Development and Application of a Methodology Employing Simulation To Evaluate Congestion at School Locations

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A methodology was developed to evaluate traffic congestion at school locations during the morning hours, when parents drive their children to school. The methodology is applied at two school sites in the Auburn-Opelika area of Alabama, and involves the development of a simulation model in GPSS/PC that replicates existing traffic conditions. The model simulates the arriving of vehicles, their entering the school driveway, parking, or dropping off students, and leaving the school site. As a result of high interarrival rates and low service rates at the two school sites, queues form on the adjacent street and disrupt traffic. Following model validation, selected components were changed and their effect on queue length was determined. An evaluation of alternatives was conducted to reveal the best recommendations for alleviating the school congestion problems. It was concluded that the methodology developed is a very efficient approach, because conventional methods do not directly apply. The methodology can be used in similar situations in which queueing of vehicles occurs or when the traffic patterns are too complex to describe analytically.

Evaluation of traffic congestion at locations for which flow patterns are complex or unusual can be a very time consuming task if site-specific mathematical models are to be developed. At two school locations in the Auburn-Opelika area of Alabama (Wrights Mill Road Elementary School in Auburn, and Opelika Junior High in Opelika), congestion problems occur during the early morning and mid-afternoon hours when parents drive their children to and from school, even though school buses are available. After entering the circular driveway in front of the school, they stop, unload the children, and leave. The arrival rate, for the approximately 30 min before the classes begin, is very high, and the traffic volumes very much exceed the driveway capacity. The average interarrival time is 11.6 sec at the first school and 16.8 at the second, whereas the average service times are 122.0 and 81.9 sec, respectively. As a result, traffic queues build up on the street. Queue lengths as high as 17 vehicles have been recorded. Waiting times are also high, creating anxiety to the drivers, thus increasing the probability of erratic driving maneuvers and accidents. Because the roadways in front of the schools are two-lane and two-way, through traffic is also much affected. Consequently, there is a need to evaluate traffic movement at the schools, including the loading-unloading process.

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The development of a simulation model for each site was considered to be the most appropriate approach to the problem. Computer simulation can model unusual arrival and service patterns, provide detailed information about the process, and evaluate the effect of changes in the system. Thus after formulating and validating a simulation model that replicates a real-world situation, one can experiment with new alternatives economically and study their effects using the model before recommending a final solution. A literature search revealed that even though simulation has been widely used in traffic engineering, the study approach of developing site-specific simulation models to evaluate school zones or similar facilities has not been reported in the literature.

The objectives of this study were to develop a methodology employing simulation that can be used where queueing of vehicles occurs or when traffic patterns are complex or unusual. This methodology is demonstrated at two problem locations, and after examination of traffic and operating conditions, alternative solutions are identified, and the best one to alleviate the congestion problem is recommended. The two models were developed using the simulation language General Purpose Simulation System (GPSS/PC), student version, which runs on an IBM personal computer.

SITE DESCRIPTIONS

Wrights Mill Road Elementary School is located on Wrights Mill Road, a suburban two-lane two-way highway in southeast Auburn. Figure 1 shows the street layout in the immediate vicinity of the school. The width of the school driveway, which is one-way, is 5.2 m at its narrowest point, barely accommodating two passenger cars simultaneously. At all subsequent points, the driveway is wide enough to accommodate two cars.

The main queue builds up on the northbound approach. A smaller queue is created in the southbound lane. Sometimes two vehicles enter the driveway simultaneously, creating two lanes at the entrance. These eventually merge to allow for unloading at the sidewalk in front of the school building. At the driveway exit a police officer directs traffic because vehicles exit at a rate greater than the gaps on the highway can accommodate. In addition, many children cross the road at that point.

School employees account for about a fourth of the peak-hour traffic. Two parking areas totaling 61 spaces are accessible through the driveway. School buses constitute a negli-

