

INFLUENCE OF VARIABLE SPEED LIMIT AND DRIVER INFORMATION SYSTEM ON KEY TRAFFIC FLOW PARAMETERS ON A GERMAN AUTOBAHN

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ABSTRACT

This paper examines key freeway capacity parameters for an 18-kilometer segment of a German autobahn that contains a surveillance system and a variable speed limit and congestion level information system using overhead variable message signs located on gantries. This paper includes an analysis of the relationships between vehicle flow, density, and speed surrounding an active bottleneck. The relationships between key traffic flow parameters have been based on reproducible traffic features observed on multiple days. Further, the speed/flow relation for various proportions of heavy vehicles is investigated and results are presented.

KEYWORDS

variable speed limit, driver information, traffic flow, freeway bottleneck

INTRODUCTION

This paper presents findings of an empirical analysis that has evaluated the impacts of a variable speed limit (VSL) and driver information system on key traffic flow parameters on a German autobahn. This system employs in-lane sensors and incrementally spaced overhead dynamic message signs (see Figure 1) in an effort to 1) postpone or prevent freeway traffic breakdown, 2) eliminate large speed differentials to reduce vehicle crashes, 3) dampen shock-waves moving upstream, and 4) harmonize traffic flow and speed across lanes during peak periods.

The VSL system was deployed primarily to enhance roadway safety. In our present work, we evaluate the operational benefits of a VSL system. To this end, we are conducting a before and after study of a VSL system deployed on a German freeway. This builds on previous research where only the “after” data were available. Our particular interest is in the impact of the VSL system on the dynamic features of a (recurrent) bottleneck, such as the mechanism of bottleneck activations, bottleneck capacity, and the temporal and spatial characteristics of resulting queues.



Figure 1 - Sample VSL gantry

The analyses rely on archived inductive loop detector data for both before and after system deployment to systematically diagnose freeway bottlenecks and to measure key traffic flow parameters such as pre-queue flow (before a bottleneck activation), bottleneck outflow (on an individual and total lane basis), shock and oscillation (stop-and-go driving) velocities. Fortunately, the speeds and flows of trucks and autos are measured separately, so additional insights into driver behavior can be analyzed. Many on- and off-ramps are also instrumented, which can lead to an understanding of how merge and diverge movements impact overall traffic conditions. The paper will discuss how these parameters have changed due to the implementation of the system. In parallel to this, we will analyze the control mechanism of the variable speed limits and the response (compliance) of drivers. In light of the findings, we will provide recommendations for further (operational) improvement of the current VSL systems and for potential applications on the U.S. freeways.

STUDY AREA

The study area is located on Autobahn 9 between Munich and Nürnberg, Germany and is shown in Figure 2. Analysis considers both the northbound and southbound travel directions as indicated by respective arrows between kilometers 510.34-528.15. The northbound travel direction is equipped with 17 inductive loop detector stations imbedded in the roadway (labeled 630-160) and the southbound 16 (labeled 25-57). The detector station spacing is provided in meters. Unique to this particular section of freeway is the use of a variable speed limit system that incorporates the application of variable message signs located overhead. These signs span the traveled way such as gantries and are indicated in Figure 2 by the solid vertical lines across lanes. The northbound direction exhibits 5 message signs (labeled AQ 304-312) and the southbound 10 (labeled AQ 201-215a). The labeling technique is consistent with that of Autobahndirektion Südbayern. The roadway geometry varies between 2-3 lanes with one lane drop in the southbound direction and one pick up lane in the northbound direction.

OVERVIEW OF VARIABLE SPEED LIMIT SYSTEM

The VSL system deployed in Munich, Germany, is part of a driver information system that combines the use of real time traffic information provided via inductive loop detectors, closed circuit television, and remote weather information systems to evaluate the existing traffic,

weather, and roadway conditions as bases for determining a recommended speed or advisory for a particular autobahn segment. Typical displays presented to driver via variable message signs are illustrated in Figure 3.

