ARTWORK: A Simulation Model of Urban Arterial Work Zones

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Several studies pertaining to the modeling of freeway and arterial traffic movements were reviewed, but none of them were applicable to lane closure in construction work zone on arterials. Hence the goal was to develop a computer-based methodology for the evaluation of traffic control systems at arterial street lane closure in the vicinity of signalized intersections. More specific objectives were to develop a microscopic computer simulation model of traffic flow at arterial street lane closures, to derive a series of system measures of performance as an output of the model, and to validate the model's logic by using field data. Delay, fuel consumption, and queue buildup were used as the measures of effectiveness in validating the model. It was concluded that the model performs satisfactorily.

Most previous research related to traffic flow near work zones has been done with respect to freeways. While several techniques, theories, and methods (taking into consideration the number of open lanes, number of closed lanes, length of work zone, etc.) are available to calculate vehicle delay at freeway work zones, no literature is available with respect to work zones on arterials.

A review of previous research concerning the evaluation of arterial street lane closure performance revealed a common flaw. Although most studies attempted to investigate the impact of individual traffic control elements on some performance measure of traffic flow, many failed to treat the arterial lane closure site as a total information system. A controlled experiment was needed to develop a ranking procedure for the variables that affect traffic flow quality at arterial street lane closures.

The traffic flow model described in the next section is a first attempt at a more systematic approach to the lane closure problems of urban arterials. In addition to the traditional aspects of arterial traffic flow (such as traffic volume, speeds, headways, car following, and gap acceptance rules), the model explores a wide range of parameters describing driver behavior in a construction lane closure. Parameter effects on the overall system performance are also assessed.

ARTWORK, a simulation model of urban arterial work zone lane closure, was developed by using the SLAM II simulation language (*1*). In this study, a hybrid model was selected so that the fixed time mechanism could be used to update the vehicle positions in the system and the next event increment could be applied to the vehicle-generating pool, that is, the processing of vehicles that have just entered the system. This paper summarizes the development and the validation of the ARTWORK model.

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MODEL STRUCTURE

ARTWORK consists of a main program and 23 subprograms and functions. The model is microscopic in nature; that is, each driver-vehicle unit is identified as a separate entity. Periodic updating of each vehicle's status is performed at 1-sec intervals. The simulation model consists of the following elements:

Vehicle Representation

In the simulation model, each vehicle is assigned a set of 25 attributes upon entering the system. Some of these attributes, representing the status of vehicle in the system, stay constant, and the remaining attributes are updated during the simulation run.

Vehicle attributes are generated at the entry point either stochastically or deterministically and are updated throughout the system. Vehicle design characteristics such as length, width, and driver eye height are input to the model by the user. The model is capable of handling different types of vehicles.

Traffic Control Device Representation

The modeling of various traffic control devices (TCDs) is accomplished in the same way that vehicles are represented. All TCDs in the construction zone were categorized as "merge stimuli." Attributes that describe each TCD are related to their design features, such as height, maximum recognition distance, and message information processing time, as well as location characteristics, such as longitudinal and lateral position in the zone and TCD placement on one or both sides of the road.

Roadway Representation

Vehicles are generated at entry point and are released at exit point. The roadway includes two traffic signal lights. The locations of data collection points are dependent on the user, and up to 20 simulated data collection points can be used.

The primary concern in the collection of traffic flow data in the model is compatibility with the field data collection method. This method consisted of recording vehicle arrival times at tape switches (grouped in pairs) and obtaining vehicle speeds, headways, and frequency of lane changes at each tape switch pair. The simulated system works in an identical fashion. The locations of data collection elements are provided as input to the model.

Traffic Signal Representation

Traffic signals were worked into the model with green, yellow, and red signal phasings and provision for exclusive left turn phase, if needed. The model only handles pretimed signal settings. The offsets for each traffic signal can also be input by the user.

Vehicle Generation

Nine probability distribution functions (PDF) are available in the model, each of which has a separate code provided by the user as input. Vehicle arrivals, desired speeds, and reaction time are randomly generated by using the proper distribution. Before arrival of a vehicle, tests are performed internally by the model to ensure that the car-following rules are satisfied at the entry point.

Car-Following Rules

The car-following rules adopted in this study apply only to vehicles in platoons, that is, those cases in which drivers cannot maintain their desired speeds because of a slower vehicle ahead. Vehicle positions are updated according to their location from the entry point. In a fixed-interval scan of 1 sec the leader position and speed are first determined; following vehicle speed and position are then updated by the car-following rules. This approach closely follows the noncollision constraints developed in the INTRAS model (*2*). The car-following rules state that drivers in platoons will maintain a spacing at least equal to their reaction distance plus length of lead vehicle when their speed is less than or equal to that of the platoon leader. This spacing is incremented by the deceleration distance to the platoon leader speed if the speed of the following vehicles is higher than the lead vehicle speed.

Gap Acceptance Rules

The process of lane changing from the closed lane to the open lane is initiated as soon as the vehicle has advanced beyond the legibility distance of the assigned merge stimulus. A minimum information processing time is needed by the driver to initiate the desired action.

When a lane change is attempted, the car-following rules for the lead and follower vehicles in the open lane are tested to ensure a safe merge into the open lane. Next, the gap between the lead and follower vehicles in the open lane is compared against the critical gap randomly assigned to the vehicle from the observed distribution of critical gaps. Once these conditions are satisfied, the process of lane changing occurs.

Input Data

The following input data must be entered by the user to run the model: traffic characteristics, vehicle characteristics, roadway characteristics, construction data, signal settings, distribution functions, and simulation control parameters.

