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# Near-Side or Far-Side Bus Stops: A Transit Point of View

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**The optimum location of a bus stop near an intersection is defined as that which minimizes the sum of the cost of time to passengers and the operating cost of buses. Two cases, controlled and signalized intersections, are presented in this paper. A theoretical approach is adopted. A near-side and a far-side bus stop are assumed in the vicinity of the intersection under consideration. The relevant costs are calculated and compared. The location that minimizes these costs is chosen. The optimum location is shown to be dependent on the demand for boarding and alighting from the bus at the near side or the far side and on the expected delay to the bus. Some simple rules are suggested. The method is illustrated by a numerical example to show the validity and practicality of the theory developed.**

In the vicinity of an intersection, a bus stop may be located at the near side or at the far side. The two sides are defined by the Highway Capacity Manual (1) as follows:

> Near-side curb stops--located at the curb on the intersection approach in advance of the intersection proper.
> Far-side curb stops--located at the curb immediately beyond the intersection proper on the straight-through exit from the approach under consideration.

The Institute of Traffic Engineers (2) has issued guidelines and recommendations for locating stops. Terry and Thomas (3) conducted a field study on a portion of a major arterial street. Their analysis indicated that far-side stops tend to be more favorable in terms of reducing queuing, providing additional maneuvering space for vehicles, and avoiding delay to right-turning vehicles. However, Feder (4) recommended the near-side stop, since it allows the bus to achieve a shorter travel time over its route. For the case in which more vehicles turn right than left at the intersection, the far-side location was recommended. Bodmer and Reiner (5) summarized the advantages and disadvantages of both locations.

The choice depends on the different factors that have been discussed in the literature. However, in all the studies carried out, no attention was given to the effect of the location on the cost of travel time to passengers and on the operating cost of the bus system. In general, the near-side, far-side studies (3-4) have considered only choosing one of the two alternatives for the complete series of intersections along a specific route; intersections have not been considered separately. These studies are either simulations or field studies. No theoretical work has been carried out as far as we can ascertain.

The objective of this paper is to investigate the optimal location of bus stops in the vicinity of some of the most-common intersection configurations. The optimum location is defined as that which minimizes the sum of the cost of travel time to passengers and the cost of operating the buses. Other factors, not included in this study, are delay to traffic, effect on right-turning vehicles, parking conditions, effect on the capacity of the intersection, and safety, which is also a primary concern.

The procedure followed in the analysis is as follows. At each intersection, a near-side location and far-side location are assumed. The related costs are calculated and compared, and the location that minimizes these costs is chosen. General rules are given when it is possible.

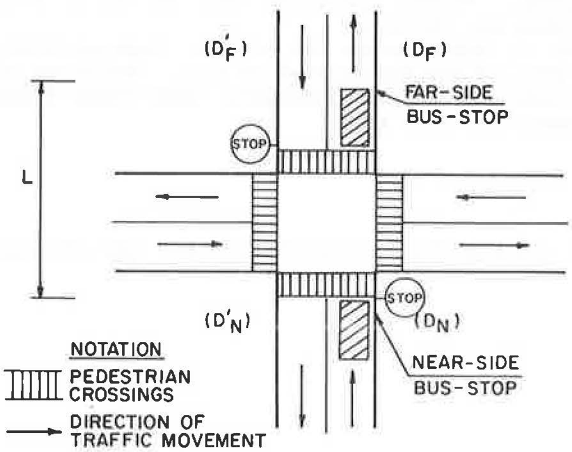
Other intersection configurations not discussed here can be analyzed in a similar manner (6). The general conclusion drawn from this analysis (which represents the transit point of view) and from other studies related to the near-side, far-side problem should provide a useful guide to transit planners and traffic engineers.

## CONTROLLED INTERSECTIONS

Consider a four-leg intersection at which one of the streets (i.e., two opposite approaches) is controlled by stop signs (Figure 1). Buses operate on one or both approaches of the controlled street. The following analysis deals with either of the two approaches.

First, consider a near-side bus stop. It is assumed that the near-side bus stop is close enough to the stop sign so that the bus does not have to stop twice. Thus, if the bus stop was located on the near side, a bus would decelerate from its cruising speed to a stop in time $t_B$, load and unload passengers in time $t_S$, wait time $t_G$ for a suitable gap to occur in the uncontrolled street, and then accelerate to its cruising speed in time $t_A$. The variables $t_S$ and $t_G$ are random

Figure 1. Controlled intersection.