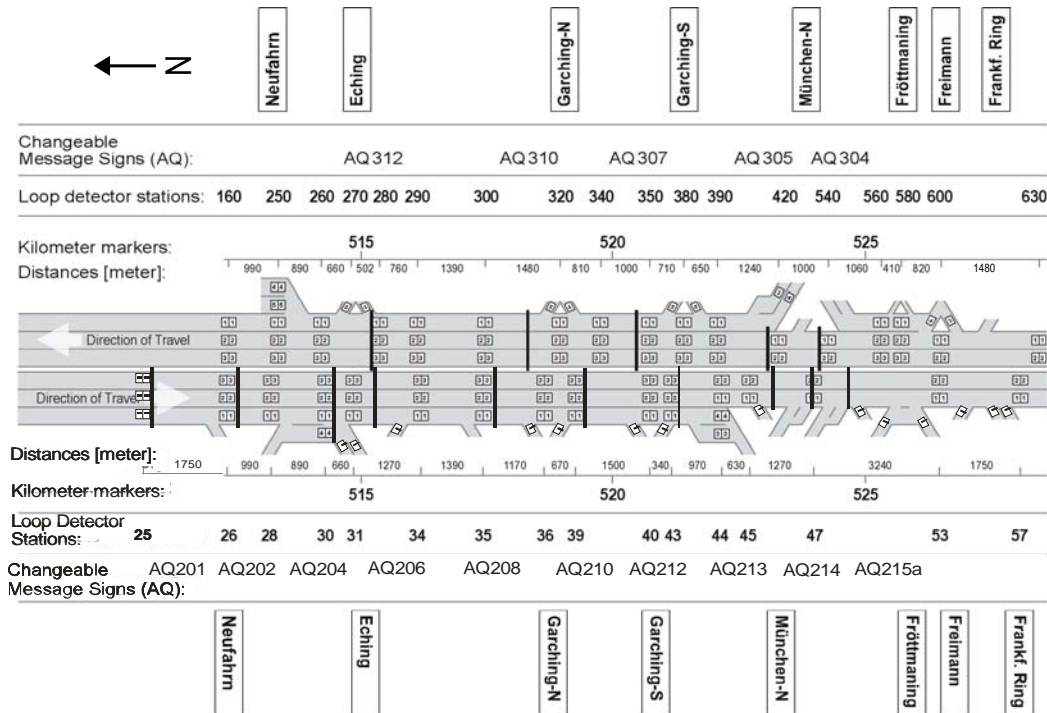


Figure 2 – Study area

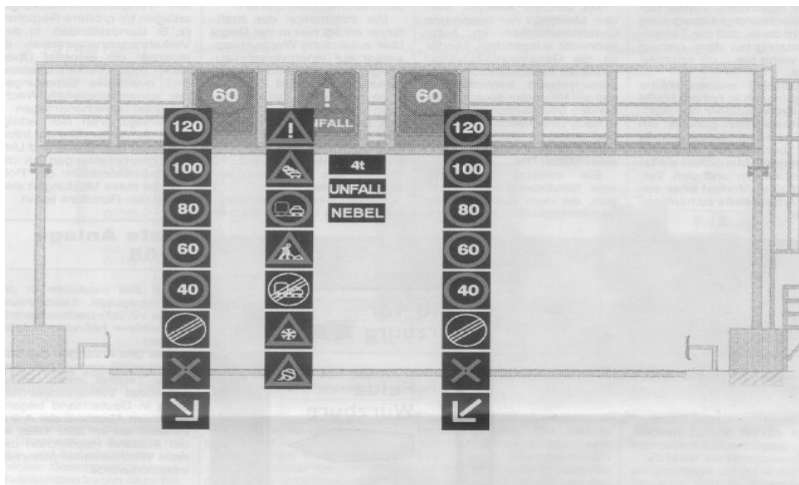


Figure 3 - VSL message menu

The VSL system uses a series of algorithms to determine the most appropriate speed limit based on three control strategies. These are incident detection, harmonization and weather detection. Harmonization, also referred to as lane homogeneity, refers to the control of dense but still flowing traffic by equating both speed and flow across all lanes and is used to postpone or

