TIME-MOTION RELATIONS IN OPERATION OF GARAGES

EDMUND R. RICKER, *Traffic Engineer*
New Haven, Connecticut

The parking problem robs us of the primary attribute of the private automobile - its capacity for speed, or more exactly, the reduction of travel time. The majority of trips have been found to be relatively short in length, and a large proportion of them have the downtown district of a city as their destination. Perhaps it is reasonable to say that the average time-length of such trips is not over 30 minutes. Upon arrival in the downtown area, the driver is faced with a choice of either a great deal of milling around to find a curb space near his own destination, or of placing his car in an off-street facility. If he chooses the curb stall, he must often search through several extra blocks of congested traffic, and then accept a rather severe limitation of the duration of his stay. If he chooses an off-street lot or garage, he loses the ready accessability of his car, and must spend a considerable period waiting for its acceptance and delivery. In either case he adds materially to the time-length of his trip. While the time consumed in parking and unparking may not be large in absolute terms, or in comparison to the time saved over horse-and-buggy transportation, it is large enough to cause the motorist to seek other means of transportation or other destinations. He compares the time of waiting for his car to be delivered from a garage - in some cases 20 or 30 minutes - with his known experience of less than two minutes to remove it from the family garage, or less than one minute to unpark from a curb stall.

Public officials and businessmen alike are dedicated to the maintenance and improvement of downtown business areas through the provision of additional off-street parking facilities. It is of the utmost importance that these new facilities be sound financially and also meet the demands of motorists, i.e., that people not only be attracted into the center of the city, but that the accommodations provided be demonstrably more desirable than the alternatives at the curb. The factors which attract parkers into off-street facilities may be summarized as:

1. Location nearby the destinations of the motorists.
2. Low parking fees.
3. Attractive appearance.
4. Protection from weather, theft, and damage.
5. Rapid service in acceptance and delivery of cars.

It is the belief of the author that the last-named factor - rapid service - is the most important. The element of time saving is common to all the other factors, since efficient operation is necessary if parking fees are to remain low, and on the other hand, hasty operation, which may result from trying to "push" an inadequate design, will result in minor accidents and a dangerous-appearing operation.

With this in mind, a research project was undertaken at the Yale Bureau of Highway Traffic to study the design of parking garages as it affects the time of handling incoming and outgoing cars.[1] Field observations were made in numerous parking lots and garages to evaluate the various design

[1] For a complete report of this research refer to THE TRAFFIC DESIGN OF PARKING GARAGES published by the Eno Foundation for Highway Traffic Control, Saugatuck, Connecticut.

features and operational methods. Time-motion studies were made on the critical operations to determine their relative importance, and to compare different parking arrangements and types of design. Parking lots are conceded to require less time than do garages for the handling of cars, as well as being cheaper and more readily created. In these studies, more attention was given to garages because of the greater complexity of the traffic design.

In this paper, primary consideration is given to attendant-parking garages, because the operations are more complex, and time savings are important to attendant efficiency as well as customer satisfaction.

ACCEPTANCE OF CARS

In the acceptance of cars into a garage, the operations may be broken down into two classifications - those which entail the customer's time, and those which may be carried on independently of his presence. The first has the smaller time value, and seldom requires the customer to stay in the garage more than a minute. The steps may be described briefly as follows:

1. The customer drives into the garage. If the storage of cars is proceeding smoothly, this step merely involves the travel time from the street into the reservoir space at low speed. The time value may be a matter of 5 to 15 seconds.

2. A garage employee issues an identification ticket. Various types of tickets are used, but practically all have the common features of a receipt issued to the customer, a section placed on the car, and a section marked with the car registration and stall location which is filed in the cashier's office. The issuance of a ticket requires time stamping, writing down of the car registration, tearing the ticket into sections, and placing these in their proper place. A good floor man will issue an average of 120 tickets per hour, or at a rate of 30 seconds per car.

3. The customer, after accepting his receipt, leaves the garage. Most customers will leave immediately, particularly those who park in the garage regularly, or who are on business trips. Others, such as shoppers and hotel patrons may spend considerable time unloading passengers and bundles. In the latter case, the car cannot be stored until they have finished.

It may be seen then that the steps involving the customer are simple, that he is doing something all the time, and, in general, this process is quite satisfactory from the customer's point of view.

