factors, as discussed elsewhere (5-7).

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Queuing at Drive-up Windows

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The development of drive-up windows may cause serious problems, where (a) additional fuel is consumed and pollutants are generated by vehicles, in queue, waiting to be served; (b) serious off-site operational problems may occur due to queued vehicles extending onto adjacent streets; and (c) queued vehicles often interfere with the use of on-site parking spaces. Queuing theory is used in the development of a procedure to identify and quantify the magnitude of the problems associated with drive-up windows. Estimated arrival rates and service rates are used to predict a failure rate, i.e., the percentage of time in which a queue length will exceed a selected length of queue. The average time of vehicles in the system, estimated from arrival and service rates, is used to calculate the amounts of air pollutants generated and the fuel consumed. An example problem is included. A brief description of applicable queuing theory is included. Some geometric design guidelines are suggested for the efficient on-site operation of drive-up windows.

The fast-food industry is booming. New businesses are springing up everywhere, and older establishments are adding services to stay competitive. One area where this affects the transportation system is in the development of drive-up windows. Many of these businesses seem to feel it is their inalienable right to have a drive-up window. The traffic engineer and planner have had very few tools to combat drive-up-window developments, which may have an adverse impact on area air quality, fuel consumption, smooth flow of vehicles on site and off, and/or use of on-site parking. Although many businesses, new and old, have adequately sized and shaped lots so that the drive-up-window queues can be handled without harm to other area activities, some do not.

The standing of operating vehicles in queue can cause problems, including consuming fuel and producing air pollutants. In addition, the cars in queue may stack up to the point that they block the flow on site. Of greater concern are those times when the queues extend into area streets. An ancillary problem is the loss of use of those on-site parking spaces adjacent to the area of the queue buildup.

The purpose of this paper is to provide tools that will quantify the impacts in terms that will be understandable to decisionmakers and to provide some guidelines for geometric design of facilities. This paper should assist in the development of local guidelines that will help in determining the situations where drive-up windows should or should not be allowed.

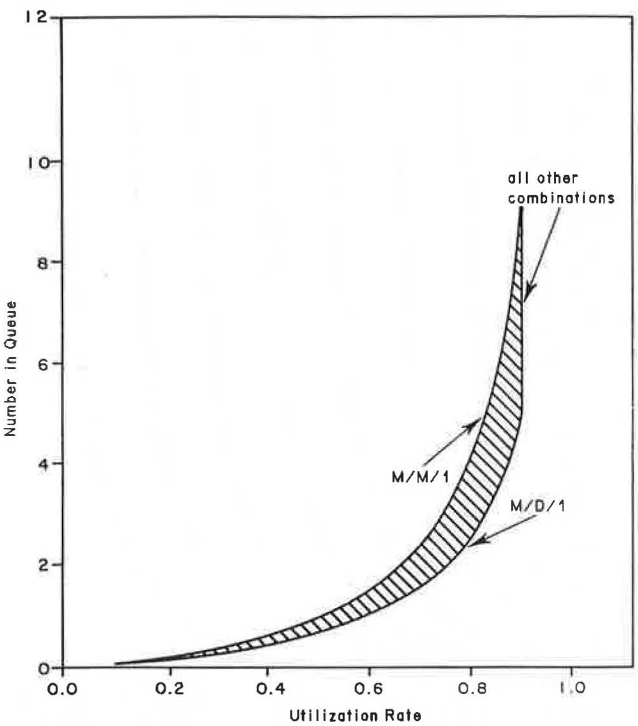
QUEUING THEORY

Queuing theory involves the mathematical study of waiting lines. [General discussions of queuing theory may be found elsewhere (1-3).] Customers show up at some arrival rate (λ) and then stand in the queue until assisted by a server. Service occurs at some service rate (μ). Both arrival rate (λ) and service rate (μ) are expressed as the number of activities per hour. The utilization factor (ρ) is the ratio of the arrival rate (λ) to the service rate (μ).

Every queuing situation can be described by using six descriptors. They are

1. Arrival time distribution--a mathematical description of the times between arrivals;
2. Service time distribution--a mathematical description of the times taken to serve customers;
3. Number of servers--in this case, number of service lanes;
4. Service discipline--in what order will the customers be served; the most popular is first come, first served;
5. System storage capacity--how many vehicles can fit in the area where the queue is located; and
6. Size of the customer population--how many vehicles there are in the community.