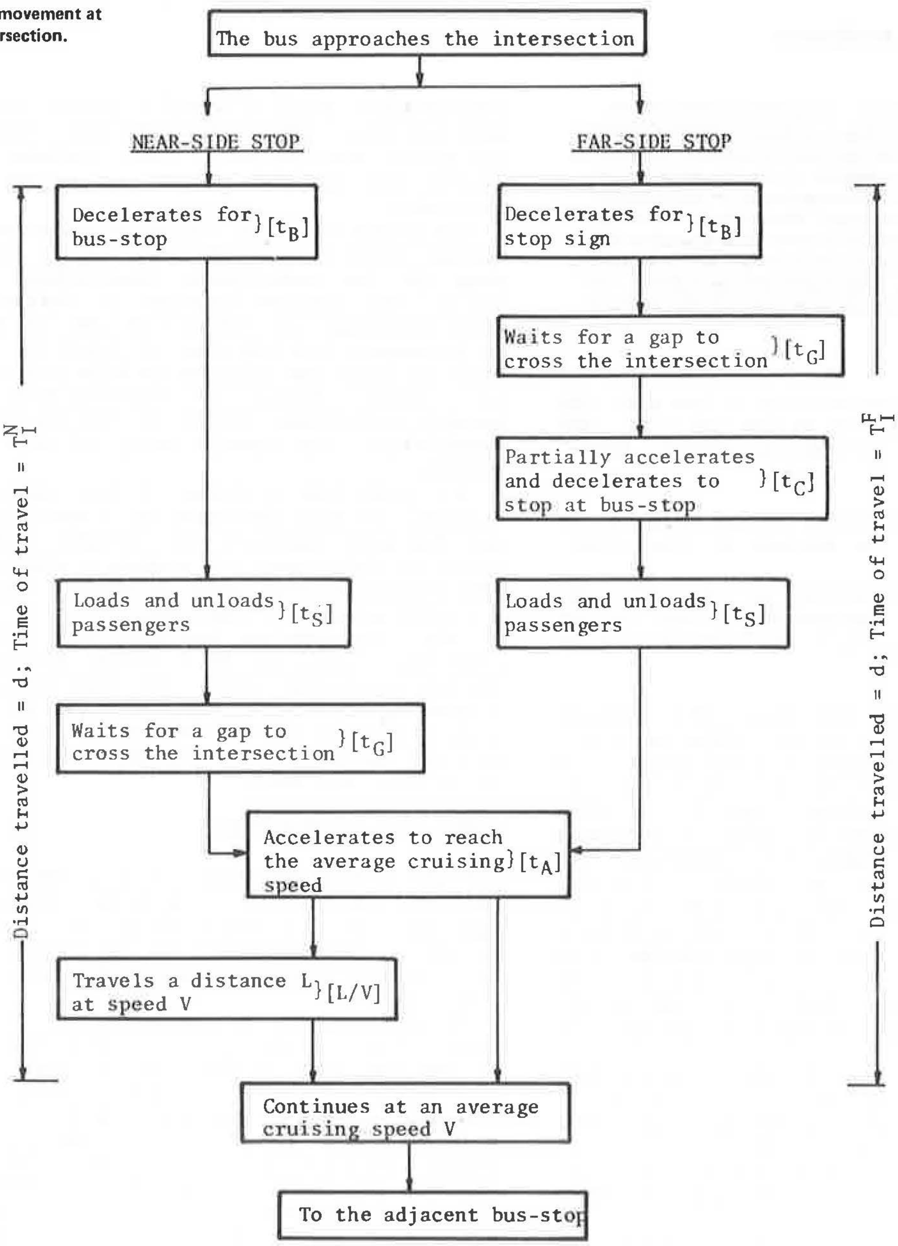

variables for which the expected values may be used for calculations. The dead time is included in $t_S$. This sequence is illustrated in Figure 2.

Second, consider a far-side bus stop. There a bus would decelerate from its cruising speed to a stop in time $t_B$, wait time $t_G$ for a suitable gap in the uncontrolled street, cross the uncontrolled street by partially accelerating and decelerating to a stop at the far side in time $t_C$, load and unload passengers in time $t_S$, and then accelerate to its cruising speed in time $t_A$ (Figure 2).

Thus, the only real difference between near-side and far-side bus stops as far as the movement of the bus is concerned is that the bus has to lose some time while it crosses the uncontrolled street.

