate by more than 10 vpm or 10 km/hr respectively.

Figure 2 presents the speed-flow, speed-density, and flow-density relationships at detector 390 northbound A9 on June 27 and June 28, 2002. Two days are shown for the same detector location to

ensure the reproducibility of the relationships. The VSL system was in operation on these days, and weather conditions were fair. Therefore measured capacity should not be influenced by varying weather, but may be influenced by speed regulations (Bertini, Boice and Bogenberger 2005). Previous studies found that wet roadway conditions can decrease capacity by as much as 350 (500) vph on two (three) lane autobahns respectively (Brilon and Ponzlet 1996). These plots illustrate the relationship for all vehicles over all lanes. These detectors are just upstream of the bottleneck between detector stations 390-380. Consistent with findings on June 27, a bottleneck was activated between detector stations 390-380 on June 28. All plots appear to follow a well shaped continuous function which is usually not visible in raw scatterplots of these relations.

The diagrams in Figure 2 reveal that the maximum sustainable flow appears to be near 5800 vph where the speed-flow and flow-density curves in essence break off and the slope changes from positive to negative. The traffic state changes from the uncongested regime to the congested (queued) regime. This estimated maximum flow is nearly equivalent to the pre-queue flows measured on northbound A9 that were shown in Table 1. With the cross-section of the freeway consisting of three lanes at this location, this is equivalent to an average of approximately 1930 vphpl. The value is similar to pre-queue and queue discharge flows observed in the middle lane. The critical speed appears to be near 80 km/hr. It is noted that the average peak 15-minute flow observed over both days was 1475 vehicles while the average peak hour (16:00-17:00) flow observed over both days was 5605 vehicles across all lanes (1870 vphpl).

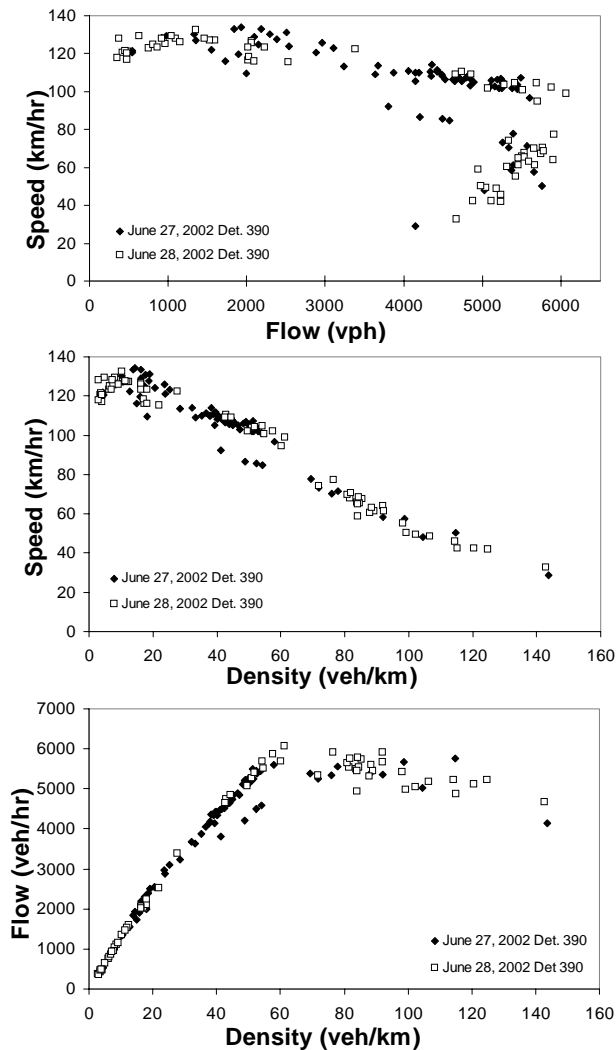


Figure 2: Fundamental Relationships

With the availability of individual lane data these relations were further explored for each lane. Figure 3 illustrates averages for all vehicles traveling in the median, middle and shoulder lanes respectively on June 27 and June 28, 2002. Points for different days at the same detector station are similar. A peak flow of near 2300 vph appears to be the break point for the median lane, while peak flows of 2000 vph and 1700 vph appear to be the maxima for the middle and shoulder lanes respectively. Critical speeds are 70, 80, and 90 km/hr for the shoulder, middle, and median lanes respectively. Lower maximum flows measured in the middle and shoulder lanes are likely due to the many on- and off-ramps located throughout this segment as well as moderate to high truck percentages present in these lanes. By German law, trucks must travel at 80 km/hr and are also subject to passing restrictions as is this case for this particular section of A9. An average truck percentage of 43% was observed in the shoulder lane and 6% in the middle lane over these two days. As was seen in Table 1, pre-queue and queue discharge flows were generally much lower in these lanes.

