Abridgment

Transitions in the Speed-Flow Relationship

MARGOT A. GUNTER AND FRED L. HALL

Transitions between regimes in the speed-flow relationship were the topic of a recent paper by the authors (*Transportation Research Record 1005*, 1985). Subsequently, the authors have found that a different analytic technique provides better insights into this problem. This approach involves the use of daily time-traced and overlaid time-traced plots. The result of the re-analysis is that four previous conclusions are confirmed and one is not. Several questions that remained after the first paper about the shape of the relationship and its transitions are resolved, although why operation in shoulder lanes is different from that in the nonshoulder lanes is still unclear.

In this paper the focus is on the nature of transitions between the congested and uncongested regimes in freeway traffic flow, particularly in the speed-flow relationship. In a previous paper, the authors used an event-based averaging procedure to gain insights into the process involved in the breakdown and recovery of traffic flow *(1)*. Since that time, the authors have identified a better means of analysis to resolve the problem. Application of that technique has suggested that the event-based averaging was somewhat misleading and that perhaps the transitions were being incorrectly defined. One of the conclusions in the previous paper is therefore invalid, and several of the questions raised in it can now be resolved.

The analytic technique consists of examining a time-connected plot of speed and flow for each individual day. Preparation of such plots is not new. Ceder, for example, used them in his dissertation *(2)*. Using them to focus on transitions, as demonstrated in the next section, is perhaps a bit novel. The main discussion, contained in the third section, is based on overlaid time-connected plots for many days. The data utilized here are described by Allen et al. *(1)* and Hall et al. *(3)*, and in a paper by Hall and Gunter elsewhere in this Record.

EXAMPLES OF ANALYSIS

The analytic technique can best be described by displaying examples of the plots for a single lane at a specific location. Details of decisions made to arrive at these particular plots are discussed by Hall et al. *(3)* and in a paper by Hall and Gunter elsewhere in this Record. These examples help to demonstrate the variety of information that can be obtained by using this approach. Station 4, median lane is used because it *(a)* is geometrically ideal, and *(b)* experiences a wide range of flows. The station is about 4 km and three entrance ramps upstream of the primary bottleneck, and therefore regularly experiences transitions between regimes.

The flow-occupancy trace was found to be useful in this analysis because of the more easily identified critical operation (e.g., Figure 1a compared with Figure 1b), and because some 5-min intervals are identified to be transitional only by examining occupancy (e.g., the point in the middle of the return to uncongested flow in Figure 1b). From the trace of any individual day, it is possible to determine some information on the nature of any transitions (speed of occurrence, change in flow). Examination of the data is greatly aided by an overlaid time-traced plot (Figure 2), which provides a framework for the underlying relationship for all of the daily plots. Overall trends in the transitions can also be observed from the overlaid plot, such as the changes in flow that may be associated with the jumps, and the flow ranges at which they occur.

DISCUSSION OF ANALYSIS

The new approach is substantially different from the event-based averaging in the authors' previous paper *(1)*. Although four of the earlier conclusions are supported, one is altered. The five conclusions in the previous paper are summarized briefly as follows:

1. Transitions toward both regimes occur fairly rapidly.
2. Recovery to the uncongested regime occurs at almost constant volume.
3. Different locations along a highway require different speed-flow relationships to describe their operation.
4. The reduction of flow and low starting speed associated with the line representing transitions from upper to lower branch operation are not easily explained.
5. Speed-flow relationships differ according to lane.

In addition, several questions were left unanswered, as follows:

1. The exact shape of the underlying relationship near capacity is not clear.
2. The values of parameters such as critical speed and capacity flow were not ascertainable.
3. Operation in the shoulder lanes was very different from that in the nonshoulder lanes, and could not be explained.

Conclusion 4 is altered by the re-analysis: the line representing transitions to the congested regime can now be explained. The explanation is simply that the line shown to represent the average of transitions was incorrect. The reason that it was incorrect is that transitions from uncongested to congested

M. A. Gunter, IBI Group, 240 Richmond St. West, Toronto, Ontario M5V 1W1, Canada; formerly with McMaster University. F. L. Hall, Department of Civil Engineering, McMaster University, Hamilton, Ontario L8S 4L7, Canada.