Assume a far-side bus stop as shown in Figure 1. Distance L between the far-side and near-side stops may be obtained from field measurements. Assume that the maximum speed the bus reaches while it travels distance L during the partial acceleration and deceleration is $V_0$. Then

Figure 2. Bus movement at controlled intersection.



$$t_C = (V_0/A) + (V_0/B) \quad (1)$$

where A and B are the average acceleration and deceleration rates of a bus and

$$L = (V_0^2/2)[(1/A) + (1/B)] \quad (2)$$

From Equations 1 and 2,

$$V_0 = \{2L/[(1/A) + (1/B)]\}^{1/2} \quad (3)$$

and consequently

$$t_C = \{2L[(1/A) + (1/B)]\}^{1/2} \quad (4)$$

The actual time loss for a bus due to the acceleration and deceleration maneuver is the difference between $t_C$ and the time (L/V) that it would take to cross the uncontrolled street at the cruising speed, i.e., $\{2L[(1/A) + (1/B)]\}^{1/2} - (L/V)$. This amount is relatively small and is possibly of theoretical interest only.

The costs associated with the location of the bus stop at the near side are the time for passengers to walk between the far side of the intersection and the bus stop, the additional riding time $T_I^N$ for passengers inside the bus, and the bus operating costs related to $T_I^N$. The costs related to $t_A$, $t_B$, and $t_S$ are independent of the location of the bus stop at the near side or the far side of the intersection. Therefore, these costs will not be included in the analysis.

The cost per unit of walking time for passengers who originate or have their destinations at the far side of the intersection is given by

$$(D_F + D_F')t_w\gamma_w \quad (5)$$

where

$D_F$ = combined far-side demand for boarding and alighting from a bus per unit of time on the right side of the intersection,
$D_F'$ = combined far-side demand for boarding and alighting from a bus per unit of time on the left side of the intersection,
$t_w$ = time for a passenger to find a gap and cross the uncontrolled street, and
$\gamma_w$ = average value of a unit of walking time to a passenger.

The relevant cost per unit of riding time for passengers inside the bus is expressed by

$$(P_0 + P - Q)[t_G + (L/V)]\gamma_R \quad (6)$$

where

$P_0$ = total number of passengers inside a bus before it stops at the bus stop per unit of time,
P = total demand for boarding a bus at the bus stop per unit of time,
Q = total demand for alighting from a bus at the bus stop per unit of time, and
$\gamma_R$ = average value of a unit of riding time to a passenger.

The relevant cost per unit of bus-operating time at the intersection is given by

$$N[t_G + (L/V)]\gamma_B \quad (7)$$

where N is the number of buses that arrive at the stop per unit of time and $\gamma_B$ is the operating cost of a bus per unit of time.

The total relevant cost ($C_N$) per unit of time for the location of the stop at the near side is then obtained by adding expressions 5, 6, and 7:

$$C_N = (P_0 + P - Q)[t_G + (L/V)]\gamma_R + [(D_F + D_F')t_w\gamma_w] + N[t_G + (L/V)]\gamma_B \quad (8)$$

Similarly, the different costs associated with the far-side bus stop are as follows.

The cost per unit of walking time for passengers who walk between the near side of the intersection and the bus stop is given by

$$(D_N + D_N')t_w\gamma_w \quad (9)$$

where $D_N$,$D_N'$ is the combined near-side demand for boarding and alighting from the bus on the right and left sides of the intersection, respectively, per unit of time.

The relevant cost per unit of additional riding time for passengers inside the bus is given by

$$P_0(t_G + t_C)\gamma_R \quad (10)$$

and the relevant cost per unit of bus-operating time is given by

$$N(t_G + t_C)\gamma_B \quad (11)$$

By adding expressions 9, 10, and 11, the total relevant cost ($C_F$) per unit of time for the far-side stop is obtained:

$$C_F = P_0(t_G + t_C)\gamma_R + (D_N + D_N')t_w\gamma_w + N(t_G + t_C)\gamma_B \quad (12)$$

In order to evaluate the near-side and the far-side locations, the total costs $C_N$ and $C_F$ are compared. The best location from a transit point of view is that which minimizes the sum of the time costs for passengers and the bus-operating costs. The necessary condition for choosing the near-side location is $C_N < C_F$; i.e.,

$$(P_0 + P - Q)[t_G + (L/V)]\gamma_R + (D_F + D_F')t_w\gamma_w + N[t_G + (L/V)]\gamma_B < P_0(t_G + t_C)\gamma_R + (D_N + D_N')t_w\gamma_w + (t_G + t_C)N\gamma_B \quad (13)$$