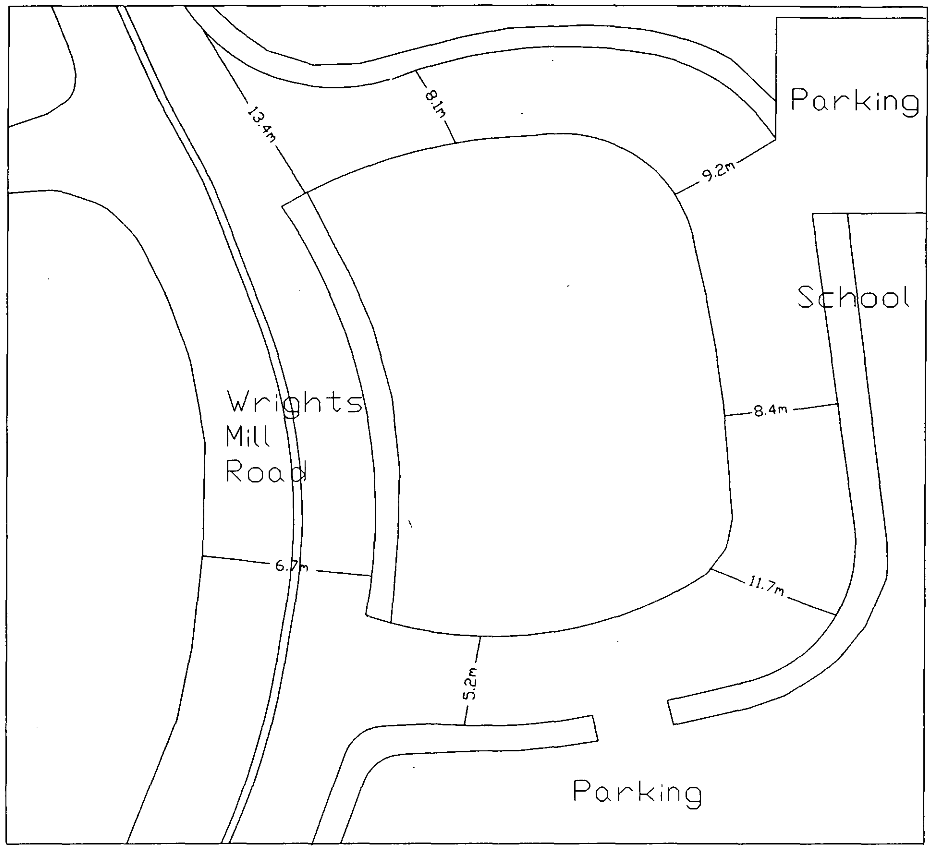

FIGURE 1 Wrights Mill Road Elementary School layout.

gible percentage of vehicular traffic, but they also must wait to enter the driveway. There is a reserved space for buses to unload in front of the school.

Opelika junior high school is located on Denson Drive at McLure Street on the north side of Opelika. Figure 2 depicts the street layout at the school. Although arrival rates during the peak hour are approximately the same for the two approaches, the major queue is formed in the northbound storage lane. Vehicles approaching the driveway entrance from the southbound lane have priority, and waiting times for them are much shorter. A small queue is occasionally created. Unloading is prohibited, except at the sidewalk in front of the school. However, many vehicles unload before reaching that point. As a result, a vehicle may block the entrance to unload while the driveway in front of it has cleared.

There are 60 parking spaces accessible from the driveway for school employees and visitors. Some vehicles pass through the parking area to unload, thus jeopardizing the safety of children who must cross the congested driveway to reach the school sidewalk.

A separate driveway is provided next to the exit of the school driveway for school buses only, which unload at the southern entrance to the school. Thus, they don't interfere with other traffic. Additional parking is also provided near the bus unloading area, which is accessible from a third entrance on Denson Drive.

DATA COLLECTION

In models of waiting line systems, the principal parameters are the interarrival and the service time distributions. From these two independent variables, other system parameters (queue length distribution, transit time distribution, etc.) can be determined. To define the two distributions, the time and license plate number of each vehicle were recorded as it joined the queue and entered and exited the school driveway. Traffic data were collected during the morning peak hour, including the buildup and dissipation of the queue. Weekday traffic operations at the school sites during the peak hours are repetitive; the same people bring their children to school at the same time throughout the school year. Therefore, data collection during one peak period was considered adequate. It is also noted that the data collected at each school site were used for the development of the model for only at that specific school.