Figure 1. Utilization rate versus number in queue M/M/1 and M/D/1.



To simplify the procedures to be discussed, the following assumptions were made:

1. The arrival of customers at the queue is totally random. Each arrival is completely independent from every other.
2. There is a single service lane.
3. The service discipline is first come, first served.
4. The system storage is very large. In fact, it is of medium size. This variable applies to those situations where the area is critical.
5. The customer population is large enough to not affect the results, i.e., there are always cars available to join the queue.

Notation

The notation usually used is A/B/C, where A = arrival distribution, B = service distribution, and C = number of servers.

Distributions

There are a large number of distributions that can be used to describe the arrival and service rates. The primary ones include

M = Markovian (random),
E = Erlang,
H = hyperexponential,
D = deterministic (constant, every service takes the same time), and
G = general (includes those mentioned above plus all of the other possible distributions).

The study of queuing has found that, with Markovian (random) arrivals, the distributions for service rates that bound all of the rest are the Markovian and the deterministic (constant). Figure 1 shows a plot of the utilization factor (ρ) versus the average number of cars in the queue. Because the distribution of the service rates is unknown, the M/M/1 case is used, as it represents the worst case estimated of the queue length. The narrow width of the band between the M/M/1 line and the M/D/1 line provides confidence that the findings should be realistic. The margin of error is likely within that of the accuracy of the estimates of the arrival rates (λ) and service rates (μ).

Design Chart Development

The design charts were developed by using queuing theory for the M/M/1 case. M/M/1 denotes random arrivals and random service times with a single server lane. Figure 2 is a chart that will predict the number of cars in the queue from the utilization rate (ρ) and the percentage of time the system will be allowed to fail, i.e., the percentage of time the queue will be equal to or longer than the number shown. The chart was formed by using the following equation:

$$P(\geq k) = \rho^k \quad (1)$$

where P ($\geq$ k) is the probability of there being k or more vehicles in the queue, and ρ is the utilization factor. This form is a discrete function that has been converted to a continuous function for ease of use.

Figure 3 is a chart that uses the arrival rate (λ) and the service rate (μ) to find the average time the car will be in the system. It was made by using the following equation:

$$T = (60 \text{ min/h})/(\text{service rate - arrival rate}) \quad (2)$$

where T is the average time in queue (min).

PROCEDURE

This section outlines a suggested procedure for using Figures 2 and 3 to find queue lengths, quantity of pollutants generated, and the amount of fuel used.

Step 1: Data Collection

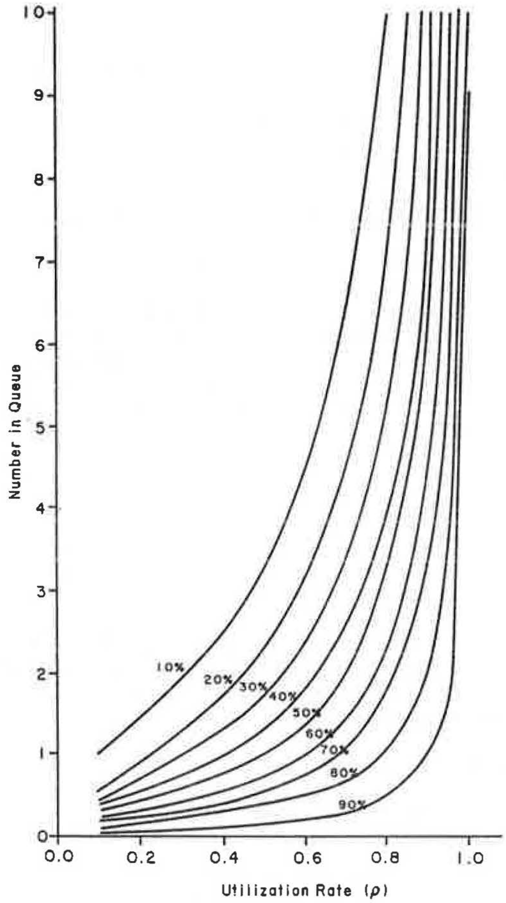
The design charts require the arrival rate (λ) and the service rate (μ) as inputs. Usually, the drive-up window under consideration has no history; therefore, data can only be estimated. If a similar establishment exists in the area, data can be taken at that site. Caution should be used when estimates of these values are provided by the developers, as they would most probably be more oriented to the furtherance of their case rather than the definition of reality.