MOVEMENT TO STORAGE FLOORS

Let us now turn attention to the movement of cars to the storage floors, which may be considered almost separately from the steps described above. The procedure in a typical garage may be described as follows:

1. A driver employed by the garage (hereafter termed an attendant) gets into the car and starts the motor. This soon becomes a standardized operation to experienced attendants, in spite of the differences between various makes and models of cars. The average time required is 8 seconds.

2. The attendant drives the car along the main floor and up or down the ramps to the storage floors. The travel time on the main floor depends upon the location of the car relative to the ramp, but in any event, is of small duration. The travel time on the ramp is more interesting - and more important.

The type and location of ramps is the governing factor in the layout of most garages. Many different kinds have been patented and built, each having its advantages and disadvantages. The choice for a particular garage, however, must be based on the shape and layout of the land parcel. No one type of ramp is superior to all others, and a garage designer should be familiar with each type in order to select the one most suitable for a particular garage. There are two general classes of ramps. One, which may be termed the "clearway", provides a completely separate path for vehicles traveling on the ramp from that of vehicles being parked and unparked. The other is the "adjacent parking" type, in which parking stalls are placed along the ramp, and the ramp is in effect used as an aisle for these stalls. The travel time on clearway type ramps is smaller and more consistent, since there is no interference from other vehicles and a fairly uniform speed may be maintained. Speeds of 10 to 15 mph. are common, with an average floor-to-floor time of about 12 seconds. When cars are not being moved into or out of the stalls abutting the adjacent parking type, these ramps may operate with almost the same efficiency as the clearway type. It is obvious, however, that serious delays may be incurred due to a blocking of the ramp whenever cars are parked or unparked. This delay is difficult to measure accurately, due to the unpredictability of its occurrence and the irregularity of arrivals of successive cars on the ramp. Measured in an overall effect for the average travel time of all cars moving on the ramp, it was found that the travel time might be increased from 15 to 30 seconds due to this kind of delay.

The ineffectiveness of fast driving on the ramps is easily demonstrated. In one garage studied, the differences between normal driving and "fast" driving, as evidenced by the squealing of tires, was found to be less than one second per floor. Other factors which affect ramp operating speeds and convenience of operation are: amount of curvature, superelevation, and sight distance at approaches to storage floors.

3. The attendant drives along the aisles of the storage floor until he reaches the stall in which he parks the car. Driving speeds on the storage floors were found to average 9 mph. The actual time spent depends upon the length of the aisles, that is, how large the garage is, and the type of car location system used. When attendants are allowed to place the car in any convenient stall they may sometimes save time, but during busy periods may use extra time in finding an open stall. Further, they must mark the location of the stall on part of the identification ticket and return it to the cashier's office. On the other hand, if the cars are placed in pre-assigned stalls, the attendant may drive directly to that stall with assurance of finding a vacant space and does not have to perform any location bookkeeping. The time of driving on the floor may occupy a period of 4 to 25 seconds.

4. The attendant parks the car in the stall. It can be shown geometrically on the basis of car dimensions and turning radii that, for parking at 90 deg. to the aisle, considerably less space is required to back cars into stalls and drive them out than to drive in and back out. This is also confirmed on the basis of experience and operating time. In all garages observed, parking stalls were placed 90 deg. to the aisles and cars were backed in. A few minor exceptions were noted because of special layouts near corners, ramps, or columns. The parking time varies inversely with the width of the stall and the width of the aisle. With adequate dimensions for safety and convenience, a reasonable average parking time is 18 seconds. With inadequate space, parking time may often be increased to a matter of several minutes, depending on the number of passes required to wedge a car in between other cars or building restrictions.

5. The attendant turns off the motor, pulls up the handbrake, and gets out of the car. This is another operation which soon becomes automatic, and will average six seconds.

6. The attendant notes the location of the car on the office stub of the identification ticket, if this system is used. A reasonable time may be about 15 to 30 seconds. However, it may be considerably less as the attendant will often write this information down while walking away from the car or while waiting for an elevator.

7. The attendant walks to the interfloor driver travel means. The walking speed of attendants was found to be about five feet per second. In some garages the elevators or stairs were placed in a remote corner, apparently to save parking

space. This is a false economy since these interfloor driver travel means are a center of activity and the attendant must spend a large part of his time walking to and from them. From this point of view they should be placed at the centroid of the parking area, with free access to all aisles.

