Development of Compact Microsimulation for Analyzing Freeway Operations and Design

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The development of the freeway microsimulation FOMIS is described and an example of the kind of analysis possible with it is given. The model uses the vehicle-behavior algorithms of the freeway component of the simulation INTRAS, which is the corridor microsimulation developed for the Federal Highway Administration. The integration of these algorithms into a revised model structure overcomes some traffic operations difficulties experienced with INTRAS, greatly improves model speed, and provides a simulation model that can run on computers of very limited capacity. As an example of its application, a weaving section on I-95 in Dade County, Florida, is analyzed. The resulting analyses indicate operating patterns not generally derivable with existing methods. Varied and unusual design solutions emerge from the analyses. A model of this kind, which uses the particular traffic algorithms of INTRAS, has a potential as a supplemental tool to established procedures for applied freeway design problems. It could also assist in research into weaving and merging behavior in complex situations.

Most freeway operations and design problems are currently analyzed with standard capacity analysis procedures (1,2) or by macroscopic computer models such as FREQ (3). In many instances, however, an additional level of analysis may be desirable if the problem involves unique or unusual geometric features and/or traffic operating characteristics. In such cases a microsimulation could provide the necessary analysis capability.

An effective freeway microsimulation with the appropriate capabilities is contained in INTRAS, the corridor-simulation model developed for the Federal Highway Administration (4). This model, however, has some drawbacks with regard to model size, running time, and availability. It would be useful, therefore, to have the unique capabilities in INTRAS available in a more compact form for application to specific freeway analysis problems.

This paper presents an example of how this might be done through the development of a compact freeway microsimulation that integrates the vehicle-behavior algorithm of INTRAS into a modified model structure. This revised model, FOMIS, can operate on a small computer system with limited capabilities and has a running time substantially faster than INTRAS. As an example of the potential use of a model of this kind, an example of an analysis of a freeway weaving section is provided.

BACKGROUND

Since most freeway analysis problems of significance involve traffic flows at or near capacity, a simulation, to be useful, must have the capability of modeling these traffic conditions. In particular, the simulation must be able to reproduce weaving and forced lane changing at high-traffic concentrations, it should be able to internally generate the breakdown from free flow to congested flow, and it should be able to replicate the wave propagations of congested flow.

The microsimulation that has these characteristics is INTRAS and, accordingly, it provides the starting point for the development of FOMIS. Unfortunately, for its applicability to many freeway analysis problems, INTRAS is primarily a research model of great size and limited availability. Thus, there appears to be a need to use the power and flexibility of its algorithms in a simpler framework more suitable for applied problem analyses.

Users of INTRAS have reported problems with some aspects of traffic behavior. These relate mainly to vehicles that merge from acceleration lanes, vehicle behavior at exit ramps, and the method of assigning destinations. Some of these relate to the complications of communication between vehicles across link boundaries. The link structure in INTRAS defines geometric conditions along the freeway. Vehicle processing in the simulation is carried out on a link-by-link, then a lane-by-lane, basis. In each time period, two complete scans of the system are needed--one to handle car following and the other to handle lane changing.

FOMIS provides a revised model structure that is intended to streamline the simulation process by restricting it to the freeway only, by eliminating the link structure, and by reducing vehicle processing to a single scan. Several of the reported vehicle-operation problems are also eliminated by the modifications. The basic vehicle-behavior algorithms, however, remain relatively unchanged and provide the central logic for this simplified model.

VEHICLE-BEHAVIOR ALGORITHMS

Vehicle behavior is modeled by car-following and lane-changing algorithms, for which the full derivations are given elsewhere (4-6). Car following is a combination of two individual algorithms. One is based on the premise that a following vehicle will always seek a desired headway, which will be a function of vehicle speed, relative speed, highway capacity, and driver and vehicle type. The other is a collision-avoidance algorithm that acts as an override on the desired following-distance equation and ensures that the vehicle is always in a safe position. The combination of these algorithms allows vehicles to be temporarily inside their desired headways; thus, the simulation can reproduce the very short headways and headway oscillations that are so prevalent in congested flow. This provides the mechanism for the internal generation of the breakdown from smooth free flow to turbulent congestion, with the associated shock-wave propagation.