MODEL DEVELOPMENT AND VALIDATION

Basic GPSS Modeling Concepts

In GPSS, models are built by selecting certain blocks from the available set and arranging them in a diagram, so that at

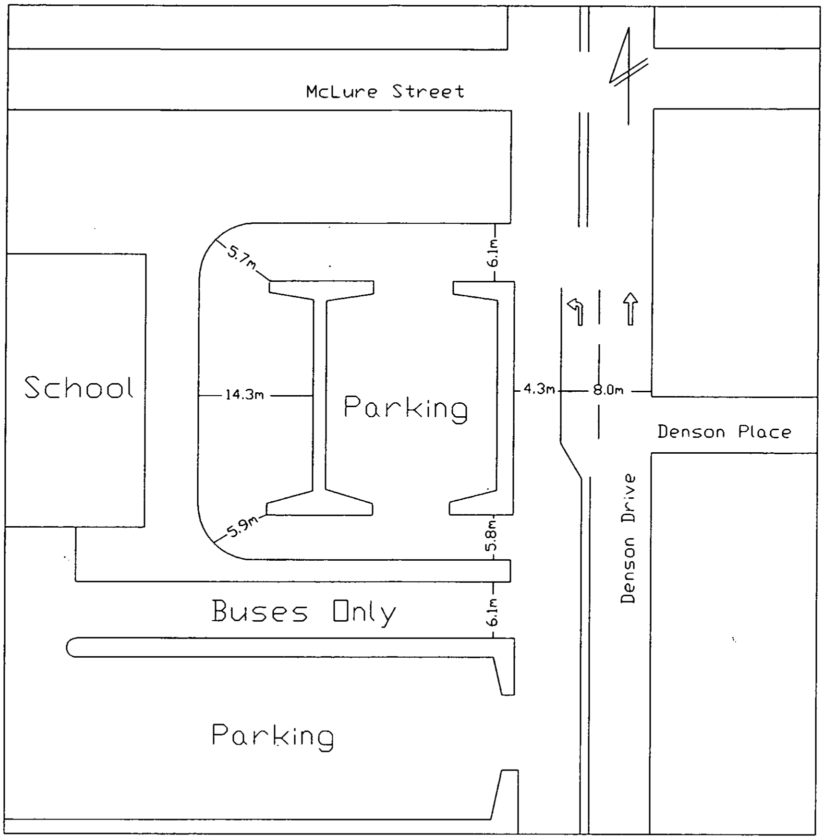

FIGURE 2 Opelika Junior High School layout.

the time of model implementation they (i.e., their images) interact meaningfully with one another (*1*). Blocks, the GPSS statements, represent actions or delays to be encountered by a set of transactions, which enter one block after another. Transactions are the units of traffic, which in the models developed for this study, represent vehicles. The GPSS processor maintains a simulated clock to provide a background for the represented events (*1,2*).

Transactions are brought into a model using the GENERATE block. The arguments of this block define the interarrival distribution. A model can contain many different GENERATE blocks. The TERMINATE block removes from the model the transactions that enter it.

Storages are used to simulate parallel servers. The ENTER and LEAVE blocks are used for the seizure and release of servers, respectively. The capacity of a storage is defined using the statement STORAGE *n*, where *n* is the number of servers. In the two school site models, a storage is used to represent the physical spaces available for service in the driveway. Each time a transaction vehicle enters the storage driveway, one server space is captured. When all spaces are captured, transactions are not allowed to enter the ENTER block. They are required to "wait" in the previous block until a space is available. Thus, waiting time characteristics can be identified. The ADVANCE block provides for the passage of time before a transaction moves to the next block. It is usually used to represent service time.

The QUEUE and DEPART blocks are used to gather statistics describing the involuntary waiting that may occur from time to time at various points in a model. When a transaction moves into a QUEUE block the event "join the queue" is simulated. Similarly, when a transaction moves into a DEPART block the event "depart the queue" is simulated. The two blocks are used as a pair in a model, thus queueing situations can be simulated.

Formulation of Models

Figure 3 shows a flow chart of the two models. For both schools, vehicles arrive and enter the driveway from two directions, which are included in the models. Vehicles enter one at a time, provided there is space available (defined as STORAGE in the programs). A percentage of them, the employees of the school, park (removed from the model). The rest drop off students and exit.

Some assumptions were necessary in building the two models to simplify the actual processes. For both models it is assumed that service time starts when a vehicle enters the school driveway and ends when the vehicle exits the driveway. It would not be feasible to distinguish between the waiting and unloading phases in the driveway, because unloading is not taking place at a specific location. The number of vehicles receiving service simultaneously represents the capacity of the

