Simulation of Detector Locations on an Arterial Street Management System

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The research presented in this paper used computer simulation to investigate the relationship between detector location and the ability of a system to monitor traffic characteristics (flow, speed, occupancy) and from them estimate link travel characteristics (link speed, travel time, intersection delay). A 3 mi (4.8 km) section of roadway in the Phoenix metropolitan area was simulated using the program CORSIM. Four detector locations within each major link were analyzed. One detector location was downstream of a major intersection; the other three locations were upstream of a major intersection. Statistical techniques, in the form of regression analysis, were used to evaluate the various dependent and independent variables. Results of the analysis indicated the link travel characteristics are unique to each link on the network. Of the variables examined, there was no one singular relationship that can be used to predict link travel characteristics. Further, there was no particular detector location that proved to be superior to all other detector locations. Detectors located downstream of major intersections can use traffic flow to predict link travel time with reasonable accuracy. Detectors located upstream of major intersections can use spot speed or detector occupancy to predict link travel speed with reasonable accuracy. The predictive capability applies to recurring congestion but does not apply to incident situations.The spacing of detectors can be critical to the operation of a system. The research showed that detector data obtained on one link could not accurately predict link travel characteristics on an adjacent link. Key words: arterial street management, traveler information, traffic detection, simulation.

BACKGROUND

The Phoenix, Arizona metropolitan area is in the middle of an ITS model deployment project called AZTech. This public-private partnership will use ITS technologies to provide traveler information on several major corridors in the area. The corridors will be instrumented with detectors spaced at roughly 3.2 km (2 mi) intervals. The detectors will feed information back to a regional computer server that will process the data. The data will then be disseminated back to drivers via several different mediums to provide them information about current traffic conditions.

In the area of advanced traveler information systems (ATIS), the initial focus has been on freeways. Less work has been done in the area of arterial street management as it relates to providing travelers with real-time information on traffic conditions. Certain factors, such as signal timing, parking activity, transit stops, driveway access, and turning movements, make monitoring traffic flow conditions on arterials much more difficult.

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PROBLEM STATEMENT

Given the budgetary limitations of many local and state agencies, outfitting arterials with vehicle detection must be done in the most cost effective manner. The primary goal of this paper is to answer the following question: What is the relationship of detector location to link travel characteristics on an arterial street network?

STUDY AREA

The study area chosen to investigate the problem statement is a 3 mi (4.8 km) section of Southern Avenue located in Tempe and Mesa, Arizona (Figure 1). This section is one of the eight corridors selected in the AZTech ITS project and has an average daily traffic (ADT) over 42,000 vehicles per day.

The westbound direction has three through lanes throughout. The eastbound direction has two through lanes to the west of Dobson Road and three through lanes to the east of Dobson Road. The portion of the corridor in Mesa has a raised median. The Tempe portion has a two-way left-turn lane in the center of the roadway. Separate right-turn lanes exist on some approaches at major intersections. The speed limit varies from 40 to 45 mph (64 to 72 kph).

There are a total of twelve signalized intersections in the study area operating on either a 94-second or a 110-second cycle length. All of the signals have some level of detection at the intersection. For permissive-protected left turns, both Tempe and Mesa use the third-car actuation technique.

LITERATURE REVIEW

A literature review was performed to determine what research has been done previously in this area. Much of the research on arterial street detection has been geared towards optimizing traffic signal operations or incident detection. Very little has been done in the area of traveler information on arterial streets. A full literature review can be found in Optimal Detector Location on Arterial Streets for Advanced Traveler Information Systems (*1*).

Sisiopiku et al. have done the most significant research in the area similar to this paper (*2*). This research was possibly the first of its kind involving the correlation of system detectors and travel time through simulation.