5.0 HCM 2000 AND HBS 2001

The Highway Capacity Manual (HCM 2000) serves as a guide for engineers and planners for the design and operations of transportation facilities in the U.S. Similarly, the Handbuch für die Bemessung von Strassenverkehrsanlagen (HBS 2001) is Germany's equivalent to the HCM. It was developed in 1993 by the Research Association for Road and Traffic (FGSV). This manual also serves as a guide for developing systematic and standardized procedures for estimating the capacity of transportation facilities. Both manuals use level-of-service (LOS) concepts to quantify how well a facility is operating from a driver perspective. The LOS thresholds for freeway facilities consisting of level terrain and having a free flow speed of 120 km/hr and a truck percentage of 10% as defined by the HBS and HCM are included in Table 3. A free flow speed of 121 km/hr was measured over detector station 390 on both June 27 and June 28, 2002 as Figure 3 supports. This speed was measured only when the flow was 1300 vph or less as recommended by the HCM. Free flow speeds for passenger cars were measured to be 133 km/hr as Figure 3 confirms.

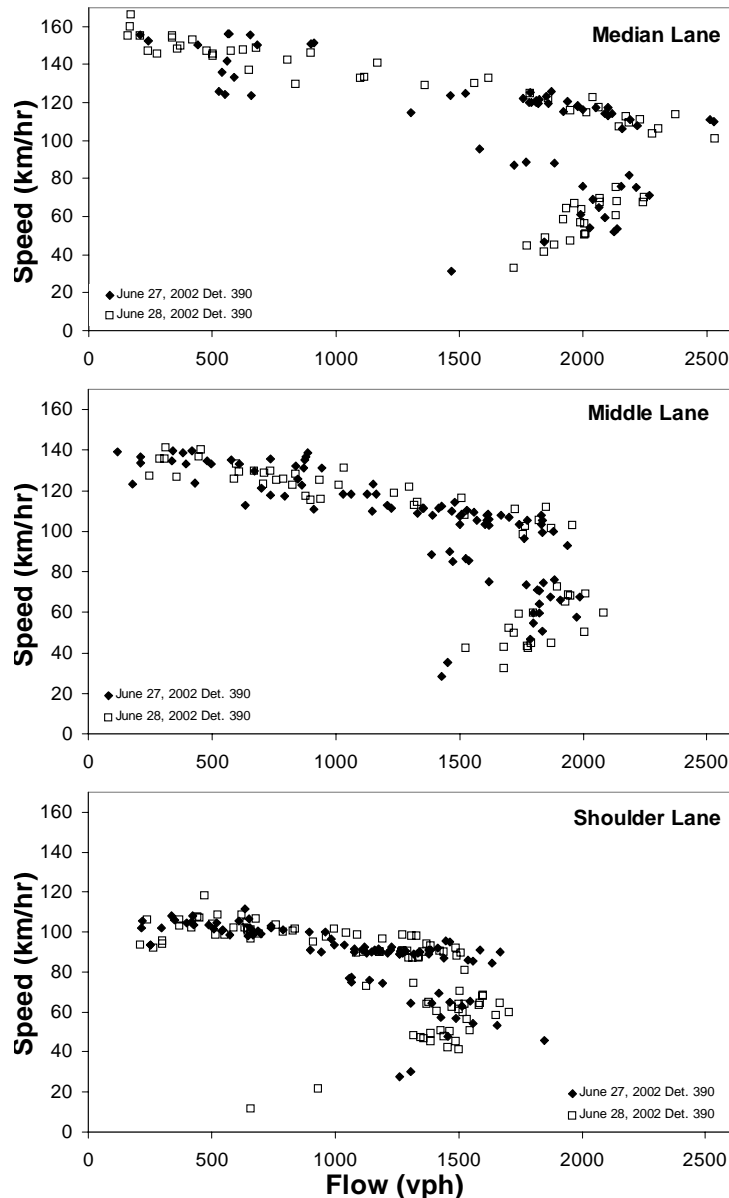


Figure 3: Speed-Flow by Lane

on the difference in estimated capacity. Various treatments with respect to trucks as well as the physical characteristics such as size and weight to horsepower ratio also play a role. It is also interesting that the individual lane capacity established by the HBS differs for 2-lane and 3-lane facilities. The emphasis on facilities classified by the number of lanes is not currently addressed in the HCM, where estimations are made solely on a lane by lane basis. This study included analysis that compared the expected capacity of A9 from each manual. Table 4 shows that the HBS estimates capacity for freeway lanes to be 6.8-22.1% lower than the HCM. These percentages range for comparisons of level 2-lane and 3-lane facilities with 0-20% trucks and free flow speeds ranging between 80-120 km/hr.