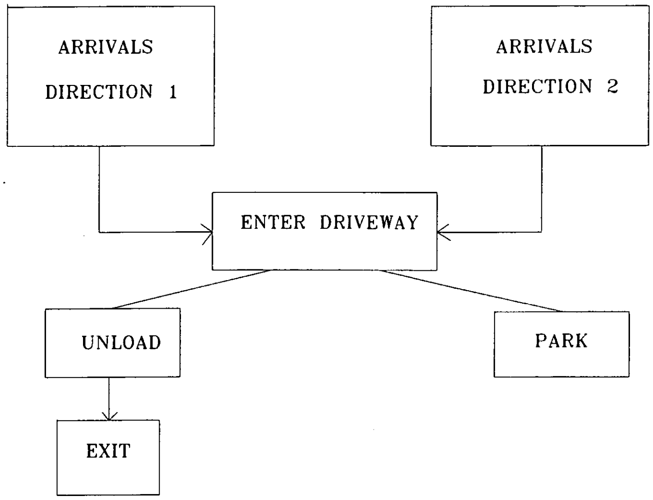

FIGURE 3 Model flow chart.

STORAGE in the models. That capacity is not a fixed number, but it varies over time depending mainly on the drivers, so that it cannot be analytically described. The number of vehicles in the driveway cannot be determined from the data, because, at any time, it is not known how many of the parking vehicles are still in the driveway. Therefore, the determination of STORAGE capacity was a trial-and-error process subject to realistic constraints.

For vehicles entering the driveway to park, it could not be determined how long they were actually occupying space in the driveway. Because they constitute a large percentage of the total number of vehicles, they could not be ignored either. Taking into account that this time is directly related to the service times of the other vehicles, it was assumed to be a fraction of service time. Depending on the location of parking spaces, a factor was determined for each school site, by which service times are divided, to determine the distribution of time spent in the driveway for parking vehicles.

As noted previously, at both school sites there were vehicles approaching from two directions to enter the driveway. Arrival times were recorded only for the direction from which the major queue formed. The minor queues were included in the models with the assumptions that arrival times were the recorded entering times and that the minor queues had priority. It was assumed that these vehicles didn't have to wait, but were entering the driveway as soon as they were arriving. That assumption does not account for the fact that a space may not be available at the time the vehicle arrives.

Random numbers are used in simulation models to create the impression that the value of the next draw from the distribution cannot be guessed (*2*). In GPSS the eight random number generators (RN1–RN8) each return an identical sequence of random numbers, unless their initial value is changed (using the RMULT statement).

Figure 4 presents the program simulating traffic operations during the morning peak hour at Wrights Mill Road Elementary School. Lines 10, 20, and 30 define the three empirical distributions used in the model: interarrival times for the major queue (Line 10), interarrival times for the minor queue (Line 20), and the service time distribution (Line 30). The second number of each pair is the end of an interval, and the first is the corresponding cumulative frequency. After a random number is drawn (0 to 0.99999), the cumulative frequency interval is determined, and a linear interpolation is performed between the pairs of points at the end of the interval. The intervals were established by sorting the data and arranging them into groups with equal numbers of observations. Different random number generators are used in each function to ensure that sampling is independent for the three distributions. In addition, in Statement 31, initial values are provided for the three random number generator, so that they will not use the same sequence of values.

The capacity of the driveway storage is nine vehicles. Transactions are generated over 23.5 min, or 1,410 sec, using a GENERATE-TERMINATE pair (Lines 190 and 200). Transactions enter the model through two GENERATE blocks (Lines 50 and 160). Line 50 represents the vehicles joining the major queue, and Line 160 represents vehicles arriving from the opposing lane. These two GENERATE blocks make use of the respective functions, ARV and SARV, to bring transactions-vehicles into the model. A maximum number of transactions to be generated is established to ensure that they don't exceed the actual number of vehicles in the system by more than 10 percent. As previously mentioned, transactions in the minor queue have priority in the model, because their arrival times are assumed to be their entering times.

Transactions attempt to enter the storage driveway in Line 70. If no space is available, they are required to wait at the previous block (QUEUE). At the QUEUE block, two queues are identified to distinguish between the major and minor queues, and statistics are gathered for them separately. As soon as a space is available, transactions ENTER the driveway and DEPART the queue. In Line 90, the TRANSFER block is used to remove from the model the 8.3 percent of the total number of transactions, which represents the through vehicles. Even though the through vehicles recorded were only in the northbound lane, in the program the percentage removed is of the total number of vehicles. This has a minor effect on the queue lengths and no effect on service times. It should also be noted that through vehicles in the model are waiting in the queue until a space becomes available in the driveway, whereas in the actual system they drive away as soon as they reach the beginning of the queue.

The TRANSFER block in Line 100 distinguishes between the vehicles that park (24.3 percent of the total) and those that exit the driveway. Those that part are staying in the driveway for one-third of the respective service time (Lines 35 and 110). In randomly selecting transactions to be transferred, the two TRANSFER blocks make use of the RN1 random number generator.