The lane-changing mechanism uses the collision-avoidance algorithm, as it is assumed that the desired following behavior is not present during a lane change. The changing vehicle must satisfy the safe headway conditions for both the leader and the follower of the gap that it is moving into. The lane change is assumed to take the finite amount of time that a vehicle needs to physically change lanes, and this is accomplished in the simulation by projecting ahead to the end of the lane-change time, i.e., the final positions of the interacting vehicles. They must be in safe relative positions at that time but, during the time of the lane change itself, temporarily unsafe positions are allowed. This mechanism has been shown to replicate forced lane changing as it allows changing vehicles to crowd into otherwise nonexistent gaps in congested conditions. The lane-changing rules also allow for courteous drivers to create gaps for changing vehicles.

STRUCTURE OF FOMIS

The vehicle-behavior algorithms described above, which are the logical core of the freeway component of INTRAS, are also the basis of FOMIS. It is in the simulation structure that contains these algorithms that the major differences exist. In particular, the link-by-link description of the freeway is not used. In FOMIS the freeway is structured as a single continuous unit with all elements, whether moving vehicles or fixed objects, defined by their longitudinal distance from some fixed origin and their lateral position by lane number. Within this structure, the simulation can handle a wide range of geometrics at any desired location, which includes lane drops and adds, weaving sections, entrance and exit ramps of any number of lanes, and freeway-to-freeway merges or diverges. Structurally, FOMIS has no upper limits on the length or the number of lanes of the freeway to be modeled. The specification of array size, however, does place practical limits on these parameters.

Other characteristics that can be implemented are vehicle detectors and lane-capacity reductions caused by permanent geometric characteristics or temporary traffic incidents. These features may be placed anywhere on the freeway in any number. There is one constraint on the fixed features in that they must have a longitudinal separation such that a vehicle cannot cross two physical features in a single scanning period. In practice this means a spacing of at least 150 ft.

SIMULATION OPERATION

Vehicles are processed from downstream to upstream in the order of their physical location, regardless of lane. A single sweep is made each scanning period and all functions, including car following and lane changing, are carried out during this sweep. The moving window in which the vehicle processing is carried out contains all adjacent vehicles. This means that for lane changing, the adjacent gaps can be referenced directly whereas in INTRAS they must be searched for individually whenever they need to be referenced.

The lane-changing algorithm has been upgraded to improve high-volume weaving. In the original lane-changing mechanism, the projected behavior of the lead vehicle had to be its worst deceleration condition, which was somewhat unreasonable. Now, however, the projected behavior of the lead vehicle is based on its own leader and this gives more realistic acceleration projections during weaving.

Another change with FOMIS is its handling of vehicle destinations. In INTRAS, these are randomly assigned on a link-by-link basis. In FOMIS, an origin-destination matrix provides the distribution of destinations by lane and exit ramp for vehicles that enter each lane of each entrance ramp. This destination pattern remains consistent thoughout the length of the freeway. Once on the freeway, the lane choice of a vehicle is controlled by the destination characteristics and by two overlapping zonal influences. The first indicates whether the current lane is incompatible physically with the vehicle's destination and, if so, the distance still available to reach a compatible lane. The second set of zones gives lane desires when lane choice is not mandatory. These zones can be keyed to driver information given by signs and allow lane changing as vehicles approach their destination ramps.

Information on speeds, volumes, and densities for each detector is printed out at intervals set by the user. Individual vehicle data can also be displayed. The simulation currently runs on a DEC 10 with 20K core. This gives arrays that allow up to 8 lanes (including ramps) with a system of up to 25 lane miles of congested traffic. Under these conditions, which include heavy concentrations of weaving traffic, the model runs at about 1500 vehicles/scanning period. In comparison, INTRAS with overlays requires 500K in modeling a corridor. FOMIS runs at three to four times the speed of only the freeway component of INTRAS for the same size problem on the same DEC computer. Compared with the full INTRAS model, the running time of FOMIS is probably on the order of 10-20 times faster.