LOS F is estimated to occur when the demand reaches 2286 vehicles-per-hour-per-lane (vphpl) according to the HCM and 1900 vphpl for 2-lane facilities and 1800 vphpl for 3-lane facilities according to the HBS. This indicates that this is the maximum flow the facility can withstand based on measured vehicle headways. The concept of passenger car equivalents is introduced in the HCM in which all vehicle types are converted to an equivalent number of passenger cars to create uniformity for comparisons. The value of 2286 vphpl includes a 10% heavy vehicle factor and is equivalent to the 2400 passenger cars per hour per lane (pcphpl) stated in the HCM. The difference in estimated capacity is likely due to different operating and control strategies as well as driver behavior. Average headways were measured to be 2.6, 2.0, and 1.8 seconds per vehicle for the shoulder, middle, and median lanes respectively during the PM peak period (16:00-18:00). The implementation of ramp metering on U.S. freeways may also have an impact

Table 3: HCM vs. HBS

	Density (veh/km/ln)		Volume/Capacity		Speed (km/hr)		Capacity (veh/hr/ln)			
	HCM	HBS	HCM	HBS	HCM	HBS	HCM (pc/hr/ln)	HCM Adj	HBS 3 lanes	HBS 2 lanes
A	0-7	0-4	≥0.34	≥0.3	≥120	≥130	≤820	≤781	≤540	≤570
B	>7-11	>4-8	≥0.56	≥0.55	≥120	≥125	≤1350	≤1286	≤990	≤1045
C	>11-15	>8-12	≥0.76	≥0.75	≥113	≥115	≤1830	≤1743	≤1350	≤1425
D	>15-21	>12-16	≥0.9	≥0.9	≥100	≥100	≤2170	≤2067	≤1620	≤1710
E	>21-26	>16-23	≥1.0	≥1.0	≥85	≥80	≤2400	≤2286	≤1800	≤1900
F	>26	>23	>1.0	>1.0	<85	<80	>2400	>2286	>1800	>1900

FFS = 120 km/hr, Truck % = 10%, Level Terrain

Table 4: HCM vs. HBS

FFS (km/hr)	Capacity (veh/hr/ln)									
	HCM (pc/hr/ln)	0% Trucks			10% Trucks			20% Trucks		
		HCM ¹	HBS	% Diff.	HCM ²	HBS	% Diff.	HCM ³	HBS	% Diff.
None	2400	2400	2000	16.7%	2286	1900	16.9%	2182	1800	17.5
120	2400	2400	2000	16.7%	2286	1900	16.9%	2182	1800	17.5
100	2320	2320	2050	11.6%	2210	1950	11.8%	2109	1850	12.3
80	2200	2200	2050	6.8%	2095	1950	6.9%	2000	1850	7.5