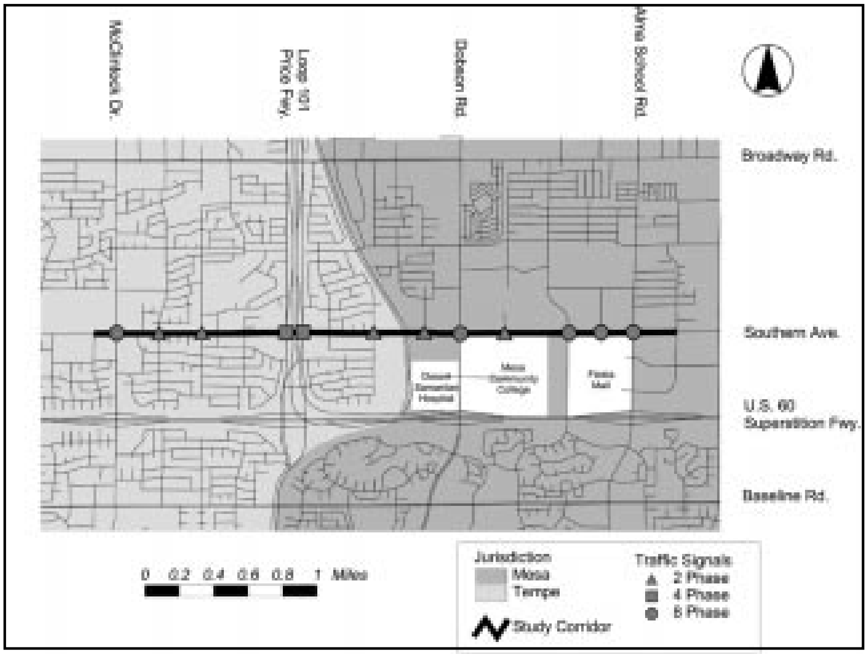

FIGURE 1 Study area

Among some of the conclusions of their study were the following:

1. Travel time is independent of both flow and occupancy under conditions of low traffic demand.
2. As percentage occupancy increases, the correlation between travel time and occupancy becomes more significant.
3. Simulation and field data indicate a strong correlation between flow and occupancy for certain ranges of values.

They noted that the observed relationships are complex and that substantial research is needed to investigate the relationship completely. The authors suggested that future research will further detail the models.

The research presented in this paper builds upon the research by Sisiopiku. The primary change is that detector location is varied in order to determine if there is an optimal location to place detectors in order to make accurate predictions.

DATA COLLECTION

Roadway and Signal Information

Roadway information was gathered from a number of sources. Traffic signal construction plans and aerial photographs were obtained from the cities for most of the study area. The aerial photographs provided turn lane storage lengths. A geographic information system (GIS) base map was obtained to determine the distance between signals to a degree of accuracy superior to aerial photographs or field measurements (< 3 m). Both jurisdictions provided signal timing sheets for all of the traffic signals in the study area. The timing sheets provided cycle lengths, phase split settings, yellow and red clearance intervals, minimum green times, pedestrian clearance intervals, and cycle offsets. All of these data elements are used to define the actuated controllers in the CORSIM program.

Traffic Information

Fifteen-minute morning peak turning movement counts were made at all of the signalized intersections in the study area. These counts were used as input to the simulation network. Mid-link traffic volumes were also collected at three locations as part of the AZTech project. These counts were used to calibrate the network.

The City of Mesa provided additional traffic volume information in the form of approach counts for the intersections of Southern/Dobson and Southern/Alma School. Since these intersections represent major inputs into the traffic network, the approach volume counts were used to determine volume inputs at the respective nodes. This research examined a fifteen-minute interval, and it was assumed that the turning movement percentages are the same throughout the time interval.

Heavily used transit routes can greatly affect the operation of the network. Although transit activity is low along Southern Avenue, the routes were coded into the network.

NETWORK CALIBRATION

Three methods of calibration were examined. Although other more precise methods of calibration exist – measured observations and the two-fluid method (*3*) – the simulation model was calibrated by observation due to limited resources in collecting data in the first case and lack of source coding in the second case.

The observation method involves visually comparing the graphical and tabular output of CORSIM with the actual conditions in the field. Observations can be made at intersections relating to cycle failures and queue lengths. This method is not as accurate as either of the first two methods. However, the time and expense to collect field observations are much lower. The goal of this research was to determine optimal detector location on an arterial. This research could have been performed on a fictitious section of roadway and still achieved the desired goals. In that case, calibration would not have been an issue. However, to improve acceptance of the research results and to maximize the application to the AZTech project, the research simulated one of the AZTech corridors.

Observations were made at the four major intersections. The primary observed value was the average queue length in the left turn pockets and the through lanes. The simulation of the base volumes reflected similar queue lengths at the major intersections. Therefore, it was concluded that the simulation model is a reasonable approximation of actual conditions.

A comparison was also made between the simulated traffic counts and the actual traffic counts observed on the links. With the exception of link 5, all of the comparisons are well within an acceptable range (< 6 percent difference).

NETWORK DETECTION

The most recent version of CORSIM (Version 4.2) allows the user to place surveillance detectors on the network links. The simulated detectors measure three data items: traffic volume, mean spot speed, and occupancy. Each of the six links was assigned a number (1 – 6) for analysis purposes.