8. The attendant goes down the interfloor driver travel means to the main floor. The average travel time per floor on a stairway is 12 seconds. The travel time on passenger elevators varies with the speed of elevator, the number of elevators, and the distribution of parking stalls between the various floors. It will average perhaps one minute per trip, including waiting time. The travel time on service elevators or man lifts is about six seconds per floor. The travel time on fire poles is about two and one-half seconds per floor.

9. The attendant walks to the reservoir space for another trip.

The entire time required for storage of an individual car may be seen to average about three to four minutes. This corresponds to an attendant handling rate of fifteen to twenty cars per hour. The total number of cars handled in a given period can be obtained by multiplying this rate by the number of attendants.

RESERVOIR SPACE

The relationship between the time required for the customer to leave his car and for the attendant to remove it to the storage floor is concerned with the operations in the reservoir space. Thus it may be readily seen that the reservoir space is the most important single area in the garage. When it is full, customers must wait in the street before entering the garage, regardless of the number of cars already stored, and this adds directly to their waiting time and dissatisfaction with the parking operation.

A theoretical basis for determining the capacity of reservoir space has been worked out and has been checked emperically against the few garages observed to have adequate reservoir space. The storage of cars in a garage may be thought of as a kinetic problem of the rate of arrival and the rate of storage, rather than the static problem of total number of cars stored. From parking surveys and experience in similar garages an estimate can be made of the expected arrival rate -- that is, how many cars per hour will be presented for storage. For a garage which is in the design stage it may be difficult to determine the exact time required to store each car. However, it is certainly reasonable to assume that enough attendants will be hired so that the average rate of storage will equal the average rate of arrival. If this is the case, then the reservoir space need only be adequate to store the cars which arrive at momentary rates higher than the average rate. Studies were made of the arrival times of cars in garages and it was found that they arrived on a random basis which could be described through the theory of probability or Poisson's Law. In applying this theory, it is necessary to select an arbitrary degree of perfection, that is, the percentage of time that over-filling of the reservoir will not be allowed.

AN APPROXIMATE SOLUTION OF THE RESERVOIR PROBLEM[2]

Consider an interval A of time. Let it be assumed that the probability that x cars arrive at the reservoir during A is given by the Poisson distribution:

$$\frac{e^{-m}m^x}{x!} \qquad (x = 0,\ 1,\ 2,\ \ldots) \qquad (1)$$

The rate of removal of cars from the reservoir will be represented by m'. L will represent the reservoir's capacity.

It is desired to know the probability that the reservoir will never be overfilled during A and to know how large L should be (when m and m' are given) in order that the probability of no overfilling be equal to some preassigned probability, say 0.99. Approximate answers to these

[2]The author is indebted to David F. Votaw, Instructor in Mathematics, Yale University, for the derivation of the formulas shown in this section.

questions will now be given.

The probability of no overfilling equals approximately

$$\sum_{x=0}^{L+m'} \frac{e^{-m}m^x}{x!} \qquad (2)$$

The expression in (2) is closely approximated by the cumulative normal (Gaussian) distribution when m is large (say 30 or more).
We have:

$$\sum_{x=0}^{L+m'} \frac{e^{-m}m^x}{x!} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{L+m'-m}{\sqrt{m}}} e^{-u^2/2}\,du. \qquad (3)$$

In obtaining (3) from (2) one makes use of the fact that the mean value and standard deviation of x are m and $\sqrt{m}$, respectively.

Using tables of the normal distribution we have that when m is large and the probability of no overfilling equals 0.99,

$$\frac{L+m'-m}{\sqrt{m}} = 2.4; \text{ and so}$$

$$L = (2.4)\sqrt{m} + (m-m') \qquad (4)$$

APPLICATION OF RESERVOIR SPACE FORMULA

The relationship between the capacity of reservoir space, rate of arrivals, and rate of storage is shown in Figure 1. The central curve represents the desirable condition, wherein the average rates of arrival and storage are equal. This may be represented by the formula:

$$L = 2.4\sqrt{m}$$

Where L = capacity of reservoir and
m = average rate of arrival.

As an example, if the expected arrival rate is 100 cars per hour, the reservoir should have a capacity of $2.4\sqrt{100}$ or 24 cars.

The upper and lower curves in Figure 1 illustrate the conditions where the rate of storage is 0.9, 0.95, 1.05, and 1.1 times the rate of arrival. As an example, if the rate of arrival is 100 cars per hour and the rate of storage 90 cars per hour, then the reservoir should have a capacity of $2.4\sqrt{100} + 100 - 90$ or 34 cars. This arithmetical increase is obvious, since the cars not stored will accumulate in the reservoir.

