Drive-Up Windows, Energy, and Air Quality

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The increasing popularity of drive-up windows as a means of conducting business brings with it questions of the best use of this kind of facility. In addition to studies on the best designs for drive-up facilities, there is the question of the fuel consumption and automobile emissions associated with this kind of operation. At what queue length would a driver save fuel by parking his car and walking into the facility to conduct business? What data and methods do policy makers need to be aware of to understand drive-up windows in the context of a fuel shortage or an air quality emergency? Data collected at a fast-food restaurant is used in this paper. It was found that a very large percentage of the fuel and emissions associated with the drive-up queue could be saved if people would forego the convenience and time savings usually provided by drive-up facilities.

Drive-in theaters and old-fashioned drive-in restaurants with carhops may have become a thing of the past, but other forms of transactions are being conducted directly from vehicles with increasing regularity. Many fast-food restaurants and banks offer a drive-up window, so that business may be conducted without ever shutting off the engine. Similar services, although not as common, are provided by dry cleaners and even funeral homes. The design *(1)* and queueing *(2)* aspects of drive-up service have been addressed in a number of papers. The issue of efficient use of motor vehicles in the drive-up environment is of special interest. Regarding fuel efficiency and vehicle emissions, is waiting in a line of vehicles to place and collect your fast-food order always better than parking your car and restarting it later? In an era of stable gasoline prices, this topic may sound anachronistic. However, air quality is an ongoing concern, and there may come a time when such information is again important to energy-conscious policy makers. In fact, for frequent patrons of establishments with drive-up windows, even a modest difference in fuel use may gradually add up to noticeable cost savings if they regularly apply the guidelines developed in this paper.

METHOD OUTLINE

The analysis begins with the accumulation of data regarding vehicle movements in the special environment of a drive-up facility. Certain kinds of data are needed regarding fuel consumption and vehicle emissions (by vehicle engine size, if possible) for

1. Idling mode,
2. Move-up movement in a queue, and
3. Restart of an engine that has been shut off for a specific length of time.

The intent is to combine the elements of a representative queueing model with data on vehicle operation and drive-up window service to develop relationships of the sort hypothesized in Figure 1.

It is likely that these relationships vary with vehicle size and type, and drive-up facility type, configuration, and service rate. Nevertheless, the goal is a simple, practical method whereby

1. An individual driver can make an informed decision as to whether to join a queue, park his car, or neither if his own fuel savings or reduction of emissions are his primary concern.
2. A public policymaker can use average or aggregated values to decide whether it is in the public interest under certain conditions (e.g., fuel shortage or smog alert) to encourage, prohibit, or revise drive-up operations.

The intended method is reminiscent of the rule of thumb concerning an idling automobile engine at a railroad grade crossing blocked by a passing train. The suggestion is to estimate how long the car has to idle, and if that time exceeds some critical value, the engine should be shut off to save fuel. This critical value has been given as anywhere from 30 sec to 2 min, but it is apparently not documented.

DATA SEARCH

The vehicle performance data needed for this analysis are rather specialized, and therefore difficult to obtain. At the time

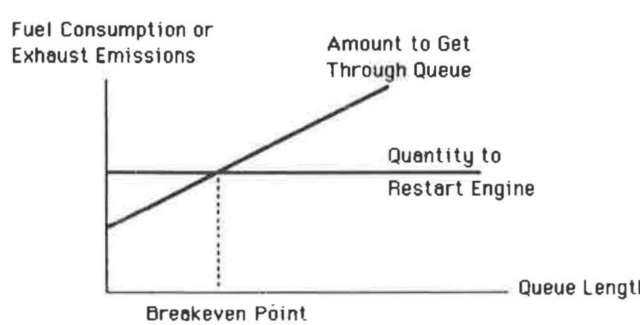

FIGURE 1 Queue length at which idling becomes ill-advised.

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of this study, idling fuel consumption and emission values were available from several reports *(2–9)*, but these were sometimes based on vehicles manufactured in earlier years. The move-up and restart values were especially hard to find, but after a lengthy literature search and a series of telephone calls to fuel and emissions experts, the values in Table 1 were adopted. The numbers shown are the result of an effort to translate existing data into numbers that fit the specific modes of vehicle operation pertaining to this study.