prevent breakdown of the facility. The need for lane homogeneity is heightened in Germany where driving rules provide for separate truck speed limits and requirements for trucks and slow moving vehicles to remain in the right lane, with the left lane reserved for passing. The algorithms are based on the fundamental relationships of speed, flow, and density between successive detector stations. Measured values are compared to pre-established threshold values and the recommended speed and/or warning is deployed based on the measured state of traffic. When critical states are identified, the system responds by reducing the speed limit upstream and warning approaching drivers of the potential for breakdown downstream. Enforcement of the variable speed limit is typically carried out by the use of video detection located on the overhead gantries to ensure high compliance rates with the system. With the availability of detailed traffic flow data both before and after system deployment, this analysis will be able to determine alternations in traffic flow patterns such as bottleneck activation locations and changes in shock oscillations as well as pre-queue and bottleneck outflows.

For the most part variable speed limit systems have demonstrated positive results in the United Kingdom, Australia, Netherlands, and Germany. A system installed on a 22-km section of the M25 in the United Kingdom has reduced injury-related crashes by 30-percent and property damage only accidents by 25-percent. Traffic flow was said to be harmonized across all lanes with a 15-percent increase in flow observed in the shoulder lane. Traffic volumes reportedly increased by 1.3–3.7 percent during the AM and PM peaks. The VSL system implemented on the A2 in the Netherlands was not found to improve freeway performance and was deemed as not an ideal system for solving congestion. Better traffic distribution across all lanes did occur with the system however the flow measured downstream of the existing bottleneck under study did not change.

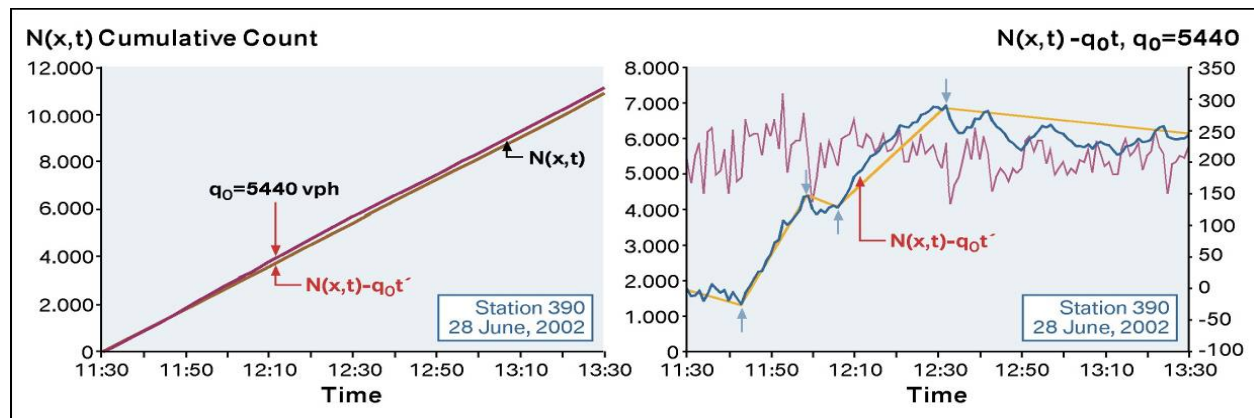


Figure 4 - Loop detector data analysis method

METHODS

Loop detector data available for this study are vehicle counts and speeds measured at the sampling interval of one minute. Vehicle speeds are measured directly with double-loop configuration. These measurements are available for both autos and trucks for each lane. As shown in Figure 4, plots of cumulative vehicle counts and cumulative (time-averaged) speeds over time are primary diagnosis tools used in this study to analyze bottleneck activations and related traffic parameters. Careful data processing allows for the identification of sharp changes

in flow and speed generally associated with bottleneck activations. [1,2] Speed limits and driver information presented to drivers are also available for analysis.