It would seem to be a false economy to provide extra reservoir space to offset a planned deficiency in attendants. On the other hand, it will certainly be necessary to hire additional attendants if insufficient reservoir space is provided. It cannot be emphasized too strongly that the reservoir space is of the greatest importance in rapid acceptance of cars into a garage, and that most existing garages are deficient in reservoir space.

DELIVERY OF CARS

One important difference between the acceptance and delivery of cars is that the customer's time is involved in the entire operation of delivery. Further, much of this time he is inactive -- just waiting -- which makes it pass slowly. The customer's time may be considered in three parts -- paying the cashier, the actual time for an attendant to deliver his car, and waiting his turn for an attendant.

The time spent at the cashier's office is small. Standard procedures are employed, including time-stamping the ticket, computing the elapsed time and charge, and making change. This procedure need not require more than 30 to 45 seconds. More often, the customer at the cashier's office is required to wait in line, not because of the time required for the cashier operation, but because cars are not being delivered fast enough, and his waiting time can thus be broken into two parts.

The operation of delivering a car from the storage floor to the outbound reservoir space is almost the reverse of the storage operation, and equivalent in time. In instances where cars are being accepted and delivered at the same period, attendants may reduce the time per car

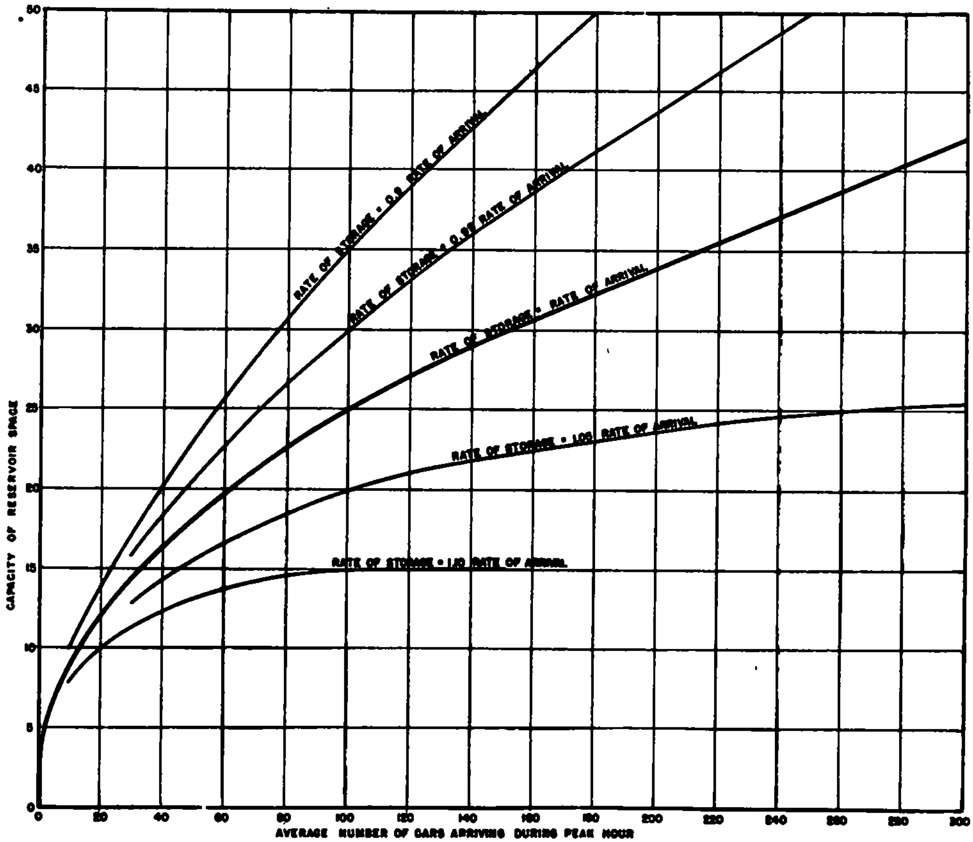

Figure 1. Relationship between Capacity and Rates of Arrival and Storage.

handled by as much as one third. While this makes for efficient employment of attendants, when the delivery operation is considered alone the time per car is thus increased by one-third.