TABLE 1 FUEL CONSUMPTION AND EMISSION RATES

Operation Mode	Fuel Use	Exhaust Emissions HC	CO	NO_x
Idling	0.65 gal/hr[a]	0.16	2.43	0.05 lb/hr[a]
Move-up	0.002 gal/cycle[b]	0.2	2.31	0.045 lb/hr[c]
Restart	0.0017 gal/start[b]	0.0036	0.005	0.0002 g/start[d]

[a]See *(6)*.
[b]See *(3)*.
[c]See *(1)*.
[d]See *(5)*.

An interesting immediate finding is the extremely low fuel requirement for a "hot start," that is, an engine restart within an hour after turnoff. At 0.65 gal/hr (Table 1), a car can idle for only 9.4 sec before exceeding the fuel needed to restart. In fact, according to Claffey *(3)*, 0.0017 gal per start may be a high estimate for hot starts:

> The engine draws no fuel from the carburetor bowl during engine cranking operations. Apparently the engine starts using fuel vapor already in the firing chamber or in the intake manifold. This could be a helpful note for fuel conservation, since drivers should not hesitate to turn off their engines instead of letting them idle at stops because they mistakenly think extra fuel will be used to crank the engine to re-start.

Although the fuel breakeven point is only 9.4 sec, the breakeven points for emissions are also surprisingly low: 5.6 sec for hydrocarbons, 61 sec for carbon monoxide, and 31.5 sec for nitrogen oxide. If fuel saving and air quality are an individual's top priorities, parking the car and walking into the restaurant is the obvious choice. Note that subsequent to the completion of this study, a report on passenger vehicle fuel consumption and emission estimates *(10)* was published, citing values in substantial agreement with those used in this paper.

The extent to which actual usage of drive-up facilities consumes fuel and adds to air pollution remains to be determined. Generally, such facilities are of considerable convenience and time savings, but at what cost? For the fast-food restaurant shown in Figure 2, 245 vehicles were observed entering the parking lot during the two noontime hours in which data were collected. The data collection was undertaken as follows:

1. Record the license plate number of an entering vehicle and its time of entry.
2. If the vehicle joins the drive-up queue, record that time and the number of vehicles ahead of it before the ordering location.

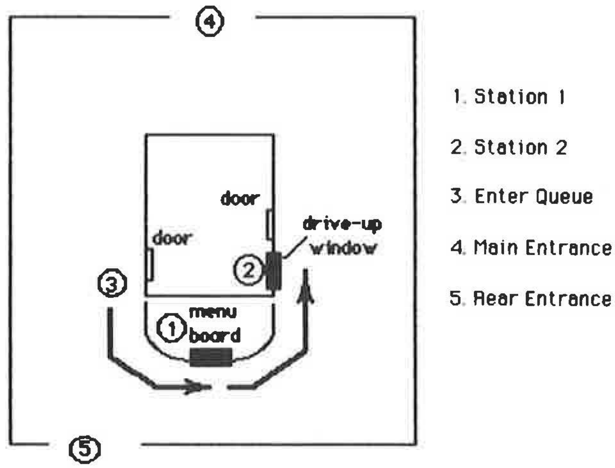

FIGURE 2 Layout of a drive-through facility.

3. After an order has been placed, record the number of vehicles queued at the pick-up window.
4. Record the time at which the vehicle leaves the pick-up window.
5. Record the time at which the vehicle leaves the parking lot.

Based on observations made October 2, 1984, it was determined that

- Total number of vehicles using the drive-up facility during the 2-hr period of observation was 131 (53.5 percent of the 245 arrivals);
- Average elapsed time between entering and leaving the parking lot for customers who ate inside the restaurant was 21.85 min;
- Average elapsed time between entering and leaving the parking lot for users of the drive-up facility was 3.73 min or 223 sec;
- Average time spent in the drive-up lane was 3.54 min or 212.6 sec;
- Average time spent in the drive-up lane, if there was no queue at Station 1 at the time of arrival was 113 sec;
- Average queue length at Station 1 (the menu board) was 1.65 vehicles; and
- Average queue length at Station 2 (the pickup window) was 1.46 vehicles.

