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A problem of limited-access special lanes. Part II: Exploring remedies via simulation

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ABSTRACT

Spatiotemporal analyses of freeway sites in Part I have shown that special-lane access points are prone to become bottlenecks. These can degrade traffic flows, sometimes in all lanes. Part II explores select impacts of re-designing the means of entering and exiting a special lane, and of altering the policy governing its use. Parametric tests were conducted using a computer simulation model that was calibrated to one of the sites studied in Part I; one with a buffer-separated carpool lane. Though less reliable than what might have been observed via experiments in real settings, the simulated findings seem to offer useful insights nonetheless.

The findings indicate that traffic conditions would improve at the site by elongating the carpool lane's buffer opening beyond its present length of 400 m. Yet, only modest improvements were predicted, even when the opening was elongated to 1000 m or more. Greater benefits were predicted from disentangling the movements made into and out of the carpool lane. This was achieved by placing first a buffer opening to serve only ingress, followed by another immediately downstream to serve egress. The benefits of this treatment were again limited, even when each tandem opening was elongated to a length of 700 m. Fully removing the buffer that physically separates the carpool lane from the regular ones was predicted to bring the greatest improvements to traffic. Also examined was pending legislation that would leave the carpool-lane buffer in place, while limiting the times of day when the lane is reserved for special use. Simulations predict that this legislation would degrade travel conditions below those that presently occur at the site. The extent of this predicted degradation varied, depending upon the time of day when the lane-use restriction went into effect.

1. Introduction

Part I established that the access points to special-use freeway lanes can become bottlenecks. Part II pursues a handful of possible solutions. Exploring solutions by means of experiments conducted in real settings would have required cooperative agreements with highway departments that are difficult to obtain. Moreover, the attendant costs of field experiments would have severely limited their scope.

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Computer simulation was therefore used instead. A well-tested model of driver car-following and lane-changing behavior was chosen for this purpose. The model was calibrated to match observations from one of the freeway sites studied in Part I; one that features a limited-access carpool lane with a 400 m-long buffer opening. Details on these matters are offered in the following section. Parametric tests using the calibrated model are described thereafter.

The first round of parametric tests is presented in Section 3. It features experiments in which access to the site's carpool lane was redesigned, first by (i) elongating the buffer opening incrementally; then by (ii) inserting openings of various lengths in tandem, with one opening for ingress and the other for egress; and finally by (iii) fully removing the buffer, such that the carpool lane became a non-separated one. Benefits were predicted under all three treatments, though not in equal measure. Traffic generally benefited more from tandem openings, as compared against an elongated single one. Yet neither of these first two treatments completely eliminated the flow disruptions caused by focused ingress and egress, even when tested using travel demands that were relatively small. Greatest benefits were predicted when the buffer was fully removed from the site, despite conservative assumptions made in regard to how carpoolers might respond to that removal. Yet even this treatment was not a silver bullet against congestion: buffer removal eased the constraints on merging and diverging at nearby ramp junctions, and a new bottleneck triggered by weaving maneuvers was predicted to emerge as a result. This new bottleneck was a relatively minor one, however, and was less damaging to flows.

Section 4 examines pending legislation under which the site's limited-access lane would be reserved for carpools only during the rush, and made available to all traffic at all other times of the day. Heightened vehicle migration through the 400 m-long buffer opening was predicted whenever the lane switched from general to restricted use, which disrupted flows. The extent of the disruption varied, depending upon the times of day when the carpool restriction took effect. Interestingly, the parametric tests indicate that, all else equal, a time-of-day restriction is always more damaging to flow at the site than is the current policy in which carpool-lane use is restricted at all times.

Section 5 discusses policy implications of the present findings. Future steps for moving forward are discussed as well.

2. Computer simulation

All experiments were conducted using a discrete-time, microscopic car-following and lane-changing model formulated in Lee (2008). The model was developed expressly for weaving sections, where a freeway's geometry causes certain vehicle streams to cross one another (e.g. see TRB, 2010), much as they do at special-lane access points. The model in Lee (2008) is itself an adaptation to one presented in Menendez and Daganzo (2007).

To simulate car-following, vehicles are assumed at each time step to have traveled the greatest distances possible, subject to constraints imposed by: maximum vehicle accelerations, driver comfort, and safety. Full descriptions of the car-following algorithms are furnished in Menendez (2006).

Vehicular lane-changing maneuvers are classified as being either (i) "mandatory," which in the present context entail movements into and out of the carpool lane, as well as merge and diverge maneuvers at on- and off-ramps; or (ii) "optional," which entail the maneuvers that are performed between regular lanes as drivers unilaterally seek to increase their own travel speeds.

Optional maneuvers were modeled as per the logic of Menendez and Daganzo (2007), and the reviewer can refer to that reference for details. Mandatory maneuvers were emulated using the logit model of Lee (2008). That model takes as input: the difference in traffic densities between a driver's present lane and her adjacent target lane; the number of lanes that a vehicle must cross to complete the maneuver; and the longitudinal road space available to do so. When a vehicle fails to perform a mandatory maneuver over a sufficient number of time steps, that vehicle or its neighbor in the target lane will decelerate to increase the likelihood of a successful lane change; see Lee (2008) for further details.

Review of Lee (2008) shows that the model fared well when compared against real data from freeway weaving sections. It is therefore not surprising that the model was able to match observed conditions at an access-point bottleneck fairly well, as shown below.

2.1. Model calibration

The study site was taken to be the stretch of Interstate 210 previously shown in Fig. 3a of Part I, which features a limited-access carpool lane with a painted buffer and a 400 m access point to serve ingress and egress. The site is reproduced in Fig. 1 below for the reader's convenience. The simulation model was calibrated to the 1490 m portion of the site that spans the detectors at D2 and D1, and to the traffic conditions measured from 14:30 h to 16:00 h on March 14, 2012. That day was selected because it was largely free of flow disruptions caused by queues spilling-over from somewhere downstream of the site. Simulations could therefore be performed without the added complication of having to estimate travel demands during periods when flows were constrained by spill-over queues.

Similar complications nonetheless occurred when the queue that formed that day at the access point engulfed the site's upstream portion. Once that queue had propagated beyond the detectors at D2, the flows measured there were constrained and were therefore lower than the demand. We were thus forced to calibrate the model by guessing at the demand to pass D2 during that constrained period. We guessed this to be the highest 5-min flow measured at D2 prior to the queue's arrival,