The delivery rate - cars per attendant per hour - depends on the design of the garage, the quality of personnel, and the methods of operation. Good traffic design of the ramps, stall, and aisles will form a basis for keeping this time to a minimum. The design and location of interfloor driver travel means is also important. Beyond this point, the personnel and operations are a function of management. Although in some garages a fortuitous combination of size, layout, operation, and parking demand make it possible to deliver cars in an average time of two minutes each, this is certainly a minimum value. A reasonable average is three to four minutes.

So far, we have accounted for perhaps five minutes of the customer's waiting time. Yet, as stated earlier, customers must often wait 20 to 30 minutes for the delivery of their cars. This condition is illustrated in Figure 2, which describes the operation of a large garage during a peak rush when the stores were open during the evening. These data were collected by counting the number of waiting customers at five-minute intervals, and by recording the time of delivery of each car. It may be seen that the number of customers waiting at some periods exceeded 70 drivers, and that the average waiting time was 30 minutes. On this particular evening, only eight attendants were on duty - obviously not a sufficient number for good operation. The average customer arrival rate was about 120 per hour, the average delivery rate about 90 cars per hour, while cars were being both stored and delivered

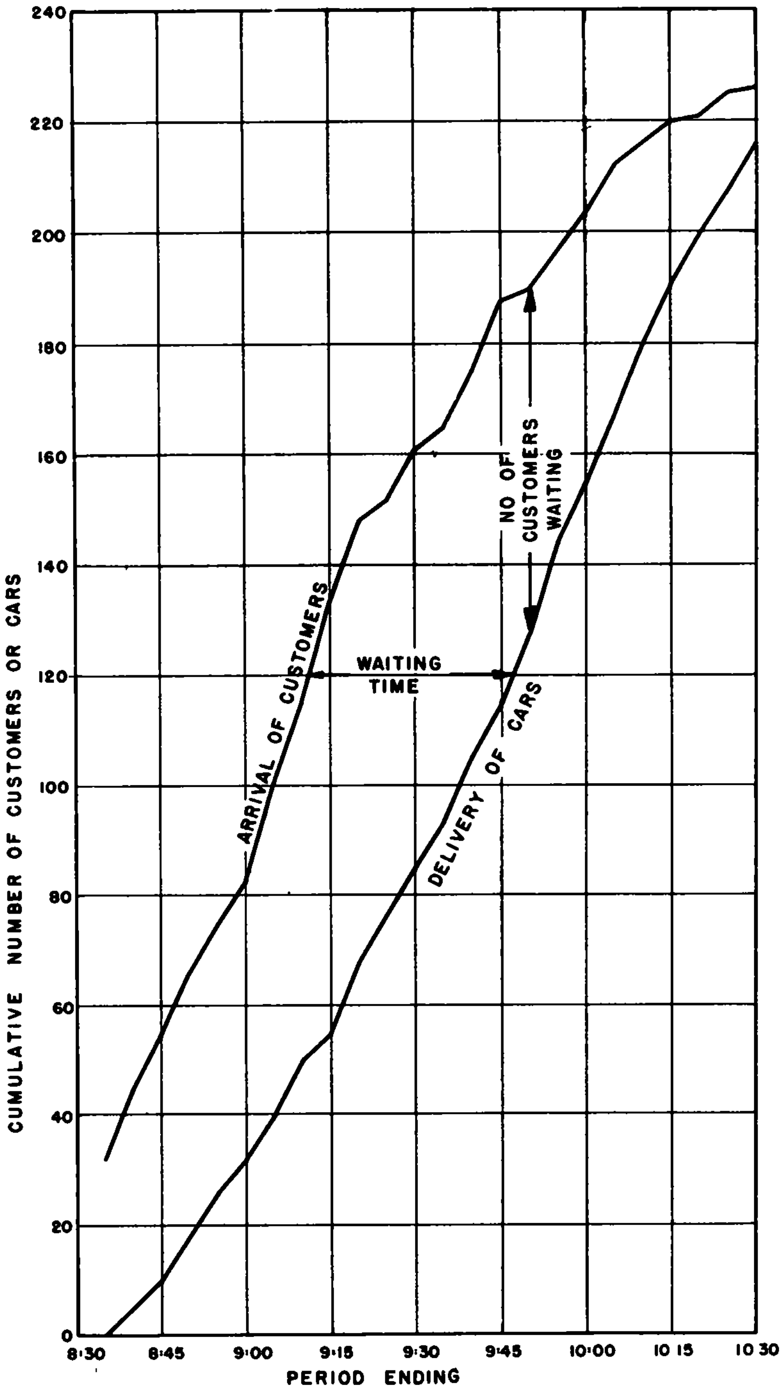

Figure 2. Garage Operation during Rush Period - Eight Attendants.