Network detection was placed in four locations on each 1 mi (1.6 km) segment of roadway. Detectors were placed in all lanes. As shown in Figure 2, detectors were placed in three locations approaching an intersection: 900 ft (275 m), 600 ft (183 m), and 300 ft (92 m) from the stop bar and labeled “B,” “C,” and “D,” respectively.

The fourth detector (A) was placed 600 ft (183 m) downstream (and labeled position A) from the major intersection. Varying the location of the downstream detector did not have a big impact on the output variables when the distance was greater than 400 ft (122 m). If detectors are placed less than 400 ft (122 m), the results could be misleading because vehicles are still accelerating close to the intersection.

SIMULATION RUNS

Two factors were varied for this experiment: entry traffic volumes and detector location. There were six levels of entry traffic volumes: the base case scenario, base +20%, base +40%, base +60%, base +80%, and base +100%.

The existing peak hour volume in the peak direction on Southern Avenue is about 1,480 vehicles per hour, a volume that results in Level of Service D, or E, or F at the major intersections. The entry level volumes used in the simulation range from about 68 percent to 135 percent of the 1480 vph volume. The “base + 100 %” volume, therefore, forces high levels of congestion in the simulation. The actual volume/capacity (V/C) ratios produced by the simulation ranged as high as 1.7.

The experimental design resulted in a total of six separately coded networks, each with detectors placed at the four locations (Figure 3). This resulted in 24 separate traffic simulation scenarios.

Once all of the simulations were run, the relevant data for each volume scenario were reduced onto a single spreadsheet. These data included the detector information, link speed and travel time, and intersection delay. After this process was complete, there were twelve spreadsheets containing the relevant data (two for each volume level: one containing detector output data, the other containing link travel information).

The various measures of effectiveness (MOEs) were averaged over the eight simulation runs. Then all of the averaged MOEs were combined into a single spreadsheet, imported into the statistical program Minitab®. Preliminary analysis was performed on the data by plotting graphs of the following data: Link Travel Time,