EXAMPLE APPLICATION: WEAVING SECTION DESIGN

As an example of its use, the simulation has been applied to an analysis of a freeway weaving section. For the example, analysis of a length of northbound Interstate-95 in Dade County, Florida, which runs between I-195 and I-395, was used. Figure 1 shows the schematic layout of the freeway with its peak traffic flows projected for the year 2005. The weaving section is about 5350 ft long with five lanes entering and six lanes leaving. Conventional analysis led to a weaving section of six lanes, with the sixth lane added to the right lane.

In the simulation analysis, six alternative geometric designs were tested. These, as shown by Figure 2, are as follows:

A. The existing design.

B. Adding the sixth lane on the left side so that it becomes part of the through portion of I-95.

C. Adding the sixth lane in the center so that the two merging highways are shifted a lane further apart.

D. A variation of alternative C where the start of the weaving section is delayed by a barrier of 1000 ft. Thus, the through part of I-95 is first expanded to four lanes and it then enters the weaving section, which is reduced to 4350 ft in length.

E. Similar to alternative D except that the initial expansion by one lane takes place on the I-395 approach.

F. A combination of alternatives D and E with both approaches expanding by one lane before the weave takes place. This gives a weaving section of seven lanes.

The simulation model was calibrated to a lane capacity of 2100 vehicles/h. General vehicle-type distributions and vehicle-speed distributions were used as detailed data from the site were not available. Since the analyses were comparisons between alternatives rather than the precise measurements of any one alternative, there was no real need for exact local traffic conditions. The model was validated to the degree that, when existing traffic flows were simulated on the existing geometrics, the congestion patterns known to exist were reproduced.

The alternatives were compared by simulating two conditions on each one. The first condition was the projected traffic volumes and patterns for the year 2005. The second condition was that of complete oversaturation. The total throughput of the weaving section was measured, given maximum entering volumes on all lanes and the same weaving percentages as in the first condition.

ANALYSIS RESULTS

The analyses of the year 2005 volumes indicated different congestion patterns for the various alternatives. Figure 3 shows the level of service in the weaving section for each alternative

Alternative A, which is the existing design, does not rate well in these comparisons. The primary weaving area is fully congested while another congested condition occurs in the area further downstream where I-395 traffic merges with the I-95 through traffic. The sixth lane on the right remains at level-of-service A. For most of its length, this lane is not used at all, and at the end of the weaving section it carries volumes of only 400 vehicles/h. Thus, while macro-weaving analyses indicate that a weaving section of six lanes will be sufficient, the effective weaving area is only five lanes, especially at the beginning of the weave; hence, the actual performance of this alternative is substandard.

Figure 1. Example weaving area with design volumes.