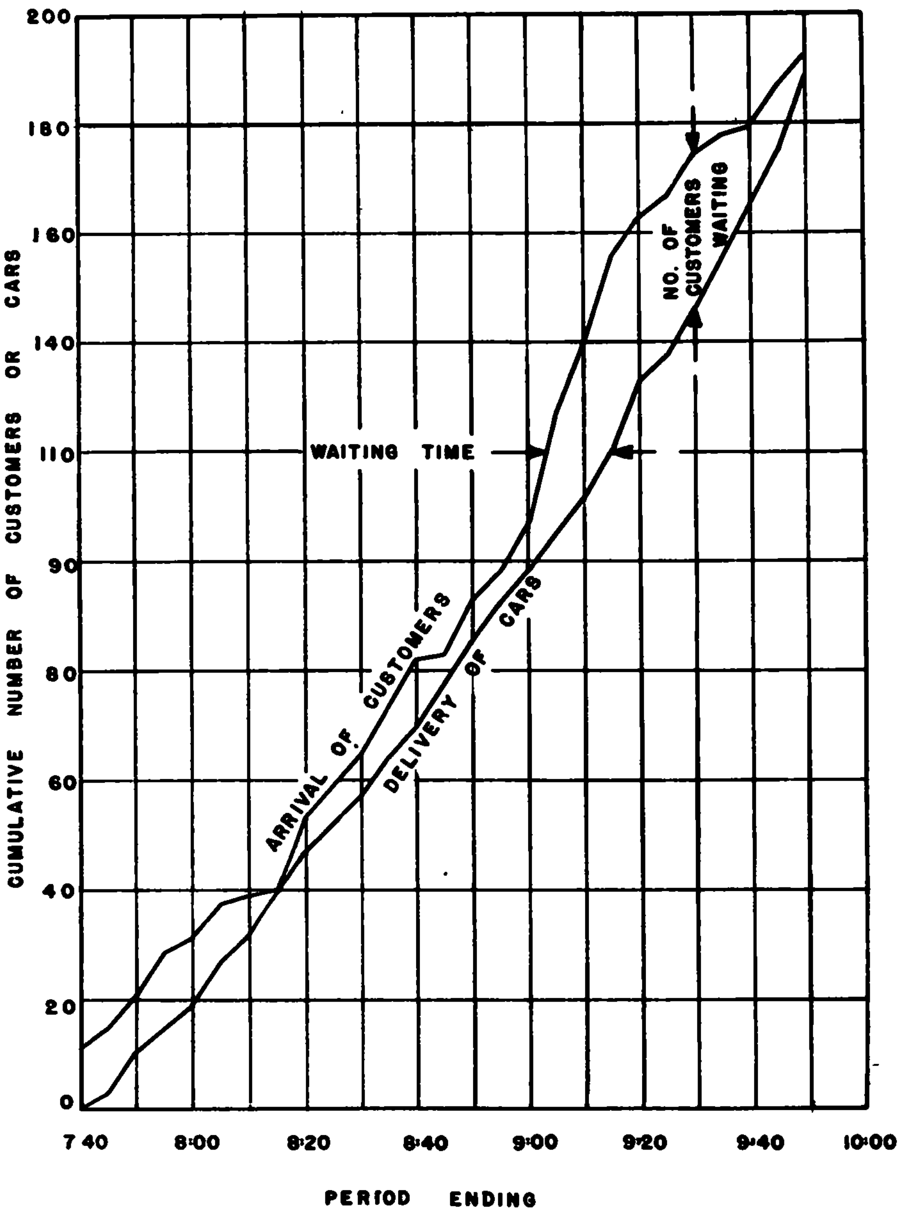

Figure 3. Garage Operation during Rush Periods - Ten Attendants.

(before 9:30), and about 120 per hour when only delivery operations were necessary.

Figure 3 shows the operation of the same garage on another shopping night. In this case, ten attendants were on duty, but four of them were relatively inexperienced. The peak number of waiting customers is 30, with a waiting time of 19 minutes. The customer arrival rate was about 110 per hour, and the average delivery rate 90 per hour. This inconsistency is due to the fact that several times early in the evening the rate of delivery exceeded the rate of customer arrival, so that the attendants sometimes had no work to do, and were never pushed as hard as on the former evening. It should also be noted that under evenly balanced operating conditions the number of waiting customers would equal the number of attendants, and the average waiting time would equal the delivery time.