Level Terrain (0-2%), ¹ $f_{HV} = 1.0$, ² $f_{HV} = 0.95$, ³ $f_{HV} = 0.91$

Pre-queue flows averaged over all lanes on the A9 were found to be lower than the estimated capacity from the HCM and greater than the capacity from the HBS for both northbound and southbound directions. Measurements revealed a free flow speed of 120 km/hr and average truck percentages ranging between 0-20% over the days analyzed. The average measured pre-queue flow of 1910 vphpl for the 5 isolated bottlenecks arising between detectors 390-380 in the northbound direction is 75 vphpl greater than the estimated capacity for 3-lane Autobahns considering 10% and 20% trucks in the traffic stream. Looking at individual lane pre-queue flows, the median lane flow is 525 vph greater than the estimated flow according to the HBS (1900 vph) considering no trucks in the median lane and a free flow speed of 120 km/hr. This flow is very similar to the capacity of 2400 pcphpl as stated in the HCM. Average pre-queue flow for the middle lane is close to the estimated capacity identified by the HBS and flows in the shoulder lane are well under the estimated capacity according to the HBS and HCM. Average queue discharge flows were found to be lower than the estimated capacity according to the HCM, yet resembled very closely the estimated capacity according to the HBS considering a truck percentage of 10%. The average by lane queue discharge flow for the median lane was found to be greater than the estimated capacity identified by the HBS and lower than that indicated by the HCM. Again, queue discharge flows in the median lane were found to be similar as would be expected by the HBS. Flows in the shoulder lane again were well below capacities identified by both manuals.

Further, the speed/flow relation for various proportions of heavy vehicles (trucks) was analyzed and compared with HBS and HCM standards. Figure 4 illustrates the speed-flow relation for detector 390 (all lanes) on June 27, 2002 for truck percentages of 0-20% in addition to the relations presented in the HCM and HBS for respective truck percentages. The plot features data for only when trucks consisted of 0, 10, and 20% of the total traffic stream traveling over this detector measured over all lanes. As shown, few occurrences arose when the traffic stream consisted of 0% trucks therefore a strong relationship was not estimated for this scenario.

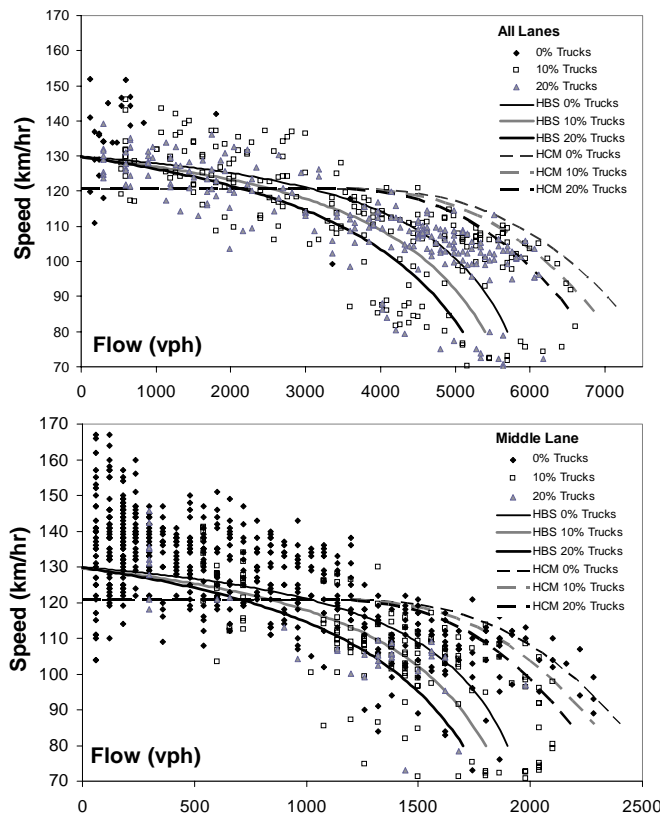


Figure 4: Speed-Flow 0-20% Trucks Actual vs. HCM/HBS

the HBS and HCM curves. The same results are seen for the middle lane. The maximum flow measured in the median lane is greater than the maximum flow as indicated in the HCM and HBS while the maximum flow in the shoulder lane is lower, largely due to a higher percentage of trucks. To further evaluate the comparison of measured capacity with that expected by the HCM and HBS, Figure 6 shows that transition points for one hour of data (15:00-16:00 on June 27) were plotted on the speed-flow diagram along with the relationship curves indicated by both manuals. Results are similar to those found in Figure 5.

