APPLICATIONS OF TRAFFIC FLOW THEORY IN MODELING NETWORK OPERATIONS

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ABRIDGMENT

Certain characteristics of roadway traffic flow, though conceptually simple in isolation, can create modeling problems in a network context. The following phenomena must be accurately represented in any network model used for evaluating traffic control measures: queue spillback, cost of queuing on each link, flow-dependent capacities of weaving and merge sections, and dynamic sharing of merge capacity by its approaches. Some methods for modeling these traffic network idiosyncracies are outlined. These methods were incorporated in the development of the CORQ traffic model, which has been validated against field data and has been found sufficiently sensitive to be applied in evaluating detailed traffic control schemes.

•AN ASSIGNMENT technique (1) that introduced the concept of queuing analysis for treating time-varying demands was found to be too general for use as a tool for evaluating traffic operations. It left a number of important questions related to road-specific networks unresolved. These were addressed (2) in the development of CORQ, a model for predicting traffic flows and queues in a corridor.

The CORQ model is based on a dynamic traffic assignment procedure (1) that divides a time period (e.g., a peak period) into a set of time slices, each of which is sufficiently short that the demand rates between origin-destination (O-D) pairs can be considered constant. There is a separate O-D matrix for each time slice. These O-D matrices are assigned to the network in order. Queuing is allowed, and its effect on travel time is reflected in the path choice phenomenon. After each time slice the network is cleared of all flows and queues. The queued vehicles are represented in the next time slice by being added to the demands for that time slice. They are then reassigned to their destinations.

This paper identifies some traffic flow characteristics that should be represented in a flow prediction model and outlines some methods for accomplishing this. The procedures used to simulate these phenomena in the CORQ model are described. The following types of phenomena had to be represented in the CORQ model:

1. Queue spillback,
2. Cost of queuing on each link,
3. Flow-dependent capacities of weaving and merge sections, and
4. Dynamic sharing of merge capacity by its approaches.

Because the general assignment technique could not simulate the effects of queue spillbacks, queue costs were attributed to the use of the bottlenecks rather than the use of the links, where the delay time is actually spent. The capacities of weaving and merge sections on freeways can vary with the flows in these sections. Therefore, neither flows nor capacities are known in advance. Further, the sharing of capacity at merge sections (e.g., freeway on-ramps) by competing approaches to the merge is a function of the demands at each of those approaches. There is little difficulty in describing and understanding these idiosyncracies of road traffic. However, preservation of their traffic flow properties in the context of a traffic assignment model is an-

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other matter. They must be represented sufficiently accurately for use in a micro type of model. The model must be precise enough to evaluate various traffic control schemes. The procedures used to represent the above traffic idiosyncracies in the CORQ model are outlined briefly herein. They are described in greater detail elsewhere (2).

QUEUE SPILLBACK

If a queue spills back through a diverge or an intersection it can delay vehicles that do not even use the bottleneck, i. e., vehicles that leave the queue downstream of that bottleneck and create no delay for other users. Users of the link with the bottleneck are generally not delayed further, regardless of the physical length of the queue.

Whenever a link absorbs vehicles at a greater rate than it can discharge them, its queue grows at a rate equal to the difference of these rates. This is caused by a limited ability of a downstream link to absorb vehicles because of flow capacity or a spillback of its own. The physical size of a queue is not important until spillback occurs, which causes delays to vehicles that will not even use the bottleneck.

The spillback process can be modeled by keeping track of the number of queued vehicles on each link and comparing this to the average physical queue capacity of the link. Because the physical queue on a link has no effect on other links until it backs through a node to another link, this additional information is sufficient. When a queue does spill upstream, the delay attributed to each link should be proportional to the size of the queue on that link divided by its discharge rate at the prevailing conditions.

REPRESENTATION OF LINK COSTS

The cost of using a link is a combination of

1. Flow, the unit cost of travel corresponding to the flow on the link, and
2. Queuing, the cost of being delayed in queue if there is a physical queue on the link.

The total cost for the link is treated as if the user drives along the link at a constant speed until he reaches the tail of the queue, where he begins to drive more slowly toward the downstream end and waits his turn to leave the link. The flow cost represents the time spent in reaching the tail of the queue. The queue cost represents the time that he is moving to the downstream end of the queue. The latter is not all delay, for he is simultaneously working his way to the downstream end of the link. It has been treated as above to take accurate account of time spent on a link and to count the time spent moving in the queue only once. This method is compatible with the modeling procedure of CORQ and takes full account of the time spent on a link without requiring the detailed space-time trajectories of the vehicles.

The unit cost of travel on a link, excluding queuing, can be obtained as a function of flow (less than capacity) in a straightforward manner such as a floating vehicle technique. This function is then approximated by piecewise linear sublink components (2) for use in the model's incremental assignment procedure. When there is queuing on the downstream portion of the link, the flow cost for the link is factored down to represent the actual cost for just the upstream portion of the link that allows flow in the nonqueuing mode.

The unit cost of queuing is also approximated by piecewise linear components. The queue service rate is estimated dynamically within the model as a function of existing conditions within the network. It is always proportional to the rate at which vehicles are discharged at the downstream end of the queue. In the simplest case, it is equal to the saturation flow rate for the downstream link serving the queue. The treatments of more complicated cases, such as a merge or diverge, are described elsewhere (2).