Data should be collected for two time periods--one being the peak service use and the other being during the peak use of the surrounding streets. Data should be taken in 1- or 2-h blocks with subtotals every 15 min. Although the data are used as arrivals per hour, if the arrival rate varies greatly through the hour, a shorter time period may be required. For example, if the hourly volume is 30 cars, but during one 15-min period 12 cars arrived, the 12 cars/15 min should be expanded to 48 cars/h.

Step 2: Parameter Calculation

The determination of the service rate (μ) is dependent on the form of drive-up service. This paper is concerned with the single-service-lane case, but there may be multiple stations that deal with the lane. The two categories in the single-lane case

Figure 2. Utilization rate versus number in queues for various failure rates—M/M/1.

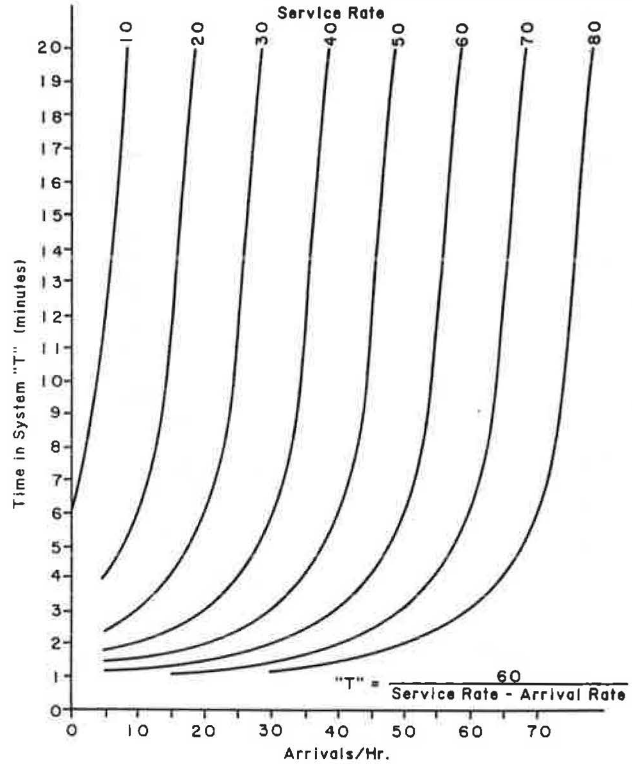


are the single-window and the multiple-window-in-series systems.

In the single-window system, the service rate may be found by taking the inverse of the window average time in minutes found while the system is working at full capacity. This answer would be in services per minute. Multiplying the answer by 60 min in the hour would provide the number of services possible in an hour.

The multiple-window system is actually a number of queues linked together. The provided equations and procedures will not be as accurate for this case, but the answers will be "ballpark" figures. Almost all of the existing systems have two stations. The first station is a menu board where the order is taken. At the second station the money is paid and the food is picked up. At least one national franchise is experimenting with a three-station operation: menu board, pay window, and pickup window. In either situation, the service rate is then used in the analysis. For example, the menu board rate is 120 services/h, and the window works at the rate of 70 services/h. The limiting factor is the window, where 70 services/h would be used as the service rate and the queue lengths found would extend back from the pickup window. If the numbers were reversed and the window was 90 services/h and the menu board rate was 60 services/h, the 60 services/h should be used in the analysis. In the case of the menu board being the limiting factor, the average time in queue found from the figure will be an underestimate. The desired queue length found in the figure will extend from the menu board.

Figure 3. Arrival rate versus time in system for various service rates—M/M/1.



Utilization Factor

The utilization factor (ρ) is found by dividing the arrival rate (λ) by the service rate (μ). For example, if the arrival rate is 45 arrivals/h and the service rate is 60 services/h, the utilization rate would be 45/60 = 0.75.

Failure Rate

The failure rate is a measure of the quality of the service provided. A failure is defined as any length of queue longer than the provided lane. A failure rate of 10 percent would mean that in every hour of operation the line will be longer than was provided for--one-tenth of an hour or 6 min. The failure rate chosen for a location should be related to the problems that would be caused by a failure. For example, if the failure of the queue will back onto an arterial during a peak driving period, a 1 percent failure rate may be appropriate. On the other hand, if failure just makes some of the parking spaces harder to use, a higher failure rate value could be used.