7.0 CONCLUDING REMARKS

Construction of speed-flow, speed-density, and flow-density relations under nearly stationary traffic states has helped to understand the capacity of a freeway segment and the influence of trucks on the estimated capacity. Capacity measurements were conducted and results compared to those that would be expected as compared to the HCM and HBS manuals. Upon bottleneck activation an average flow reduction of 5.6 percent was measured on northbound A9, while an average 5.8 percent flow reduction was measured on southbound A9. Average pre-queue and queue discharge flows were found to be comparable to flows measured on the A5 as well as other freeways in Canada. Maximum flows on U.S. freeways were found to be greater than those measured on the A9 while maximum flows on U.K. freeways were found to be lower. Analysis has also revealed peak flows on an individual lane basis which were supported by speed-flow relationships for individual lanes. As would be expected, maximum flows in the

The relationship consisting of 10% and 20% trucks in the traffic stream on A9 appear to follow the HCM curves for 10% and 20% trucks at capacity. It is evident that the maximum flow decreases with increasing truck percentages as would be expected. This relationship was expanded to the middle lane at detector 390 where a varying range of truck percentages was observed. The data for 0% trucks follows the HCM relation for 0% trucks quite well nearing capacity. In addition, the data for 10% trucks correspond with the HCM relation for 20% trucks. The observed measurements appear to be closest to the HBS relation for 10% trucks. The maximum flows observed when low truck percentages were present appear to be higher than the HBS would predict.

Figure 5 shows individual lane speed-flow relationships for detector 390 with the expected relation provided by the HBS and HCM with 10% trucks. The maximum observed flow falls between

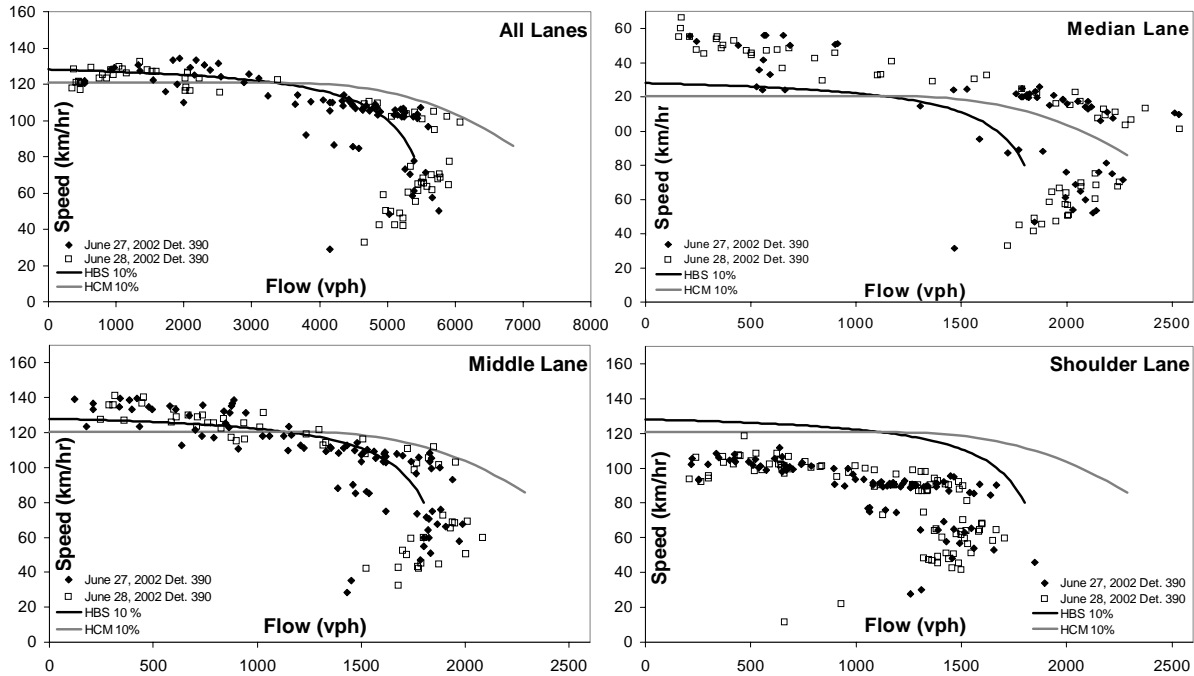


Figure 5: Speed-Flow (Actual vs. HCM/HBS)