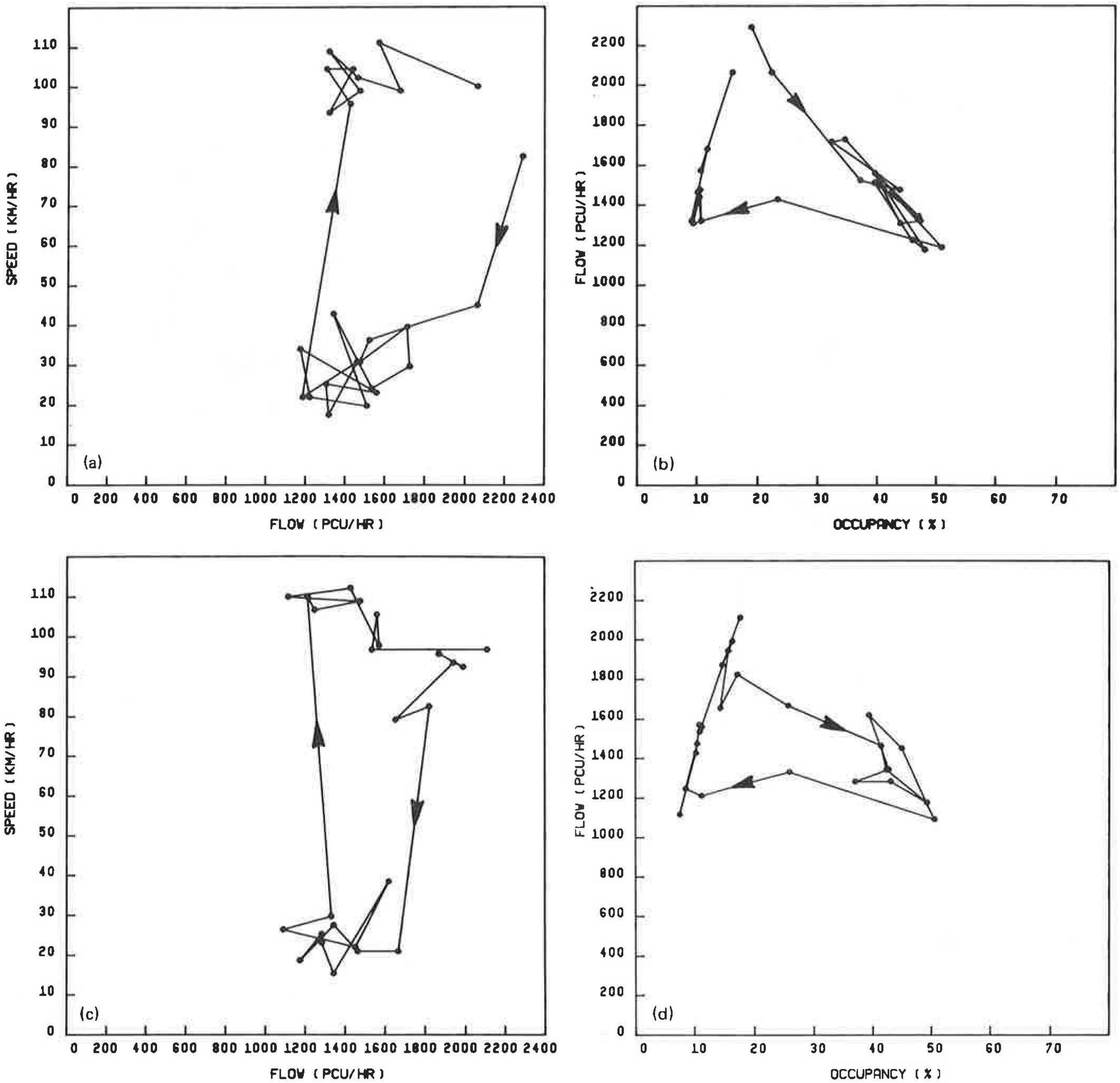

FIGURE 1 Examples of daily speed-flow (a and c) and flow-occupancy (b and d) time-traced plots for two days.

operation (such as in Figure 1c, with a large change in speed and occupancy at about the same flow) were being averaged with operation in the congested regime (Figure 1a) because the criterion to identify a transition was a speed change of greater than 15 km/hr. In other words, the daily time-traced plots indicated that the speed-change criterion could be met within the large fluctuations in the congested regime, such that events were identified that were not transitions. The other problem in the definition of events was that the equilibrium or nontransitional relationship had not been identified.