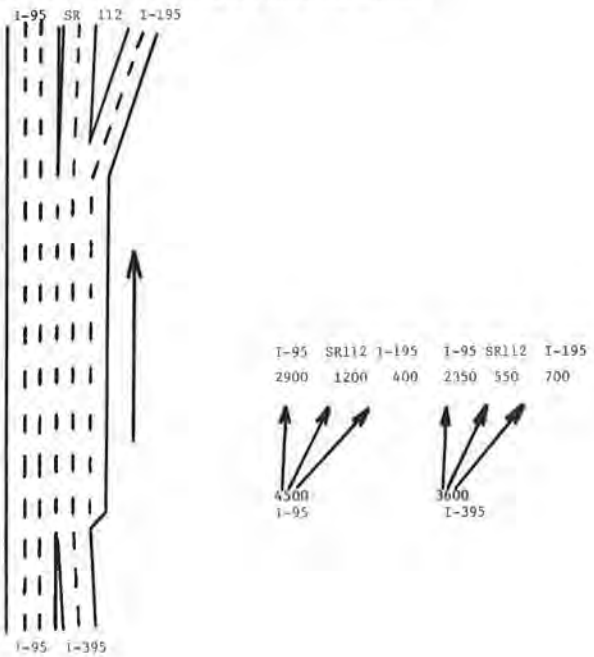
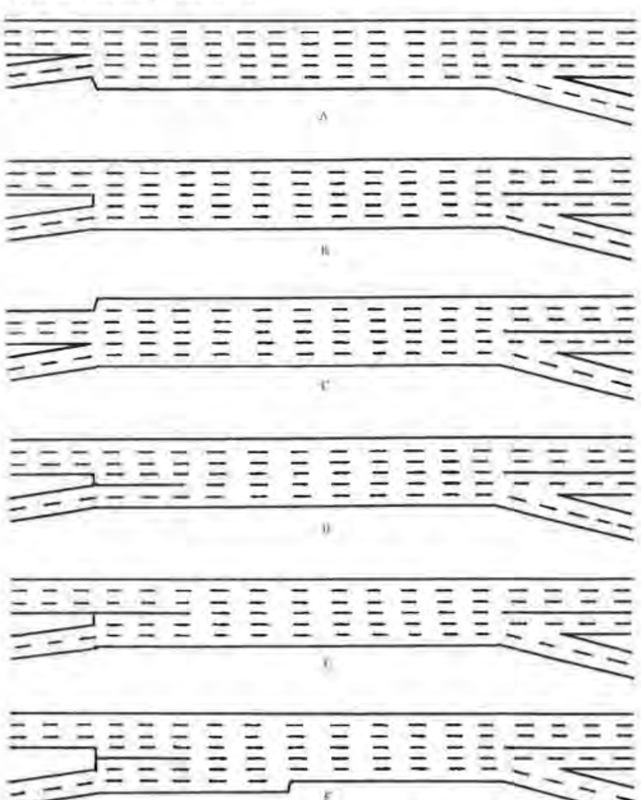


Figure 2. Six design alternatives.



Alternative C shows performance deficiencies similar to those of alternative A. Conditions on the I-395 approach to the weaving areas are worse since the weave is more difficult, while the secondary merge is somewhat better as the added lane is helping maintain the through traffic stream.

Alternative B, with the added lane in the center, is clearly a major improvement. No part of the weaving section is congested, with two limited areas at level-of-service D. In the primary weaving area, levels of service of A and B are maintained and this is the significant operational improvement over alternatives A and C, where the primary weaving area is congested for the design volumes.

Alternatives D, E, and F all show satisfactory operational levels of service, particularly in the primary weaving area. There is some congestion in the secondary merge caused by the shorter total weaving length available. The area of level-of-service D is greatest in alternative E, which constricts the main I-95 traffic flow somewhat more than the other alternatives.

With all of the alternatives, the simulation gives a detailed summary of the spatial patterns of the levels of service of traffic operations within the weaving section. The macro-analysis methods, on the other hand, give only the aggregate estimates of overall weaving section performance. This means less information on particular operational problems and less sensitivity in the analyses to detailed geometric design alternatives.

Figure 3. Operating conditions at design volumes.

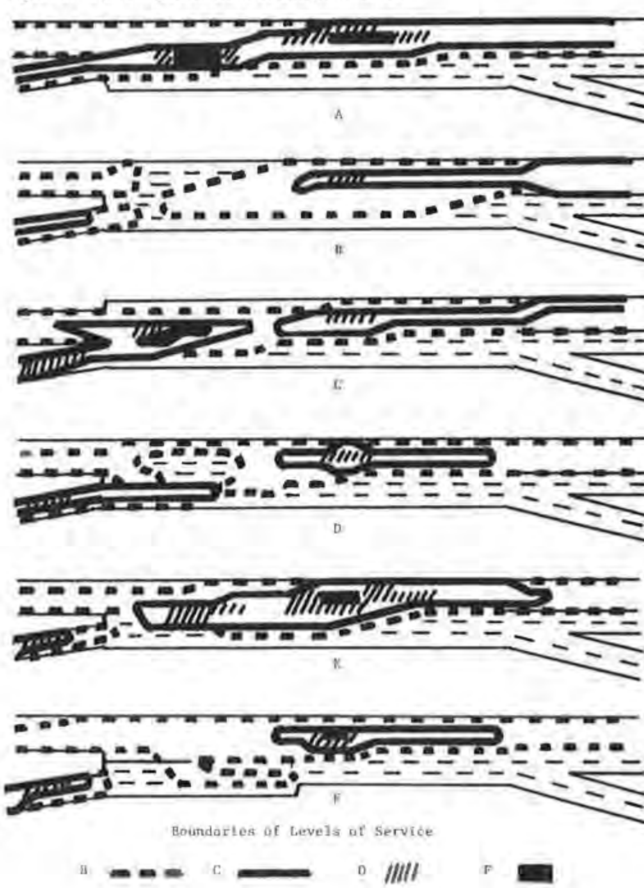
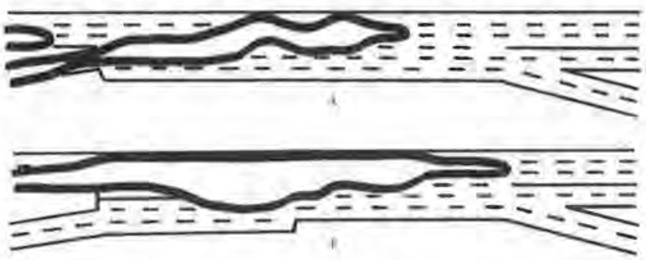