Rearranging inequality 13, we obtain

$$(D_F + D_F' - D_N - D_N')t_w\gamma_w + (P - Q)[t_G + (L/V)]\gamma_R < (P_0\gamma_R + N\gamma_B)[t_C - (L/V)] \quad (14)$$

It is clear that inequality 14 is always true if the left-hand side is zero or negative, i.e., if the following conditions are satisfied concurrently:

$$(D_N + D_N') \geqslant (D_F + D_F') \quad (15)$$

i.e., the demand at the near side for boarding and alighting from the bus is greater than or equal to that at the far side, and

$$Q \geqslant P \quad (16)$$

i.e., the demand for alighting from the bus at the stop is greater than or equal to that for boarding.

If any or both of conditions 15 and 16 are not satisfied, inequality 14 should be evaluated. It is also clear that the likelihood of a near-side bus stop increases as the frequency of service (N) increases and also as the number of people in the bus ($P_0$) increases.

# ISOLATED SIGNALIZED INTERSECTION

## Expected Signal Delay to Bus

Consider the isolated signalized intersection shown in Figure 3. Buses are assumed to arrive at the intersection at random times. When a stop is located at the near side, the time $T_I^N$ may be described as shown in Figure 4, i.e., the sum of the deceleration time $t_B$ to stop at the bus stop, the loading and unloading time $t_S$, the running time L/V, and, if the bus faces a green light after loading and unloading passengers, the acceleration time $t_A$; i.e.,

$$T_I^N = t_B + t_S + t_A + (L/V) \quad (17)$$

However, if the bus faces a red light,

$$T_I^N = t_B + t_S + T_N + t_A + (L/V) \quad (18)$$

where $T_N$ is the interval of time (delay) between the moment the bus closes the doors after loading and unloading passengers and the moment the light changes to green.

When the stop is located at the far side of the intersection, $T_I^F$ may be used to describe the case of encountering a green light or a red light on arrival at the intersection, as shown in Figure 4. If the bus encounters a green light, $T_I^F$ is composed of the running time L/V, the deceleration time $t_B$ to stop at the bus stop, the loading and unloading time $t_S$, and the acceleration time $t_A$. If the bus encounters a red light, $T_I^F$ is equal to the sum of the deceleration time $t_B$ to stop for the red signal, the delay $T_F$ until the light turns green, the time $t_C$ during partial acceleration and deceleration before the stop at the bus stop, the loading and unloading time $t_S$, and the acceleration time $t_A$.

The probability that a bus may encounter a green light or a red light on arrival at the intersection may be expressed by

$$P_G = G/C \quad (19)$$

$$P_R = R/C \quad (20)$$

Figure 3. Signalized intersection.

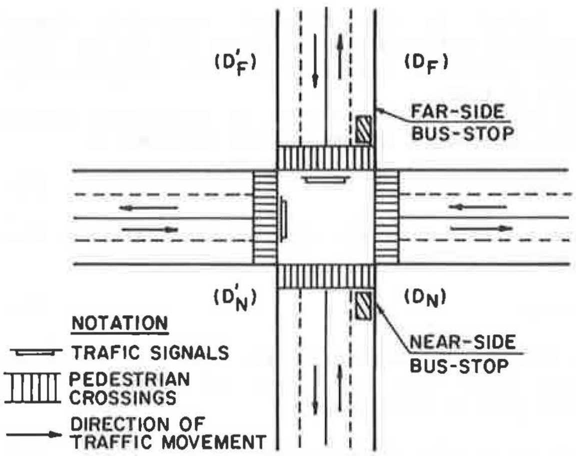



Figure 4. Bus movement at signalized intersection.