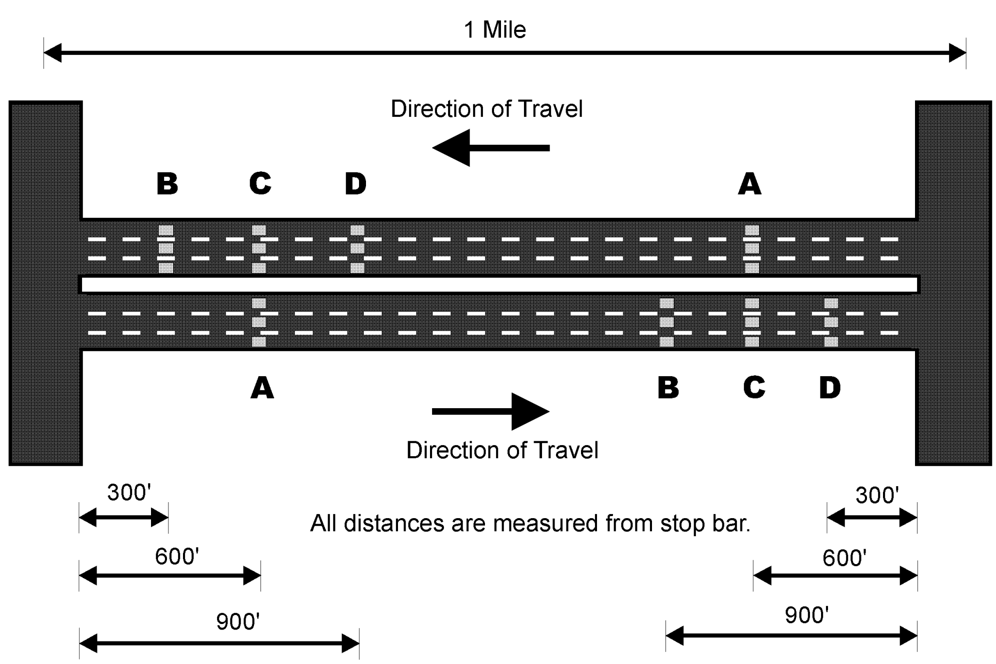

FIGURE 2 Surveillance detector locations

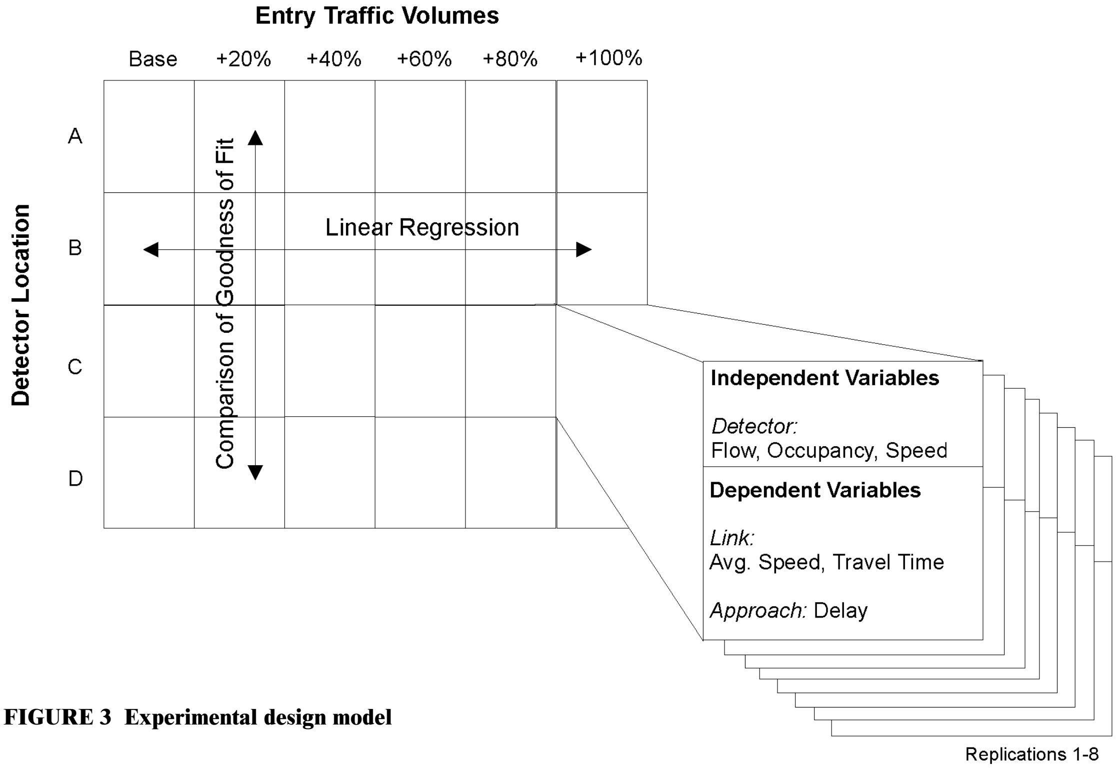

FIGURE 3 Experimental design model

Link Travel Speed, and Next Approach Stopped Delay vs. (1) Detector Volume, (2) Detector Occupancy (sum and average), (3) Average Detector Speed, and (4) V/C Ratio at the Next Intersection.

Only the through vehicles on the links were included in the data analysis. It was felt that including vehicles that traversed only a portion of the 1 mi (1.6 km) link (and turned left or right at intermediate nodes) or including vehicles that turn left or right at the major intersection nodes may distort the results. The research by Sisiopiku also did not include left- and right-turning vehicles in the analysis.

CONCLUSIONS

The amount of data generated by the simulation runs was considerable. A full analysis of every correlation is given in the main dissertation document (*1*). Only a few critical observations are shown in this paper.

The first conclusion that became evident was that the relationship between detector output variables and link travel characteristics is very link specific. Attempts to "normalize" the links (by dividing detector output by the number of lanes or downstream capacity) did not provide any more meaningful results. Therefore, further analysis was performed on specific links rather than the aggregation of all six links. Additionally, only two of the six links had any variability in link travel characteristics such as travel time, approach delay, and travel speed. Hence, only the relationships on these two links were analyzed using the regression tests. There was not a clearly "optimal" detector location for all links in all cases. The relationship between detector output variables and link travel characteristics is unique on each link and thus calibration is necessary for every link.

Table 1 is just one example of the numerous regression analyses performed on the data. Correlations of coefficients were calculated along with the P-value for both linear and quadratic relationships. The P-value represents the smallest level of significance that would lead to rejection of the null hypothesis. Finally, the residuals were examined. A residual is the difference between an observation and the corresponding estimated value from the regression model. A "yes" means that the residuals are normally and independently distributed with constant variance, abbreviated NID(0, (2), which is preferred.

In all regression analyses that were conducted, quadratic equations resulted in better statistics (high R-squared value, smaller P-values, and a "yes" for residuals) than did linear equations. The Table 1 data are examples. Table 1 demonstrates that detector Position A is the best location when detector volume is used to predict link travel time.