CUSTOMER PARKING

The alternative of customer parking has a definite advantage in satisfying the customer's desire for minimum time. While the time spent in storing his car may be longer, the delivery time is almost certain to be shorter, and he is busy throughout the period, with practically no waiting time.

Customers generally drive more slowly than experienced attendants. Ramp speeds were found to be from 4 to 12 miles per hour. Parking time, in stalls of adequate size, averaged 26 seconds. Other operations, such as elevator travel and walking, are not materially different from those in attendant garages. The normal time for acceptance or delivery in a well-designed garage should not exceed five minutes for customer-parking. While time savings to customers during the acceptance of cars are greater in attendant-parking garages, customer-parking has a definite advantage for delivery.

DESIGN FOR PEAK FLOWS

The accumulation of cars in a garage reflects the accumulation of cars in the central business district. The inbound and outbound movements also parallel the well-known rush periods of morning and late afternoon.

It is undoubtedly true that the public's habit of concentrated peak movements is somewhat irrational, and that attendants hired for the peak periods may be practically unemployed during off-peak periods. However, service during these peaks is a key element in the demand for parking, and the design and operational procedures must be based on peak rates of movement.

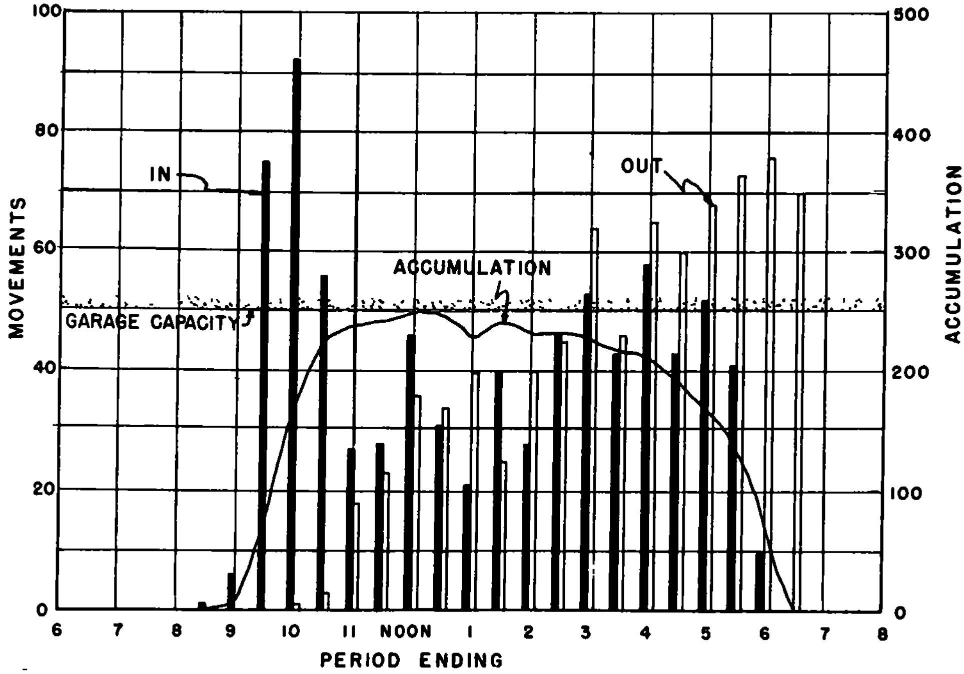

Figure 4. Movements In and Out and Accumulation of Cars in a Garage.

Figure 4 shows the inbound and outbound movements and accumulation of cars in a shopper's garage. The peak movements are 167 cars per hour inbound, and 149 cars per hour outbound. The use of this garage is definitely limited by its storage capacity.