Figure 4. Areas of level-of-service F under oversaturation.



The second condition simulated was the throughput of the weaving section with maximum demands on all lanes that enter the section. The table below shows the results of these analyses in terms of the actual input volumes that could be handled, which indicate the maximum capacity of the weaving section (in vehicles per hour):

Alternative	From Left	From Right	Total
A	5100	3354	8454
B	4947	3686	8633
C	4803	3456	8259
D	5469	3360	8849
E	5163	3774	8937
F	5130	3888	9018
Design	4500	3600	8100

In total throughput, there is a 10 percent difference between the best and worst alternatives. Alternative F allows the highest volumes of 9018 vehicles/h, and these are limited, not by the weaving area, but by the capacity of the three output lanes of I-95. Alternative E gives the best throughput of the six lane options with a capacity of 8937 vehicles/h.

Alternative A has a fairly low throughput capacity of 8454 vehicles/h, and it is of interest that the flow from I-395 of 3354 vehicles/h is lower than the design volume of 3600 vehicles/h. This means that if the flow from I-95 increases more than its design volume, then it will tend to dominate the weaving area and restrict volumes from I-395.

Figure 4 shows the congested areas of the weaving section for the oversaturated condition for alternatives A and F. For alternative A the congestion starts at the weaving and merging areas, which indicates that these areas are the capacity constraints. With alternative F the congestion extends upstream from the far end of the weaving section, which indicates that the constraint is the downstream capacity rather than the weaving area itself.

The indication from these analyses is that conventional weaving analysis can give a design that is not operationally the best that might be available. In this example, it appears that some variation of adding the lane to the middle is the solution that gives the greatest capacity under oversaturation. The center lane appears to facilitate smoother weaving at the start of the section, which is the most critical area. This improved performance occurs despite the fact that most weaving vehicles now have an additional lane to cross, thus increasing the actual number of lane changes.

Although this is only a single example, it does suggest that a better understanding of the weaving process can be obtained from a model that can differentiate traffic conditions both along and across the freeway. The initial merging area is the most important and special consideration should be given to its design. Rather than a tight design that minimizes lane changes, a design that spreads the merging area should have better operational capacity performance.

Other factors that should be kept in mind for the design process are that weaving streams should be separated longitudinally if possible and the design should specifically try to distribute traffic flow uniformly across all the lanes of the weaving section.

CONCLUSIONS

The primary objective of this paper was to show how the essential capabilities of a potentially powerful microsimulation model could be made more generally available. The relevant components of the very large INTRAS model can be reduced to a model that certainly can be accommodated on a desk microcomputer. As such, it should be most suitable for use as a supplemental tool to current macro-analysis methods.

The potential exists in two particular areas: first, for the applied analysis of practical design and operations problems and, second, for research to obtain a more detailed understanding of merging and weaving behavior. In the latter case, the amount of field data needed to further calibrate and validate the simulation is probably much less than that required to calibrate the macro methods in more detail.

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