Output

The model produces three major output components:

- Listing of input data;
- Statistics and histograms of the following variables: speeds and headways at each data collection point, vehicle merging distribution, fuel consumption, delay, and number of queue buildups; and
- Trajectory of vehicles at any specified time during the simulation run.

MODEL VALIDATION

Field studies were conducted as a means of evaluating the effectiveness of mathematical traffic flow models in describing a phenomenon under investigation (car following, gap acceptance, etc.). The purposes of the field studies were as follows:

- To provide input parameters for the simulation model, such as traffic volume, composition and speeds upstream of the construction and maintenance zone, types and locations of traffic control devices, traffic signal settings, and position of simulated tape switches;
- To compare observed driver behavior in the field (in terms of car following and lane changing) with that predicted by the model, and
- To test the model logic by comparing the actual measures of effectiveness observed in the field with those predicted by the model.

McClintock Street, located in Tempe, Arizona, was selected as the first site for a field study. The northbound approach on McClintock at the intersection with University was under construction during the morning off-peak hour. This resulted in closure of a through lane and a right lane.

Mill Avenue, also in Tempe, was selected as the second site. The southbound approach on Mill at the intersection with Alameda was under construction. This resulted in closure of a through lane. Data were collected during the morning off-peak hour.

Validation of the simulation model was performed by entering the data collected at both sites into the model and comparing the simulation results against the observed measures of effectiveness.

McClintock Site

Certain traffic description parameters were targeted for comparison. First, the number of vehicles that traveled over four road tubes for a period of 30 minutes was compared against the count made by simulated tape switches entered into the model. The results were as follows:

	Observed	*Simulated*
Open lane tape 1	445	400
Closed lane tape 1	306	253
Open lane tape 2	532	482
Closed lane tape 2	126	99

The observed counts by the road tubes were slightly higher than the simulated counts by the model.

Next, from observation the simulation model was run with the following distribution of percentage of drivers reacting to each merge stimulus:

- 10 percent to construction activities;
- 20 percent to taper cones,
- 60 percent to the "lane ends–merge left" sign, and
- 10 percent to the "left lane closed" diagram.

The results of the simulation model were a merging distribution with mean value of 1,087 ft and standard deviation of 679 ft before the University and McClintock intersection. The model also stated that the earliest merge occurred at 2,182 ft and the latest merge occurred at 298 ft upstream of the University and McClintock intersection. These results were in an acceptable range when compared to the observed merging vehicles from closed lane into the open lane.

The simulation model then calculated an average queue length of 19 and a maximum queue length of 53 vehicles for the open lane at the intersection of University and McClintock. It also calculated an average queue length of 10 and a maximum of 34 vehicles behind the taper in closed lane. The observed maximum queue for the open lane was 68 and for the closed lane beyond the taper, 35. The observed queue lengths were higher in the open lane and approximately the same for the closed lane beyond the taper in comparison to the simulated queue length.

Finally, the average speeds of vehicles traveling over the four road tubes were compared against the average speed of vehicles traveling over the simulated tape switches in the model. The results were as follows:

	Observed (mph)	*Simulated (mph)*
Open lane tape 1	37	38
Closed lane tape 1	32	35
Open lane tape 2	15	16
Closed lane tape 2	8	12

Mill Avenue Site

Again, certain traffic description parameters were targeted for comparison. First, the speed and number of vehicles traveling over two road tubes 1,000 ft downstream of the Broadway and Mill intersection for a period of 30 minutes (twice the observed values) were compared against the count made by simulated tape switches entered into the model. The results were as follows:

	Observed	*Simulated*
Number of vehicles at open lane tape	532	494
Number of vehicles at closed lane tape	348	320
Speed of vehicles at open lane tape (mph)	33	35
Speed of vehicles at closed lane tape (mph)	33	32

The observed values were slightly higher than the simulated counts by the model.

Next, from observations the simulation model was run with the following distribution of percentage of drivers reacting to each merge stimuli:

- 10 percent to construction activities,
- 20 percent to taper cones,
- 50 percent to the "lane ends–merge left" sign, and
- 20 percent to the "left lane closed" diagram.

The results of the simulation model were a merging distribution with a mean value of 1,290 feet and a standard deviation of 608 ft before the Alameda and Mill intersection. The model also stated that the earliest merge occurred at 2,458 ft and the latest merge occurred at 477 ft before the Alameda and Mill intersection. These results were in the acceptable range when compared to the vehicles observed merging from the closed lane into the open lane.

The simulation model then calculated an average queue length of 6 and a maximum of 21 vehicles for the open lane and an average queue length of 1 and a maximum of 9 vehicles behind the taper in closed lane at the intersection of Alameda and Mill. The observed maximum queue for the open lane was 24 and for the closed lane beyond the taper, 13. The observed queue length was higher than the simulated queue length in both open the and closed lanes.

The discrepancies among the observed and the simulated results were caused by the following factors:

- Vehicle arrivals were simulated by using a lognormal distribution fitted to the field data. This distribution does not match the real arrival times in the field;
- The secondary platoon arrival was ignored because there was a very small number of vehicles outside the primary platoon;
- The vehicles arriving from Apache Boulevard were assumed to be uniformly distributed, with mean of one vehicle every 2 sec turning left and one vehicle every 5 sec turning right into the arterial while the signal was green. These distributions were chosen to be as close to the field data as possible.
- Arrivals from the side streets, if any, were assumed to be negligible; and
- The seed number used to generate the random arrivals does make a difference to the number of vehicles created.

The simulation model represents true system behavior closely enough, however, to be used as a substitute for the actual system.

REFERENCES

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