After staying in the ADVANCE block for their service time, transactions LEAVE the driveway (Line 140) and exit the model (Line 150). The blocks in Lines 45 and 210 to 230 are used to tabulate queue lengths every 30 simulated sec and provide the respective distribution.

The structure of the Opelika Junior High School program is similar to the program developed for the Wrights Mill Road Elementary School; therefore the program listing is not shown here.

```
;  GPSS/PC Program File A:WRFINAL.GPS     (V 2, #37804)    01-01-1980  01:02:17
10 ARV              FUNCTION    RN2,C14
0,0/.027,2/.062,3/.106,4/.46,5/.487,6/.549,7
.611,9/.752,10/.796,13/.85,15/.894,23/.947,39/1,115
20 SARV             FUNCTION    RN3,C9
0,0/.125,5/.25,8/.375,10/.5,60
.625,85/.75,290/.875,440/1,512
30 SER              FUNCTION    RN4,C17
0,62/.06,69/.119,84/.179,89/.238,93/.298,96
.357,108/.417,115/.488,125/.548,129/.607,133
.69,137/.75,145/.81,153/.869,161/.929,176/1,203
31          RMULT       31,859,565,117
35  PARK    FVARIABLE   FN$SER/3
40  DRV     STORAGE     9
45  INQUE   TABLE       Q5,0,1,25
50          GENERATE    FN$ARV,,,125
55          ASSIGN      1,5
60  WAIT    QUEUE       P1
70          ENTER       DRV
80          DEPART      P1
90          TRANSFER    .917,GONE
100         TRANSFER    .243,UNLD
110         ADVANCE     V$PARK
120         TRANSFER    ,GONE
130  UNLD   ADVANCE     FN$SER
140  GONE   LEAVE       DRV
150         TERMINATE
160         GENERATE    FN$SARV,,,8,1
170         ASSIGN      1,10
180         TRANSFER    ,WAIT
190         GENERATE    1410
200         TERMINATE   1
210         GENERATE    30,,16
220         TABULATE    INQUE
230         TERMINATE

Definitions
ARV:  Interarrival time distribution - Major queue
SARV: Interarrival time distribution - Minor queue
SER:  Service time distribution
PARK: Variable needed to define "service" time for parking vehicles
DRV:  Storage - Driveway
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FIGURE 4 Wrights Mill Road Elementary School simulation model.

Validation

Validation is the exercise of verifying that the outputs of the model are reasonable, given the inputs and processing steps in the system. That is, validation assures the analyst that the model behaves just as the real system should. Comparisons of sample statistics with model predictions reveal whether differences result from chance or result from inadequacies of the model (*3*).

The property selected for validating the models is queue length. Queue length is the most visible manifestation of traffic congestion and is much easier to measure in the field than delay is to measure. At the study sites, it was the long queue length that the public complained about and, because of safety, that the school administrators worried about. Of course, queue length is positively correlated with delay. Successive observations of queue length depend on their predecessors to some degree (*3*). This dependence of consecutive observations is called autocorrelation, or serial correlation, and may cause an error in the hypothesis testing. Therefore, queue lengths every 30 sec are determined and the respective distributions are compared.

It was found that traffic patterns were stabilized at each site, so care was also taken to ensure consistency in the simulated results. Because vehicles are generated by random sampling from empirical distributions, the simulated results used for validation must reflect stable traffic patterns rather than erratic traffic patterns. To accomplish this, each simulation model was run five times, using five random sampling schemes. Thus five queue length distributions were obtained.

A two-step hypothesis test was then performed. Initially a statistical comparison was made between the most representative simulated distribution and the observed distribution. The most representative distribution was defined by examining the sum of the absolute values of the frequency differences between the observed and each simulated distribution. The most representative simulated distribution exhibited the lowest value using this measure of effectiveness. A hypothesis test was performed between the most representative distribution and the observed distribution. If this test indicated good agreement between the two distributions, then a second hypothesis test was performed between the average of the five simulated distributions and the observed distribution. If the initial hypothesis test revealed significant differences between the two distributions, there would be no reason to perform the second test.

The goodness-of-fit of the simulated queue length distribution to the observed distribution was determined using the

Kolmogorov-Smirnov (K-S) test. The K-S test was selected because it does not lose information because of grouping, as the chi-square test sometimes does. Even though the K-S test is usually used when the variable under consideration has a continuous distribution, and queue length is not a continuous variable, the error that occurs in the resulting probability is in the safe direction: if the null hypothesis is rejected by the test, one can have real confidence in that decision (*4,5*). The K-S test is also statistically more powerful for the smaller sample sizes.