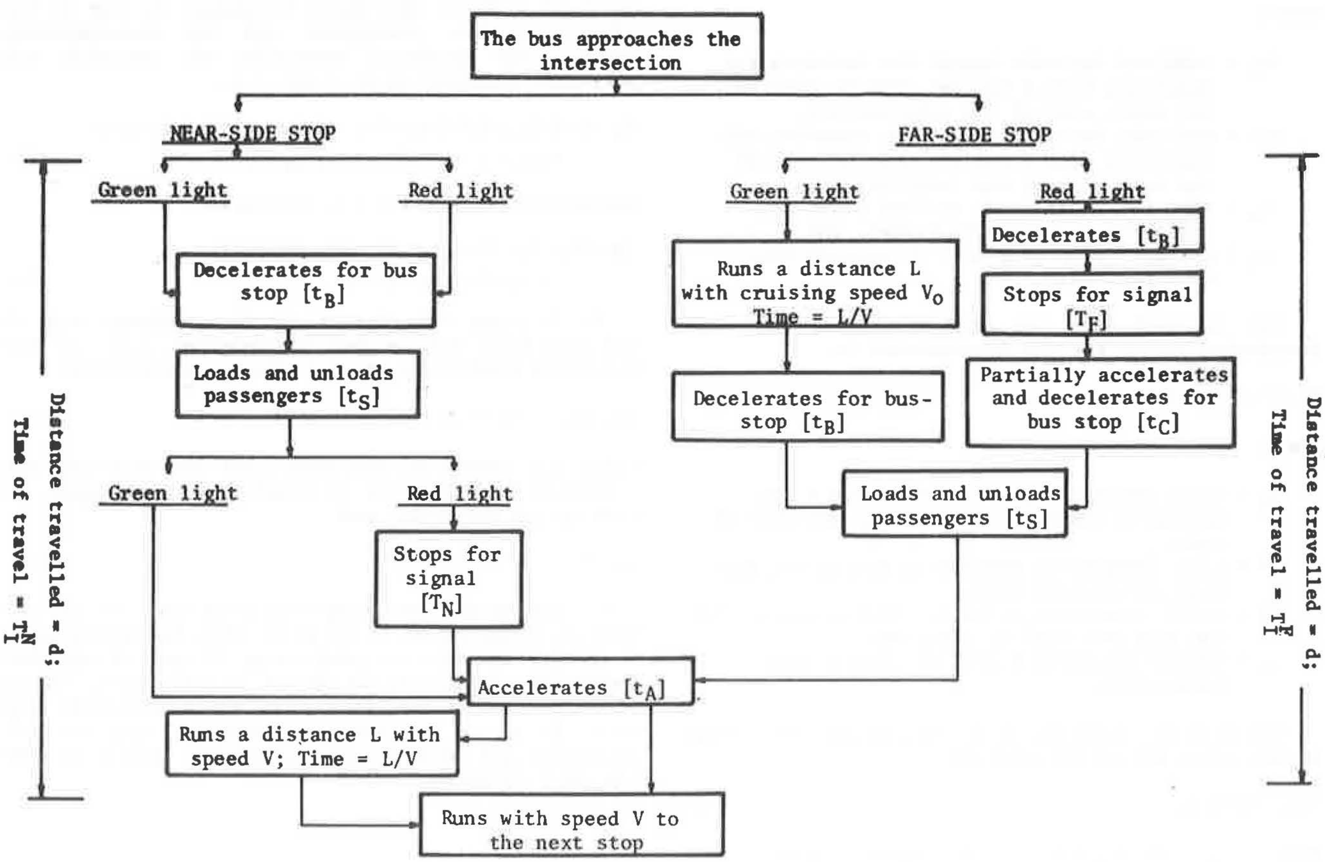
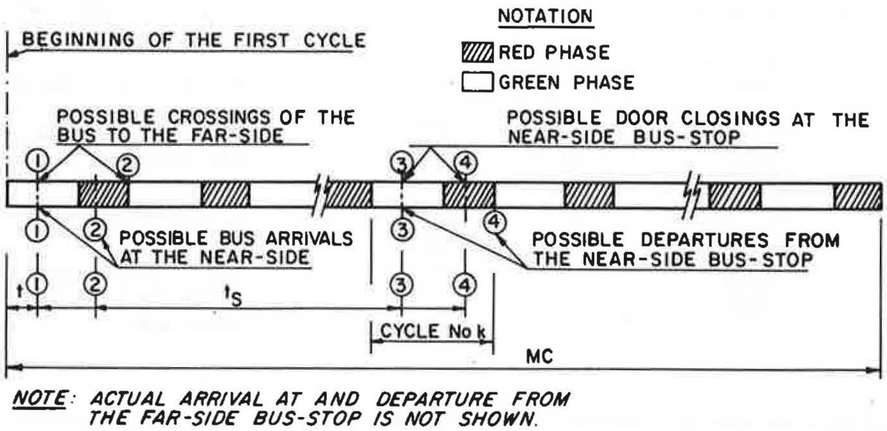


Figure 5. Possible moments of arrival and departure of bus within time period MC.




respectively, where

C = cycle length,
G = green time plus yellow time, and
R = red time.