Figure 5 shows the time of arrivals vs. the duration of stay for the same garage

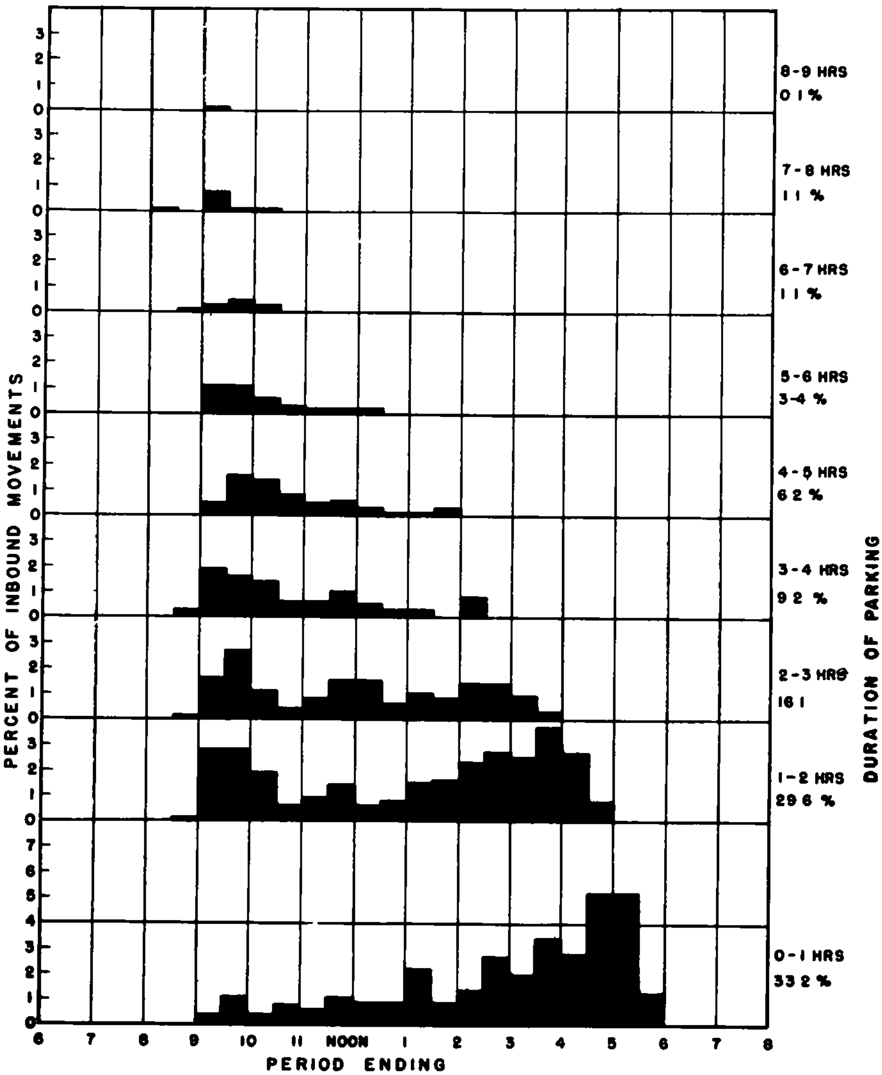

Figure 5. Time of Arrivals versus Duration of Stay.

and same day of operation. The preponderance of short-term parkers is caused by the particular demand of shoppers, and by the fact that the store management discourages all-day parking.

SUMMARY

The most important factor in attracting customers into off-street parking facilities is the reduction to an absolute minimum of the time which the customer is required to spend in storing and unstoring his car. There are no golden rules for traffic design, but in general, free paths for movement and adequate sized stalls should be provided. Adequate reservoir space is essential to the proper acceptance and storage of cars.

Proper management is of at least equal importance to design in the rapid handling of cars. Operating techniques must be simple, and geared to high rates of acceptance and delivery. The morning and evening peaks are the periods of highest demand, and a sufficient number of attendants must be employed to handle cars at an average rate at least equaling the rate of demand. The congestion of waiting vehicles or customers should not be accepted as inevitable, or as a sign of good business.

Proper design and operation of garages will allow the handling of 20 cars per attendant per hour, or more. This means that a car can be delivered within 3 to 4 minutes after the customer calls for it. This amount of waiting time would seem reasonable and should be attractive to customers.

Customer-parking also provides for reasonably rapid service, with an average of about 5 minutes each for acceptance and delivery. While many other factors must be considered in choosing between attendant and customer parking, it does have the advantage of eliminating long waiting periods.

DISCUSSION

Mr. Campbell: "Can the formula for the approximate solution of the storage reservoir problem be applied to outdoor theater use?"

Mr. Ricker: "Basically the formula can be applied to the similar problem at outdoor theaters. Some modifications may be necessary depending on values used for the average rate of arrival and probability of no overfilling. The handling time, that is, the process of selling tickets, would be much shorter, and a complete time-motion study both inside and outside the theater would be required."