FUNDAMENTAL RELATIONSHIPS

It has been demonstrated that the traffic flow parameters of 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 opposition. Thus, an attempt to the better understanding of 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, traffic states termed as "nearly stationary" were able to be depicted as were indicated by linear slopes within the curves indicating trends of constant flow and speed over a sustained period of time. The average values were then measured over the multiple durations where constant flow

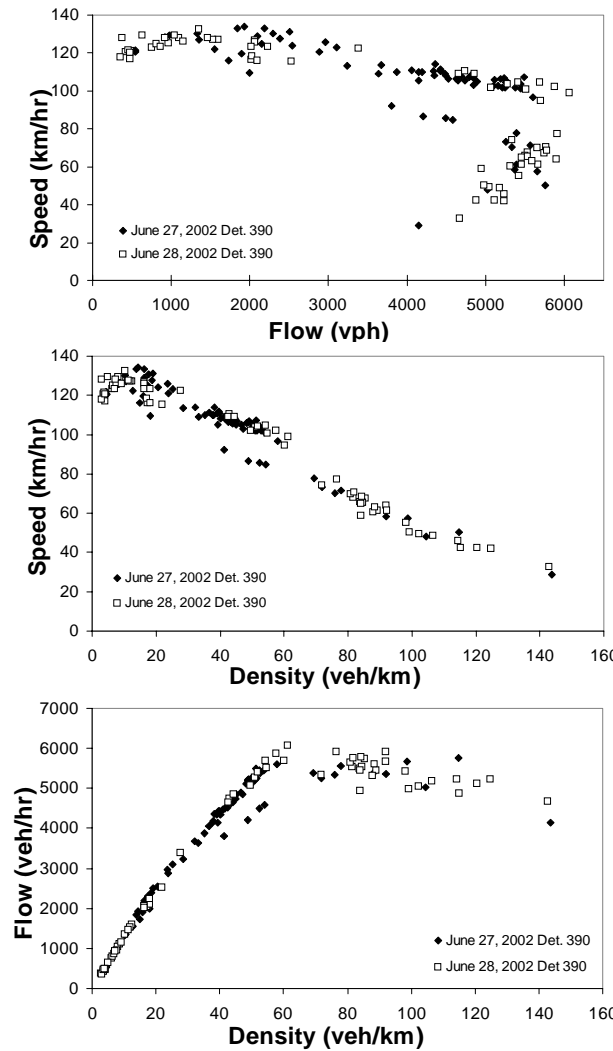


Figure 5 - Fundamental relationships

and speed were observed and plotted. The methodology used here follows that presented in [3] in which nearly stationary traffic states tended to generate well defined reproducible continuous relationships and targets the reduction of noise in these measured relations. For this paper, near 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 differentiate by more than 10 vpm or 10 km/hr respectively.

Figure 5 presents the speed-flow, flow-density, and speed-density relationships at detector station 390 for June 27 and June 28, 2002 on northbound A9. Two days are shown for the same detector location to ensure the reproducibility of the relationships. Weather conditions were fair on both days therefore measured capacity should not be influenced by varying weather. Previous studies found that wet roadway conditions can decrease capacity by as much as 350 vph and 500 vph on two and three lane autobahns respectively [4]. These plots illustrate the relationship for all vehicles over all lanes. This detector station is just upstream of the bottleneck between detector stations 390-380. Consistent with findings on June 27, a bottleneck was likewise activated between detector stations 390-380 on June 28, 2002. All plots appear to follow a well shaped continuous function which is sometimes left unseen in the common scatter plot of these relations.

These diagrams 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 one of positive to negative. This is essentially the changing of traffic states from the un-congested side of the relationship to the congested side. Queueing of vehicles is dictated on the congested side of the relationship. This approximate maximum flow is near the pre-queue flows measured on northbound A9. 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. Of note, 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 over all lanes (1870 vphpl).