A convenient way to measure service rate at Station 2 is in terms of the rate at which vehicles leave the pick-up window, as long as a queue continues to exist. For the facility we observed, this service rate is 71.7 vehicles per hour, or an average service time of 50.2 seconds per vehicle. Because a vehicle approaching Station 1 with no queue can expect to spend 113 seconds in the drive-up lane, the service time at Station 1 can be defined as:

$$1/\mu_1 = 113 \text{ sec} - 50.2 \text{ sec} = 62.8 \text{ sec}$$

This translates into a service rate, μ_1, of 57.3 vehicles per hour.

The data also helped to determine that the average vehicle experiences 4.04 moveups in the drive-up lane. The time not spent moving up is spent idling, at 0.65 gal/hr. No driver was ever observed shutting off his vehicle's engine while in the queue. Additional data collected indicated that it required an average of 8.4 sec per moveup in the queue. These values are used to modify idling time, to avoid double counting:

Moveup time: (131 vehicles x 4.04 moves/vehicles x 8.4 sec/move)/2 hr = 2222.8 sec = 0.6174 hr.
Total time spent (per hour) in drive-up lane: (131 vehicles x 212.6 sec)/(2 x 3600 sec/hr) = 3.868 hr.
Total idling time: 3.868 hr – 0.617 hr = 3.251 hr.
Values from Table 1 can then be used to carry out the following calculations:
Fuel consumption during moveups: (131 vehicles x 4.04 moves/vehicles x 0.0002 gal/move)/2 hrs = 0.0529 gal/hr.
Fuel consumption during idling time: 0.65 gal/hr x 3.251 hr = 2.113 gal.

Table 1 then allows an estimation of noon hour emissions.

Carbon monoxide (CO): (2.31 lb/hr x 0.6174 hr) + (2.43 lb/hr x 3.251 hr) = 9.326 lb
Hydrocarbons (HC) (0.2 lb/hr x 0.6174 hr) + (0.16 lb/hr x 3.251 hr) = 0.6436 lb
Nitrogen oxide (NO_x): (0.045 lb/hr x 0.6174 hr) + (0.05 lb/hr x 3.251 hr) = 0.1903 lb

QUEUEING MODEL

It would be more convenient if the vehicle movements observed and translated into energy and emission values in the detail shown in the preceding section could be approximated through use of an appropriate model. The data collected for the calculations required five observers. With only one or two observers, it would be possible to develop a dataset adequate for use in a queueing model intended to represent the operation of the drive-up facility. The average arrival rate λ (vehicles per hour) and service rates μ_i (vehicles per hour for each service location or station i) can be based on data collected with moderate effort at the stations. These parameters λ and μ_i are sufficient, under the proper conditions, to form the basis for a useful queueing model.

The queueing process at a drive-up window, shown in Figure 2, is a special case of an open Jackson network *(11)* in which all the departures from service station i go to service station i + 1, i < k, and the departures from station k leave the network. This type of network is called tandem. Most of the existing fast-food systems have two stations for drive-through service such as a menu board and a pick-up window (Figure 3). Tandem queueing models have been used to model traffic flow with k = 2.

Under the following assumptions, a tandem queue with k = 2 can be satisfactorily modeled by standard queueing equations: (a) $\lambda < \mu_1$, (b) $\lambda < \mu_2$, (c) $\mu_1 < \mu_2$, where (d) interarrival and service times are exponentially distributed and (e) independent of each other, and (f) the queues have infinite capacity. However, it is quite likely that none of these conditions (a) through (f) will hold throughout a typical peak period at a two-station fast-food tandem queue:

- For (a) and (b), peak period vehicle arrivals frequently exceed the service rate of Station 1 or Station 2, or both. In the case study, $\lambda > \mu_1$.
- For (c), Station 2 is normally where the food is both paid for and picked up. Together, these two activities often take more time than placing an order at Station 1.
- For (d), (e), and (f), arrival times can be affected by traffic controls or conditions on the adjacent streets, biasing the interarrival time distribution. Furthermore, λ at Station 2 equals μ_1 during peak periods, which may transmit any bias in the λ at Station 1. Finally, it is common for $\mu_2 < \mu_1$, causing the Station 2 queue to grow and prevent service at Station 1. If an excess queue between Stations 1 and 2 develops, this is known as a tandem queue with blocking. This is a very difficult problem, for which no solution technique has yet been published.