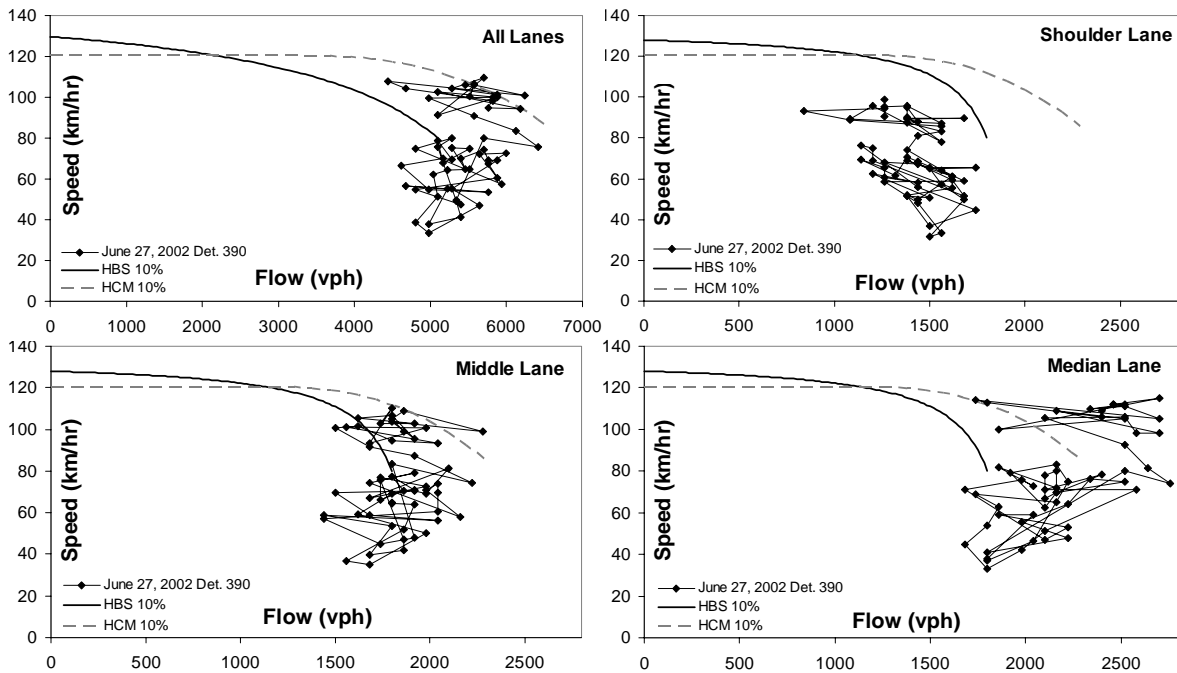


Figure 6: Speed-Flow 15:00-16:00 (Actual vs. HCM/HBS)

median lane were found to be higher than those measured in the middle and shoulder lanes. This is likely due to larger truck percentages present in these lanes. The HBS estimates capacity for freeway lanes to be 6.8-22.1% lower than the HCM. These percentages vary for comparisons of level 2-lane and 3-lane facilities with 0-20% trucks and free flow speeds between 80-120 km/hr. In contrast with the HBS, the measured capacity of 2-lane autobahns was less than that of 3-lane autobahns. The measured pre-queue flow for 3-lane autobahns was found to be 21-percent greater than 2-lane autobahns and the queue discharge flow was measured to be 25 percent

greater. The maximum flow measured in the median lane (2376 vph) consisting mainly of autos was found to be similar to the estimated capacity according to the HCM (2400 pcphpl) and lower than that estimated by the HBS (1800, 1900 vph). The maximum flow in the shoulder lane was found to be much lower than the estimated capacity by both manuals. In the middle lane, maximum flows were measured to be near the estimated capacity indicated by the HBS and lower than that indicated by the HCM. The difference in capacity estimated by the HCM and HBS is likely due to different driver behavior, rules of the road, traffic restrictions, and vehicle operating characteristics. With respect to truck percentages, it was found that with 10% and 20% trucks the measured capacity was similar to the HCM relations for traffic streams consisting of 10% and 20% trucks near capacity. This analysis has highlighted the need for further research to confirm the validity of individual lane capacities in both the HCM and the HBS. More careful empirical analyses involving international comparisons are recommended, particularly since (for example) the U.S. may be considering applications of VSL systems for speed management in the future. Finally, future analysis should consider the impacts of variations in traffic flow and geometric features such as lane width, shoulder width and vertical and horizontal geometry.

8.0 ACKNOWLEDGEMENTS

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