Table 2 lists the statistics for the best detector location for each combination of detector output variable and predicted link travel characteristic. For example, Table 2 demonstrated that Position A is best when detector volume is used to predict link travel time. These data are listed in the first two rows of Table 2. The remaining rows list the best detector location for other combinations of detector output variable and link travel characteristics. Two "best locations" are shown for occupancy predicting delay because the two locations are very competitive.

After complete analysis of the data, several conclusions were drawn about the relationships between detector location and link travel characteristics. These conclusions are supported by the data in Table 2.

Detector position A is a good predictor of link travel time, link travel speed, and approach delay when detector volume or detector occupancy are used as the independent variable. Detector position A is not a good predictor of travel time, link travel speed, or approach delay if detector speed is used as the independent variable.

Detector position D is a good predictor of approach delay when detector occupancy or detector speed is used as the independent variable. These conclusions are based on V/C ratios of up to 1.7.

TABLE 1 Regression Results for Link Travel Time vs. Detector Volume

Link	Position	Equation Type	R-Squared	P-value	Residuals?
1	A	Linear	94.6	0.001	No
		Quadratic	99.3	0.001	Yes
	B	Linear	86.4	0.007	Yes
		Quadratic	94.7	0.012	Yes
	C	Linear	79.3	0.017	Yes
		Quadratic	91.5	0.025	Yes
	D	Linear	62.0	0.063	Yes
		Quadratic	76.8	0.111	Yes
4	A	Linear	89.4	0.004	No
		Quadratic	99.5	0.000	No
	B	Linear	89.5	0.004	No
		Quadratic	98.5	0.002	Yes
	C	Linear	87.2	0.006	No
		Quadratic	97.5	0.004	No
	D	Linear	77.9	0.020	No
		Quadratic	88.9	0.004	No

Given the high degree of correlations found with detector position A, it was concluded that this position is more than adequate for modeling (predicting) link travel characteristics for recurring congestion based on traffic volumes. Detector positions C and D also showed very promising results for modeling link travel characteristics for recurring congestion based on average detector speed.

What this research shows is that significant thought and/or research must be given to locating system detectors for use in traveler information systems. There isn't a "one answer fits all" solution. Two factors that must be taken into consideration are locations of minor intersection signals and the locations of uncontrolled driveways with heavy traffic volumes that may skew vehicle speeds.

Calibration for each detectorized link will be necessary to obtain reliable information. Separate calibration may also be needed for each timing plan. There are far more variables that affect travel characteristics on arterial streets than on freeway segments.

Using similar analyses, the research also attempted to answer the question of how much detection is necessary on the network to provide accurate estimations of link travel characteristics. Is detection needed on every mile link? Or are detectors on links capable of estimating link travel characteristics on adjacent links?

When this hypothesis was tested, the results were inconclusive. For one of the links, there was a reasonably high correlation (although not as high as when the detection was on the link in question). However, for the other, the correlation was not as high. It is doubtful that detectors on one link would be able to provide consistent data on adjacent links.

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TABLE 2 Best Detector Location For Predicting Link Travel Characteristic

Detector Output Variable	Predicted Link Travel Characteristic	Link	Best Detector Location	R Squared	P-Value	Residuals?
Volume	Link Travel Time	1	A	99.3	0.001	Yes
		4	A	99.5	0.000	No
	Link Travel Speed	1	A	97.8	0.003	Yes
		4	A	99.3	0.001	Yes
	Approach Delay	1	A	96.9	0.005	Yes
		4	A	99.0	0.001	Yes
Sum of Occupancies	Link Travel Time	1	A	99.0	0.001	Yes
		4	A	99.7	0.000	Yes
	Link Travel Speed	1	A	96.3	0.007	Yes
		4	A	99.4	0.001	Yes
	Approach Delay	1	A	96.4	0.007	Yes
		4	A	99.0	0.001	Yes
		1	D	98.4	0.002	Yes
		4	D	99.1	0.001	Yes
Average of Occupancies	Link Travel Time	1	A	99.0	0.001	Yes
		4	A	99.7	0.000	Yes
Speed	Link Travel Time	1	C	98.9	0.0012	Yes
		4	C	99.4	0.0005	Yes
	Link Travel Speed	1	C	98.8	0.001	Yes
		4	C	98.9	0.001	Yes
	Approach Delay	1	D	98.9	0.001	Yes
		4	D	99.8	0.000	Yes

Note: In all cases the regression results are for quadratic equations