The K-S test was performed by specifying and comparing the cumulative frequency distributions of the observed and the simulated queue lengths. The point at which these two distributions show the greatest divergence was determined and was used to decide whether such a divergence is likely on the basis of chance. A two-tail test procedure was used. It was found that the model data reflect the observed distributions at a 95 percent level of confidence, and it was concluded that the models can be used to evaluate alternative traffic solutions.

SELECTION AND EVALUATION OF ALTERNATIVE SOLUTIONS

The effectiveness of alternative traffic solutions was tested using the models described in the preceding. The process involves the changing of a component of the system and the evaluation of its effect on the operation of the system.

It is required that the conditions under which experiments are performed be controlled as closely as possible. Thus, for the testing of each alternative, the same sequence of random numbers was used, for both the alternative and the original models. This ensures that the observed differences result only from changing the component being tested.

For the evaluation of each alternative, five simulation runs were made and compared with the field data to determine whether they were significantly different. The statistic used to test the effectiveness of the new system is the mean queue length. A hypothesis test for means is performed to determine if the mean of the alternative model queue length is significantly less than the queue length of the existing system. This implies a one-sided test procedure. Since the sample size (n) is large ($n>30$), the test statistic used is the standard normal distribution variable for sample means. The sample mean used in the hypothesis testing is the average of the five computer runs for the alternative system being tested.

Three alternative solutions were evaluated for each school:

1. Reduce the intensity of arriving traffic. This alternative is investigated to determine the impact of a shift in the arrival pattern of traffic. By this it is meant to urge or provide incentives to parents to arrive earlier. If, for example, the school is willing to accommodate children arriving earlier, many parents might be willing to bring their children earlier. Specifically, whether uniformly distributed interarrival times would reduce the average queue length was tested. The uniform distribution is a continuous probability density function used when an event occurs with equal probability between two extreme values, say a and b (*5*). The mean, m, and standard deviation, s, of the uniform distribution are:

$$m = (a + b)/2 \quad (1)$$

$$s = (b - a)/\sqrt{12} \quad (2)$$

Assigning the mean and the standard deviation of the uniform distribution to those of the existing interarrival time distribution, the parameters a and b are determined for the major and the minor queues.

Service times remained the same as in the original model, although if there are fewer vehicles in the driveway, the service times will be somewhat lower. All other components of the system, including the length of the simulated time, remained unchanged as well.

2. Increase driveway capacity. The effect of increasing the available space in the school driveway is tested. The only change to the original program listings is the statement where the capacity of the storage driveway is defined.

3. Remove Parkers. This alternative consists of separating those drivers parking at the school from those drivers unloading passengers.

CONCLUSIONS AND RECOMMENDATIONS

The methodology used in this study involved combining field data with simulation to produce a model that can be used to solve problems of traffic congestion. This method was demonstrated to address traffic problems at two school sites.

At Wrights Mill Road School in Auburn, the traffic congestion can be practically eliminated, if the interarrival times are more uniformly distributed, that is, if parents are urged to avoid the peak congestion time, which occurs from 7:19 to 7:32 a.m. The results of the simulation show that the predicted mean queue length will be 0.89 vehicle, which indicates that there still will be some vehicles waiting to enter the driveway and blocking through vehicles on the street. An additional right-turn bay with a capacity of 3 to 4 vehicles will eliminate that problem. It is recommended that parents be given incentives to avoid the 15-min period of peak congestion. In addition, a right-turn bay with a capacity of 3 to 4 vehicles should be constructed just before the entrance of the school driveway.

At the Opelika School it was determined that removing parking vehicles from the traffic that discharges passengers can improve the traffic conditions at the site. This means that parking spaces need to be relocated. There is additional available parking that can be accessed from a separate driveway, which leads to the south entrance of the school. These additional spaces can be used without causing any parking problems for the school employees. The parking spaces in front of the main entrance should be reserved exclusively for visitors.

It is concluded that development of a simulation model to investigate traffic congestion problems at school sties is a very efficient approach, particularly in cases for which conventional analysis (such as the HCM method) are not directly applicable. The methodology employed can be used in similar situations, such as where queueing of vehicles occurs or when the traffic patterns are too complex to describe analytically.

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