Step 3: Determining Queue Length

Queue length is found by using Figure 2. The values needed are the utilization rate (ρ) and the failure rate. The utilization rate is located along the bottom scale. A vertical line is extended until the selected failure curve is reached. A horizontal line is extended to the left until the vertical scale is intersected. The queue length may then be read. This value will be in a decimal form, like 3.7. Because 3.7 cars are hard to find, the value should be rounded up so that 4 cars are designed for.

If the queue length is known, and the utilization rate may be found or estimated, then this figure may also be used to determine the failure rate of the system.

Step 4: Determining Average Time in System

Average time in the system is used to estimate fuel consumption and the amounts of pollutants generated. It is found by using Figure 3. The input values are arrival rate and service rate. The arrival rate is located on the bottom scale, and a line is extended to the curve that corresponds to the service rate. The horizontal projection of that point gives the average time in the system in minutes per vehicle. Multiplication of this value by the arrival rate will give the total vehicle minutes per hour of standing. Division of this value by 60 will give the vehicle hours of idling per peak hour.

Step 5: Computation of Fuel Consumption and Emissions

The vehicle hours of idling per peak hour drawn from Figure 3 provide the basis for computing fuel consumption and emissions. This value is multiplied by the factors shown in the table below (4):

Item	Amount per Vehicle Hour
Fuel	0.65 gal
Carbon monoxide (CO)	2.43 lb
Hydrocarbons (HO)	0.16 lb
Nitrogen oxide (NOX)	0.05 lb

EXAMPLE PROBLEM

1. Step 1 (data collection): Data were taken at the site for 1 h. The resultant information is given below:

Vehicle No.	Arrival Time	Service Time (min)
1	12:00.5	0.9
2	12:05.2	0.3
3	12:05.9	1.5
4	12:18.7	4.4
5	12:27.5	4.5
6	12:29.6	2.6
7	12:30.4	2.0
8	12:37.3	3.9
9	12:38.4	3.0
10	12:45.4	0.5
11	12:48.7	0.4
12	12:49.4	0.9
--	13:00.5	--
Total		24.9

2. Step 2: The parameter calculations are as follows:

Mean service time = 2.075 min = 24.9/12.

Service rate (μ) = 28.92 vehicles/h = 60/2.075.

Arrival rate (λ) = 12 vehicles/h.

Utilization rate (ρ) = 0.415 = 12/28.92.

3. Step 3: The queue length determinations from Figure 2 are given below:

Failure Rate (%)	Figure 2 Value	No. of Spaces Needed
>50	0.85	1
30	1.4	2
20	1.9	2
>10	2.7	3
5	3.4	4
>1	5.3	6

4. Step 4: The time in the system determinations from Figure 3 are as follows: average time in system = 3.7 min, and total time in system = 44.4 vehicle-min/h.

5. Step 5: The fuel use and emission quantity calculations from the table in the previous section are as follows:

Item	Amount per Vehicle Hour
Fuel consumed	0.48 gal
CO	1.8 lb
HO	0.12 lb
NOX	0.04 lb

GEOMETRIC DESIGN CONSIDERATIONS

A search of the literature has found nothing concerning the geometric design considerations for single-lane drive-up windows at fast-food restaurants, banking institutions, etc. Some authors have discussed the trip generation rates for fast-food restaurants (5,6). Other studies have looked at multilane banking systems (7,8). Surely, some experience-based guidelines must have been written, but they have not made it into the standard traffic engineering references. Therefore, a list of general design considerations follow that are aimed at providing operational efficiency for single-lane drive-ups:

1. When facing the establishment, the drive-up should be located on the left side of the building. This location will result in a counterclockwise flow pattern with the maximum use of the available space and allow the longest queue. (The major problem with wrapping the queue around the building is the conflict with the pedestrians who use the facility.)
2. The drive-up-window operation should have at least two stations, one for ordering and the other for delivery.
3. Storage lengths for each station should be based on the arrival rate and service at that station. If the menu board is the critical activity in the system, then the queue storage for that area should be designed by using the outlined procedure. If the service window is the critical element, the combined service and menu queue length should be checked.
4. It should be noted that a drive-up facility may result in a reduction in the number of effective parking spaces on the existing property due to the queue blocking the parking spaces. Additional land might have to be purchased to meet the parking requirements in the subdivision and/or zoning regulations.
5. There should be a bypass lane or another convenient exit to an existing street so that vehicles not wanting to use the drive-up facility can leave the premises without passing through the drive-up window.
6. The drive-up-window lane should be a minimum of 12 ft wide from face-of-curb to face-of-curb.
7. The turning radius should not be less than 15 ft on any curve used in the drive-up operation.
8. The minimum vertical clearance should be 9 ft to accommodate recreational vehicles and vans.
9. Parking spaces located beyond the end of the drive-up window should be designated for use by those drive-up patrons whose orders are long in preparation. The driver would be told to park and the order would then be brought out to patron's vehicle.