With the availability of individual lane data these relations were further explored for each lane. Figure 6 illustrates averages for all vehicles traveling in the shoulder, middle, and median 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 look to be 70, 80, and 90 km/hr for the shoulder, middle, and median lanes respectively. Lower maximum flows present in the middle and shoulder lanes are likely due 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. Pre-queue and queue discharge flows were generally much lower in these lanes.

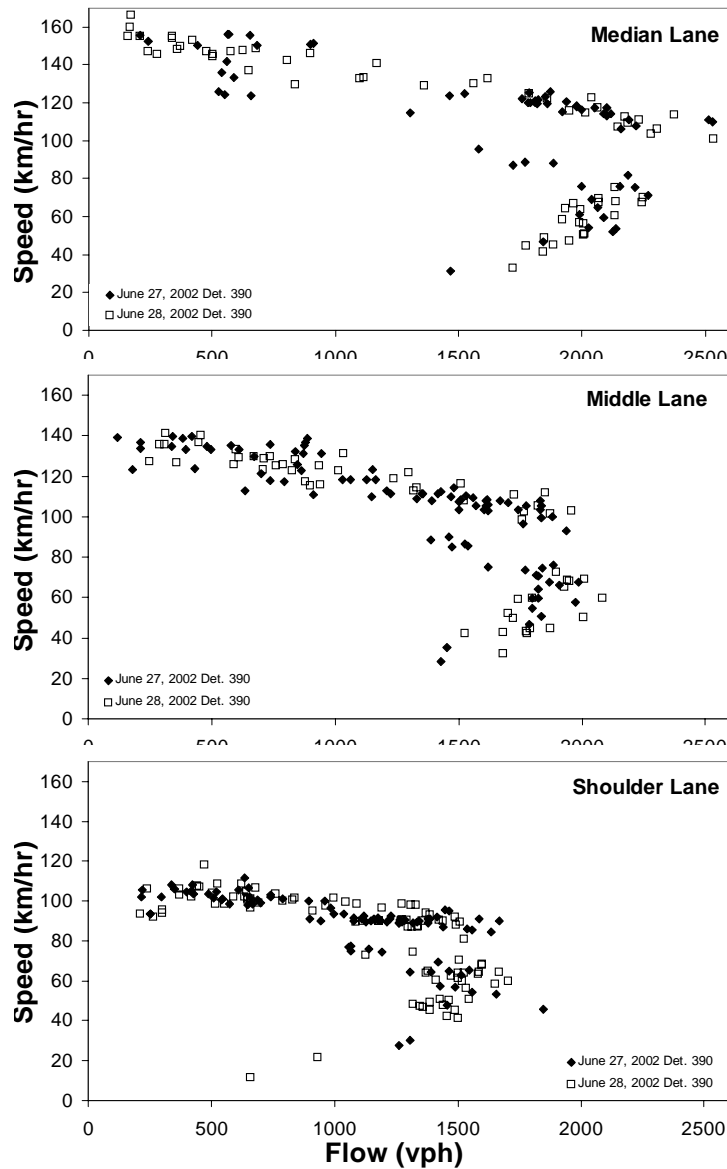


Figure 6 - Speed-flow by lane

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. In earlier studies [5,6], capacity measurements were conducted and results compared to those that would be expected as compared to the U.S. Highway Capacity Manual (HCM) and the German Handbuch für die Bemessung von Strassenverkehrsanlagen (HBS) design and planning manuals. [7,8] Upon bottleneck formation an average flow reduction of 11-percent was measured on northbound A9, while an average 6-percent flow reduction was measured on southbound A9. Analysis has also revealed peak flows on a by lane basis which were supported by speed-flow relationships for individual lanes. As would be expected, maximum flows in the median lane were found to be significantly higher than those measured in

the middle and shoulder 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.

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