The recent introduction of three-station systems, with separate windows to (a) take money and (b) deliver the order, may lead to cases in which $\lambda < \mu_1 < \mu_2 < \mu_3$ holds a significant fraction of the time, but this has not been studied. For most cases, queueing analysis using standard expressions based on λ and μ_i must be replaced by simulation or graphic techniques. For this paper, conclusions will be based on the data collected.

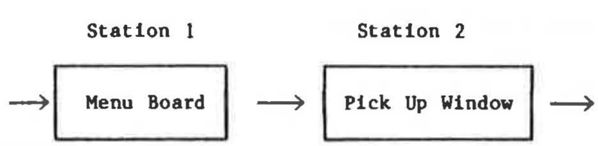

FIGURE 3 Queueing process of drive-up window service.

SERVICE AND QUEUE TIME

It is unlikely that any significant number of individuals will forgo any time savings and convenience that use of a drive-up window may offer, just to reduce fuel use and exhaust emissions. This section considers the time factor, as well as the fuel and air quality costs that follow from a decision to use the drive-up facility. Table 2 gives the average time spent for a range of queue lengths in the two-station drive-up lane that was studied. The duration in the lane increases at a decreasing rate up to a queue length of four. The expected time actually decreases somewhat, which must be explained by the small number of observations at longer queue lengths. Any time value in Table 2 can be converted into fuel and exhaust emission equivalents, as was demonstrated earlier in this paper.

Based on Table 2, if a driver approaching Station 1 (the menu board) is not willing to spend more than 4 minutes in the drive-up system, that person ought not to join a queue at this menu board if it is of size two or larger. From the point of view of fuel consumption, even if a driver approaches the menu board unimpeded, he is destined to burn more than 10 times as much fuel (0.0210/0.0017) as if he had parked.

IMPLICATIONS

The rule for an individual's decision to use a drive-up facility is clear cut: If fuel saving and air quality are most important, park

TABLE 2 AVERAGE TIME SPENT IN DRIVE-UP FACILITY

No. of Cars in Station 1 Queue	Total Time in Drive-Up System (min)	Fuel Use Idling (gal)	Fuel Use Moving Up (gal)	Total Fuel Consumption (gal)
0	1.88	0.0190	0.002	0.0210
1	2.83	0.0261	0.006	0.0267
2	4.00	0.0358	0.010	0.0458
3	4.48	0.0380	0.014	0.0520
4	5.01	0.0422	0.016	0.0582
5	4.85	0.0389	0.018	0.0569
6	4.60	0.0347	0.020	0.0367

the car and walk in. Usually, however, time and convenience are more important to the individual. A queueing analysis of the service for walk-in customers would provide the basis for a comparison with Table 2, leading to an informed time-minimizing decision.

To society as a whole, drive-up services translate into greater fuel use and automotive emissions. For the 2-hour case study described in this paper, the vehicles in the drive-up line burned fuel at a rate of 2.1659 gal/hr, which is 2.113 gal/hr for idling and 0.0529 gal/hr to move up, as calculated earlier in this paper. An average of 65.5 restarts per hour translates to 0.1114 gal/hr, which is only 5 percent as much. The Lafayette, Indiana, area (population 75,000) has over 50 drive-up windows at restaurants, banks, and dry cleaners. Expanding the scope of the analysis to the full business day leads to a potential fuel saving of several 100 gal per day in this area alone.

The closing of drive-up facilities will not yield the same reductions in energy waste and air pollution as a successful ridesharing program. Neither is it likely to be well received by the businesses involved or their customers. (Exceptions could be made for handicapped individuals, in the same spirit that parking spaces are reserved for them.) However, in a serious energy or air quality emergency, this kind of operation should be asked to make a contribution to the community's welfare. A 95 percent saving with few hardships, even in an activity of modest scale, should not be overlooked.

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