CAPACITY OF WEAVING SECTIONS

A traffic flow prediction model should contain a technique to dynamically estimate weaving capacities as estimates of traffic flow change. However, even the estimation of weaving capacities based on known flows does not seem fully resolved. Weaving studies to date (3, 4) have emphasized design of weaving sections rather than estimation of capacity for existing weaving flows.

MERGE CAPACITIES

The total capacity of a merge can vary, and, furthermore, the capacities of its approaches generally depend on one another's flow. These relationships can best be determined empirically for a given merge. Because the ultimate values of flow-dependent capacities cannot be known before the flows are known, they should be reestimated dynamically as the estimates of the flows change during the network loading process. These problems are outlined below, along with some methods for dealing with them.

Capacity of the Downstream Section

Except for weaving sections, capacity of the downstream link of a merge is generally affected only by a breakdown in flow. The occurrence of breakdowns seems random, but their incidence increases greatly as flow levels approach or even exceed the average capacity of a section.

Total merge capacity is generally treated as independent of the approach flow mix, inasmuch as breakdown and queuing generally begin just downstream of the merge after the flows on the competing approaches have successfully merged. The queuing is therefore caused by excessive merging traffic overloading the downstream link and not by friction caused by the merge. Buckley and Yagar (5) argue that the occurrence of a merge may even boost capacity.

The throughput capacity of a poorly designed merge could vary with the flow mix on the approaches. However, a preliminary study of some actual merges indicated that the approach flow ratio generally does not affect capacity, so that merge capacity can be treated as independent of the flow mix on the approaches. In isolated cases where this approximation is not accepted, the total equivalent through flow could be restricted at the merge to reflect any effect of flow mix variation on the merging capacity. The CORQ computer program (2) already has provision for this.

Sharing of Merge Capacity by the Approaches

Even where the total merge capacity is independent of its flow mix the approaches to the merge have component capacities that depend on one another's flow. When the total merge capacity is independent of the flow mix, the approach capacities are complementary. When each approach has greater demand than the merge will absorb from it, queues build upstream on both approaches. In this particular case the capacity of each approach depends on its ability to discharge vehicles into the merge during this state of competition for the merge. This particular capacity is defined as the capacity entitlement of the approach, for it is always available to the approach. These entitlements can be determined by counting the respective merging rates when there is queuing on both approaches. When one approach does not require all of its entitlement, the other approach can make use of the unused entitlement.

Estimating Capacities From Entitlements and Extrapolated Partial Flows

The phenomenon of capacity sharing at a merge section can be modeled quite easily if the demands on the two competing approaches are known. However, the flows cannot be assigned until the capacities are known, while the merge capacities in turn depend on the competing demands. To simulate the sharing of merge capacity when the flows are not known in advance, the CORQ model has a dynamic capacity borrowing routine and a dynamic entitlement updating routine.

Capacity-Borrowing Routine

This routine is considered after each increment (6) of assignment. If one of the approaches is out of capacity and another is projected to have an excess at the end of the time slice, the latter may lend some capacity to the former.

The capacity-borrowing routine also has some optimization characteristics. A common goal of freeway operations is to operate a bottleneck merge at capacity without having a queue on the freeway. The traffic analyst can model this by simulating traffic-responsive metering to predict its effects in the corridor. The analyst merely gives the main-line approach sufficient entitlement (perhaps even the total merge capacity) that it will not have a queue and uses the capacity-borrowing routine in the simulation. The merge capacity not needed by the main-line approach is passed on to the on-ramp. Use of the incremental assignment technique may result in poor projections of ultimate link flows. This might be countered by further iterations of incremental assignments using new capacity entitlements.

Entitlement-Updating Routine

Varying the capacity entitlements based on the results of the previous iteration tends to give oscillating results if a significant number of drivers have a path choice that is sensitive to merge capacities, resulting in their swinging from one approach to the other of the same merge. However, the amplitude of the oscillation tends to decrease with each iteration. In the applications (2) that were performed by the author it was found that four to six iterations generally gave reasonably good results.

The user who can estimate his merge demands sufficiently well without the routines for merge sharing or entitlement updating need not use these options and may go immediately to the final step. However, the author's experiences have found these routines to be very helpful in closing in on the final merge entitlements in spite of the problems in using them.

SUMMARY

To be practical, a model for evaluating strategies of traffic operations and control must be precise. Certain properties of traffic flow that previously did not require detailed treatment are critical in models that assign traffic to a network. For the CORQ model, it was necessary to address the phenomena of queue spillback, cost of temporary queuing on a link, dynamic determination of the capacities of weaving and merge sections, and dynamic sharing of merge capacity by the approaches to a merge. Routines were developed for modeling the occurrences and effects of these phenomena in a manner compatible with the needs of CORQ. Although these problems have not necessarily been fully resolved, they have been at least identified. Furthermore, the interim treatment that they received was sufficient to create a model that has been validated against field data (7) and found sufficiently sensitive (8) to be applied in evaluating a variety of detailed traffic control schemes.

Although the outlined routines have served as an interim measure to bridge a gap for the needs of the CORQ model, there is room for improvement especially in those related to dynamic estimation of weaving capacity and dynamic sharing of merge capacity. Further, some improvement in modeling of the merge-sharing phenomena to further automate applications could reduce the time and effort requirements of the user. The extent to which this could in fact be accomplished is limited by the use of an incremental type of assignment technique that is good for modeling queuing processes but tends to oscillate among various shortest paths.

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