The other four conclusions made in the previous paper are supported by the current analysis. Rapid changes in speed and occupancy are still observed during both the breakdown to the congested regime and the recovery to the uncongested regime. These generally occur within a 10-min period, but on a few days take longer. Different speed-flow relationships are still observed for different lanes, as subsequent analysis of Station 4 shoulder lane indicates. Finally, the transition from congested to uncongested operation still appears to take place at approximately constant volume, at least in the median and middle lanes. This can be observed from both Figures 1 and 2, in which slight variations of flow rate certainly occur, but the average trend is a zero change. The slight variations can be easily explained by changes in mainline or ramp demand over the short transition period.

Two of the questions raised in the previous paper are answered by the re-analysis because the transition from uncongested to congested operation in a median or middle lane is characterized by a speed and occupancy change at almost constant flow rate. Some confusion in the authors' previous discussion was caused because of the misleading averages, primarily as to the implications for the shape of the underlying relationship. It has now been determined that the speed at which maximum flow is observed is between 85 and 90 km/hr for the Station 4 median lane and above 80 km/hr for the other six median and middle lanes examined. Because these speeds occur at very high flow rates (2,350 pcu/hr for the Station 4 median lane), it can be assumed that operation is approaching capacity and that the critical speed is only slightly lower. The resultant critical speed will therefore be substantially higher than the 50 km/hr suggested by the new *Highway Capacity Manual* (HCM) *(4)*.

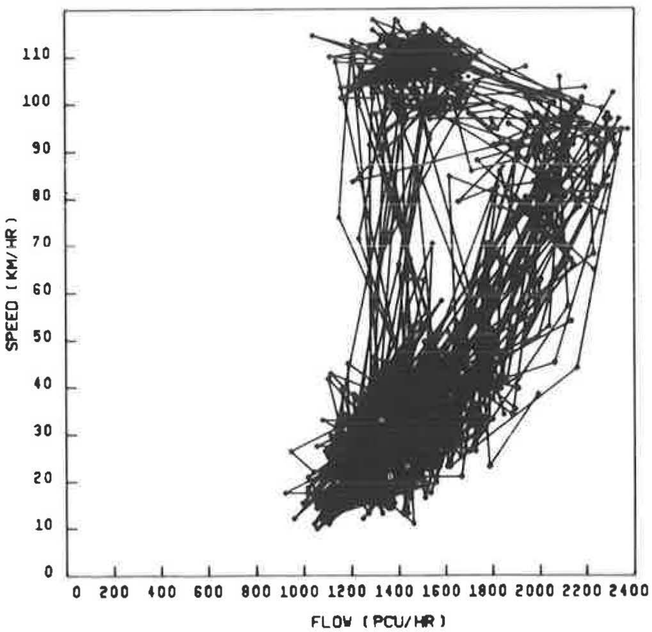

FIGURE 2 Overlaid time-traced plot for the Station 4 median lane.

One question remains unresolved: explanation of the operation in the shoulder lanes, which is obviously different from that in the nonshoulder lanes and remains difficult to explain. The major difference is in the shape of the observed relationship. Even well upstream of any entrance ramp four differences can be observed (Figure 3). First, uncongested speeds are much lower. Second, speeds change more quickly with flow in the uncongested regime than they do in other lanes. Third, maximum flows are much lower, and are observed in the congested regime.

The fourth striking difference is that the transitions identified toward both regimes do not occur at constant flow rates. Recoveries tend to occur with a decrease of 200 to 400 pcu/hr in flow, and if breakdowns occur they do so with a similar increase in flow. Two possibilities exist for the change from uncongested to congested flow: *(a)* transitions occur with an increase of flow between regimes on an underlying relationship similar to that in the nonshoulder lanes; or *(b)* operation moves along a different equilibrium relationship [which resembles the curve in the 1965 HCM *(5)*]. If it is on an HCM-type curve, then capacity would be 1,600 to 1,800 pcu/hr, depending on proximity to entrance ramps.