NEEDED RESEARCH

The further testing and refining of the application of queuing theory to both single- and multiple-lane service systems is needed. Further development of the geometric design of parking and queuing areas is needed so that the interference of queued vehicles with the use of parking spaces and/or pedestrians can be minimized. Additional information for estimating arrival rates and service times is needed. The development of a microcomputer program to carry out the analysis would be desirable.

CONCLUSION

This paper has presented some tools and guidelines to help traffic engineers and planners understand the impacts of drive-up windows, as well as to suggest ways in which the negative impacts may be reduced.

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Influence of Arterial Access Control and Driveway Design on Energy Conservation

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Driveway design standards influence turning maneuver performance and are most critical on arterial streets. The speed disparity between outside lane arterial vehicles and driveway right-turn entry vehicles directly affects both operations and safety. This study used fuel consumption as a measure of effectiveness between minimum, typical, and desirable driveway design standards for the driveway right-turn entry maneuver. A simplistic model analysis illustrated the differences in fuel consumption incurred by arterial vehicles in the outside lane traveling at a given speed (i.e., 35 mph), which are forced to negotiate a deceleration-acceleration speed-change cycle due to right-turning vehicles that enter driveways that exhibit various levels of design standards. The results for the stated condition of 35-mph arterial speed indicate little difference in annual fuel consumption as influenced by design at an arterial-driveway hourly volume product of less than 100 000 vehicles. Between the 100 000 and 500 000 arterial-driveway hourly volume product range there is demonstrated fuel savings incurred through the institution of desirable versus minimum driveway design standards. Above a 500 000 arterial-driveway hourly volume product, the fuel savings are substantial and warrant the application of desirable driveway standards on all such facilities, with special consideration given to parallel deceleration right-turn lanes. Further research is needed to fully simulate and quantify the arterial-driveway traffic operational interaction for the right-turn driveway entry maneuver.

Ordinances that manifest regulatory policy and procedures for access control have been instituted in most U.S. cities with populations greater than 25 000 persons. These statutory guidelines have been based on safety and operational criteria that have served as the measures of effectiveness for driveway design on urban streets and highways.

Studies in Texas (1) have indicated that there exists a great inconsistency in the objectives of driveway regulations (safety, operations, etc.) and a general lack of uniformity in design standards and specifications. Table 1 (1) presents a summary of both commercial and residential driveway design standards from 34 Texas municipalities. As shown, there is a considerable range in both the importance associated with a specific driveway design element under regulation and the standard values designated to any particular element. Many cities assign absolute minimum and/or maximum design limits but do not state desirable design criteria. Most cities do not recognize the interaction between driveway design features. This seems to be reflective of national trends as well.

There is a need to relate the individual and interactive effects of standards for driveway design elements to a single measure of effectiveness. In recent years, energy conservation has become increasingly important as a measure of effectiveness to various federal agencies, as can be seen by the Emergency Energy Conservation Act of 1979 and Executive Order 12185 of the Federal Highway Administration (FHWA), December 17, 1978. The objective of this paper is to assess driveway design standards on arterial streets in terms of the affected operational speed differential between arterial vehicles and vehicles turning right into driveways of various design standards. Fuel consumption of arterial vehicles forced to decelerate due to driveway entry vehicles is calculated and compared for various design standards.

OPTIMAL DRIVEWAY DESIGN

Optimal driveway design, and subsequent turning maneuver performance, is extremely critical on arterial streets. Arterial streets constitute those streets without full access control that carry traffic entering, leaving, or passing through an urban area or intra-area traffic between the central business district and outlying residential areas, between major inner city communities, or between major suburban centers. Primary arterial streets serve very high traffic volumes at moderate speeds and are