Alternatively, some proportion of the yellow time may be included in both the green and the red times.

The expected delay $T_N$ associated with the location of the bus stop at the near side depends on the moment of arrival of a bus within a cycle, the loading and unloading time $t_S$, the cycle length C, and the signal split. However, the expected delay $T_F$ for a far-side stop depends only on the signal at the moment of arrival, the cycle length C, and the signal split. The expected delays $T_N$ and $T_F$ may be determined for a near-side or a far-side stop, respectively, as follows.

Delay at a Near-Side Stop

Consider M consecutive cycles as shown in Figure 5. Assume that the bus arrives at the bus stop after a time t measured from the beginning of the first cycle. Let the loading and unloading time be $t_S$ and let the bus be ready to depart within the kth cycle, where $k \geq 1$. In most cases, k is likely to be equal to 1 or 2. At the ready-to-depart time $t + t_S$, the bus might face a green light or a red light.

We assume that the probability density $f(t_S)$ of $t_S$ is known. Since the intersection is isolated and buses arrive at random, the probability density of t is assumed to be uniformly distributed. A bus that is ready to depart within the green phase of any cycle will not be delayed. If the bus encounters a red light after the doors have closed, the expected delay associated with the possibility that a bus may arrive at any moment within the first cycle and be ready to depart at any moment within the red phase of the kth cycle may be calculated as follows.

Since t and $t_S$ are random variables and if we assume that $t + t_S = t'$, we can write

$$F(t') = \int_0^{t'} \int_0^{(t'-t_S)} f(t)f(t_S)\,dt\,dt_S \quad \text{for } t > 0 \text{ and } t_S > 0 \tag{21}$$

where F(t') is the cumulative density function of the random variable t'. Then the probability density function of t' is given by

$$f(t') = dF(t')/dt' \tag{22}$$

If a bus is ready to depart from a near-side stop at a time t', it will be delayed by a period equal to kC - t'. Consequently, the expected delay associated with the possibility that a bus may arrive at any moment within the first cycle and be ready to depart at any moment within the red phase of the kth cycle is given by

$$E(\text{delay})_k = \int_{kC-R}^{kC} (kC - t')f(t')dt' = T_k \tag{23}$$

However, a bus may be ready to depart within any of the M cycles; therefore, the expected delay over all cycles is given by

$$E(\text{delay}) = \sum_{k=1}^{M} T_k = T \tag{24}$$

Delay at a Far-Side Stop

As described in Figure 4, no signal delay is associated with a bus arrival at the intersection within a green phase. If a bus encounters a red light on arrival at time t (as shown in Figure 5), the expected signal delay is C - t. The expected delay per bus is then R/2 and the expected signal delay $T_F$ associated with the location of the stop at the far side is given by

$$T_F = (R/2)(R/C) \tag{25}$$

Expected Signal Delay to Passengers Walking to and from the Stop

Assume that the cycle for pedestrians at the intersection under consideration is given by

$$C = G_P + R_P \tag{26}$$

where $G_P$ and $R_P$ are green time and red time, respectively, for pedestrians. Obviously, a passenger who arrives at the intersection within $G_P$ walks without delay to the opposite side. But for a passenger who arrives within $R_P$, the expected signal delay is

$$D_P = R_P/2 \tag{27}$$

Therefore, the total expected delay per unit of time for passengers who walk between the far side of the intersection and a bus stop located at the near side is

$$D_N^{P_1} = (D_F + D_F')(R_P/2)(R_P/C) = (D_F + D_F')(R_P^2/2C) \tag{28}$$

Table 1. Values of parameters.

| Parameter | Value Used in Example | Parameter | Value Used in Example |
|---|---|---|---|
| A | 0.4 m/s$^2$ | $\gamma_w$ | \$5.00/h |
| B | 0.4 m/s$^2$ | C | 60 s |
| N | 6 buses/h | G | 35 s |
| $t_w$ | 10.0 s | R | 25 s |
| $P_0$ | 150 passengers/h | M | 2 cycles |
| P | 19 passengers/h | L | 37 m |
| Q | 44 passengers/h | $t_C$ | 13.6 s |
| V | 25 km/h | $R_P$ | 20 s |
| $\gamma_B$ | \$15.00/h | $t_p$ | 17 s |
| $\gamma_R$ | \$2.50/h | | |

For passengers who walk between the near side of the intersection and the bus stop located at the far side, it is

$$D_F^{P_1} = (D_N + D_N')(R_P/2)(R_P/C) = (D_N + D_N')(R_P^2/2C) \quad (29)$$

The signal delay for passengers who cross the street on which the buses operate is not included in Equations 28 and 29, since it is independent of the location of the bus stop.