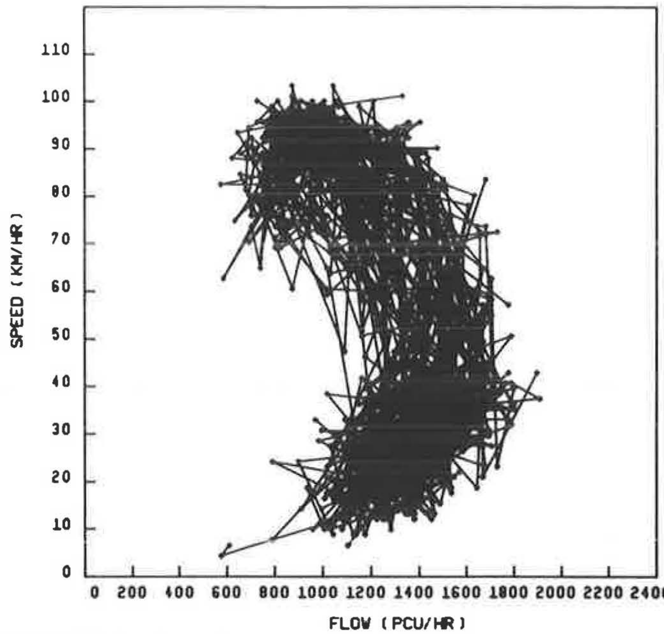

FIGURE 3 Overlaid time-traced plot for the Station 4 shoulder lane.

Thus, the question of why operation on the shoulder lanes is different from that in the nonshoulder lanes remains unanswered. An alternative method for identifying equilibrium and nonequilibrium flows is required [perhaps that used by Payne *(6)*].

CONCLUSION

The primary conclusion of this paper is that the use of daily time-traced and overlaid time-traced plots is the preferred method when analyzing transitions in the speed-flow relationship. Use of this analytic technique has demonstrated that the event-based averaging used in a previous paper on the subject could incorrectly identify the transitions. Re-analysis of the authors' data with the new technique changed one conclusion of the original paper and answered several questions raised in the original discussion.

ACKNOWLEDGMENTS

The authors would like to thank the Ontario Ministry of Transportation and Communications for providing the data for this analysis, and Geddes Mahabir, who several years ago made the data manageable on McMaster University's computer facilities. In addition, the authors should acknowledge the helpful and thought-provoking comments of two reviewers of our previous paper. Financial support was received from the Natural Sciences and Engineering Research Council through their Undergraduate Summer Research Award programme.

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Publication of this paper sponsored by Committee on Traffic Flow Theory and Characteristics.

Abridgment

FREESIM: A Microscopic Simulation Model of Freeway Lane Closures

AJAY K. RATHI AND ZOLTAN A. NEMETH

Development of a model to simulate traffic operations at freeway lane closures is described. The model logic is based on a rational description of the behavior of the drivers in a freeway lane-closure situation. The simulation program is written in SIMSCRIPT II.5 programming language. An application of the model is given with evaluation of potential safety impacts of reduced speed zones in freeway lane closures at different levels of assumed driver compliance.

With the Interstate system nearly complete, the emphasis has now shifted toward continued maintenance of this freeway network. Resurfacing, upgrading, and other corrective measures are required to maintain the original design standards and to eliminate previously unrecognized safety hazards. Construction and maintenance work activities requiring temporary closure of a freeway lane represent a frequently encountered and potentially hazardous situation. A study of road-under-repair accidents in Virginia found, for example, that of 426 accidents (for which the information on traffic control characteristics was available), 47.9 percent occurred at lane closures *(1)*.

A. K. Rathi, KLD Associates, Inc., 300 Broadway, Huntington Station, N.Y. 11746. Z. A. Nemeth, The Ohio State University, Columbus, Ohio 43210.

Freeway lane closures require properly developed traffic control plans to minimize the disturbance to the traffic flow and provide for the safety of both drivers and the working crew. Drivers approaching a work zone in the closed lane must receive and understand the information that they need to change lanes and merge into the traffic in the open lane. Although this in itself does not appear to be an unusually demanding driving task, problems still appear to develop, resulting in rear-end collisions, sideswipes, and single-vehicle fixed-object accidents *(2)*.

Improving traffic control systems requires comprehensive information on the relationship between control strategies and the quality of traffic flow (e.g., delay, travel time). Computer simulation provides an excellent basis for evaluating a wide sprectrum of traffic management schemes within the framework of controlled experiments. In this paper, development, verification, validation, and application of a microscopic simulation model (FREESIM) of traffic operations at freeway lane closures is described.

FREESIM SIMULATION MODEL

FREESIM is a microscopic, stochastic simulation model; vehicles are represented individually and their detailed, time-vary-