In addition to the signal delay, a passenger spends time $t_p$ to cross the street from one side of the intersection to the other side, at which the bus stop is located. The total crossing time per unit of time for $(D_F + D_F')$ and for $(D_N + D_N')$ passengers is given respectively by

$$D_N^{P_2} = (D_F + D_F')t_p \quad (30)$$

$$D_F^{P_2} = (D_N + D_N')t_p \quad (31)$$

As a consequence, the total cost per unit of time for $(D_F + D_F')$ passengers and for $(D_N + D_N')$ passengers between the moment of arrival at one side of the intersection and the moment of arrival at the opposite side, respectively, is

$$D_N^P = (D_F + D_F')[(R_P^2/2C) + t_p] \quad (32)$$

$$D_F^P = (D_N + D_N')[(R_P^2/2C) + t_p] \quad (33)$$

### Total Cost

The total relevant cost is composed of the cost of additional riding time for passengers inside the bus, the cost of walking time and of delay for passengers who cross the intersection, and the additional operating cost for the bus at the intersection. For a near-side stop, the total cost is expressed by

$$C_N = (P_0 + P - Q)[T + (L/V)]\gamma_R + (D_F + D_F')[(R_P^2/2C) + t_p]\gamma_w + [T + (L/V)]N\gamma_B \quad (34)$$

For a far-side stop, the total cost is given by

$$C_F = P_0\{[(R/2) + t_C](R/C) + [(L/V)(G/C)]\gamma_R\} + (D_N + D_N')[(R_P^2/2C) + t_p]\gamma_w + [(R/2) + t_C](R/C) + [(L/V)(G/C)]N\gamma_B \quad (35)$$

### Comparison of the Total Relevant Costs

The near-side location of the bus stop is preferred if

$$(P_0\gamma_R + N\gamma_B)\{T + (L/V) - [(R/2) + t_C](R/C) - [(L/V)(G/C)]\} + [(R_P^2/2C) + t_p](D_F + D_F' - D_N - D_N')\gamma_w + (P - Q)\gamma_R[T + (L/V)] < 0 \quad (36)$$

i.e., if the following conditions are satisfied concurrently:

$$T < [(R/2) + t_C - (L/V)](R/C) \quad (37)$$

i.e., if the expected signal delay for a bus when the stop is at the near side is less than that expected for a far-side bus stop;

$$(D_F + D_F') < (D_N + D_N') \quad (38)$$

i.e., if the demand at the far side for boarding and alighting from the bus is less than that at the near side; and

$$P < Q \quad (39)$$

i.e., if the demand for boarding the bus at the stop is less than that for alighting from it. If any of the above conditions is not satisfied, inequality 36 should be evaluated.

## CONCLUSIONS

It may be concluded from the previous analysis that, in general, a near-side stop minimizes the sum of the travel-time costs to passengers and the bus-operating costs if the following simple conditions are satisfied concurrently:

1. The demand for boarding and alighting at the far side of the intersection is less that that at the near side;
2. The demand for boarding is less than that for alighting; and
3. The expected delay to a bus caused by a near-side bus stop is less than that caused by a far-side stop.

## NUMERICAL EXAMPLE

Assume that the demands for boarding and alighting from buses per hour at a bus stop near an isolated signalized intersection are as given below:

| Corner of Intersection | No. That Board | No. That Alight |
|---|---|---|
| Far side, left | 5 | 15 |
| Far side, right | 7 | 10 |
| Near side, left | 4 | 7 |
| Near side, right | 3 | 12 |

Assume also that the values of the parameters are as given in Table 1.

Based on data from Chapman (7), the probability density $f(t_S)$ of $t_S$ may be approximated by the gamma distribution shown in Figure 6 and given by

$$f(t_S) = [0.138/\Gamma(2.49)]\,0.138t_S^{1.49}[\exp(-0.138t_S)] = 0.0055t_S^{1.49}[\exp(-0.138t_S)] \quad (40)$$

Assume that $f(t)$ = constant = $1/C$ = 1.60.

By following a numerical procedure to derive $f(t')$, the probability density function of $t'$ is shown to be approximately normal (as shown in Figure 7) and is given by

$$f(t') = (1/\sigma\sqrt{2\pi})\exp\{-[(t'-\mu)/2\sigma]^2\} = (1/21.85\sqrt{2\pi})\exp[-(t'-44.4)^2/2(21.85)^2] \quad (41)$$

Thus, the expected delay for a bus ready to depart from a near-side bus stop within the first cycle is

$$E(\text{delay})_1 = \int_{35}^{60}(60-t')f(t')dt' \simeq 6\text{ s} \quad (42)$$

Figure 6. Probability density of $t_S$.

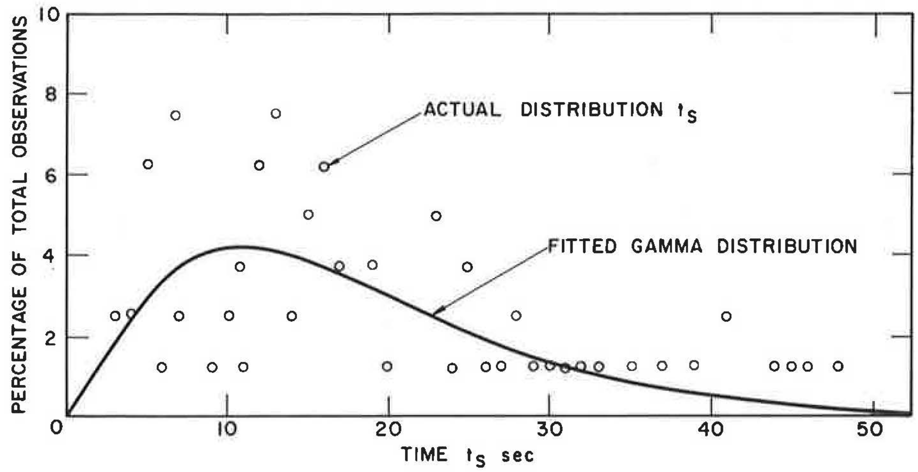
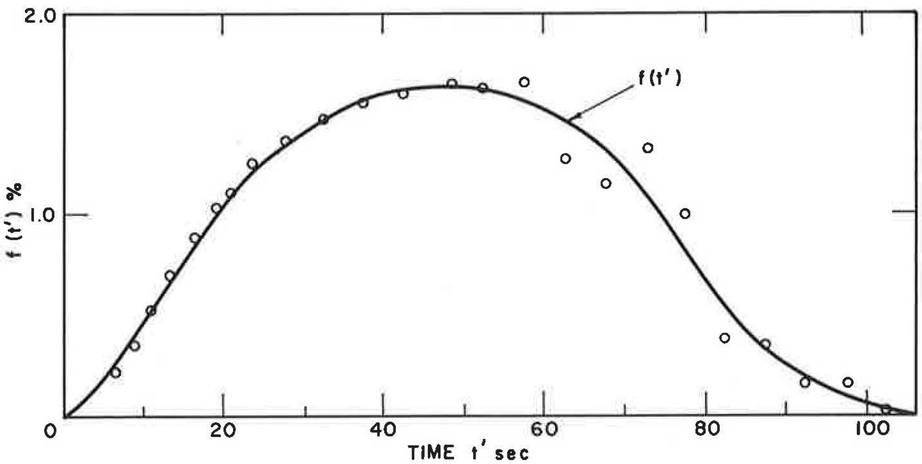



Figure 7. Probability density of t'.




The expected delay for a bus ready to depart within the second cycle is

$$E(\text{delay})_2 = \int_{95}^{120} (120 - t')f(t')dt' \approx 0.0 \text{ s} \quad (43)$$

Thus, the expected delay for a near-side stop is 6 s.

If the bus stop is located at the far side of the intersection, the value of the expression $[(R/2) + t_C - (L/V)](R/C)$ in inequality 37 is given by

$$[(25/2) + 13.6 - (37 \times 6.94)] \times (25/60) = -96.1 \quad (44)$$

Since 6 is not less than -96.1, i.e., inequality 37 is not satisfied, inequality 36 should be evaluated to decide whether the near-side or the far-side stop is better: The left-hand side of inequality 36 = $13.33/h.

Since 13.33 is not less than 0 (i.e., inequality 36 is not satisfied), the far-side stop is chosen. The saving obtained over the near-side stop, as far as the cost of time for passengers and the operating cost of buses are concerned, is equal to $13.33/h.

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