Analysis of Light Rail Vehicle Clearance Time at Intersections

WULF GROTE and JASON C. YU

ABSTRACT

The intent of this study is to determine the amount of intersection disruption created by the implementation of light rail transit (LRT) through intersections with automobile traffic. The measure for determining intersection disruption is the LRT clearance time, which is the sum of time consumed by the actual presence of an LRT vehicle in the intersection and the time required before and after LRT arrival to prepare the intersection. Clearance time is affected by several factors that have been categorized as LRT vehicle operating characteristics, geometric layout of the intersection, and the traffic control method implemented. Several equations have been developed, with these factors as variables, to determine the LRT clearance time created by various operating conditions. In addition, several graphs show the ranges of clearance time that might be experienced under specific operating characteristics.

Congestion of major roadways is becoming a problem in many cities across the North American continent. In an effort to alleviate the congestion problem, several medium-sized cities (roughly 1 to 2 million inhabitants) have turned to light rail transit (LRT) to provide more efficient usage of right-of-way within major transportation corridors. LRT is a fixed-guideway transit system that has the capability of operating safely at grade, but LRT can also be grade separated at major conflict points. This means that, in many cities, LRT will operate at street level through roadway intersections in an effort to reduce capital expenditures for the transit project.

Intersections where LRT conflicts with automobile traffic must be carefully analyzed to determine the potential delay impacts that may be created. The severity of impact will depend on the specific characteristics of the LRT system being implemented. Several previous studies have identified factors that influence intersection performance. One such study by Larwin and Rosenberg (1) identified delay at an LRT crossing as a function of

- LRT approach speed,
- Train length,
- Location of stop,
- Emergency stopping capabilities of LRT,
- Service frequency,
- Cross-street width, and
- Train detection and signal control requirements.

Although many influencing factors have been identified through previous studies, little work has been done to determine the amount of impact created by each one. The objective of this study is to demonstrate the amount of intersection disruption created by each factor. In addition, the results of this study should serve as a valuable tool for engineers and planners in selecting appropriate LRT system characteristics to minimize intersection delay. Factors affecting the delay experienced at an intersection can be divided into three categories: light rail vehicle operating characteristics, prevailing intersection geometrics, and the traffic control method implemented. Factors within each of these categories are

Light Rail Operating Characteristics	Geometric Layout	Traffic Control
Speed	Width of crossing	Degree of light rail priority
Acceleration	Turning-lane provisions	Traffic control devices
Proximity of LRT station		Effects of emergency stop considerations
Headway		Signal phasing
Train length		Automobile progression

Some of these factors have overlapping impacts and others are difficult to quantify. In this study, each of these factors was analyzed and, if possible, quantified in detail. These factors together determine the amount of time that normal traffic flow through an intersection is interrupted by the presence of a light rail vehicle. This time is defined here as the LRT clearance time. Some of this time is consumed by the physical presence of a light rail vehicle in the intersection; the remaining time is required to prepare the intersection for a rail vehicle arrival and allow necessary steps to resume automobile traffic flow after the rail vehicle has cleared the intersection. This study will use LRT clearance time as the measure for determining intersection disruption.

It is important to note that not all LRT clearance time necessarily results in lost capacity to an intersection. In some cases, traffic will continue to flow on intersection legs not conflicting with the LRT crossing. Even at locations where all traffic will be stopped during the physical presence of LRT in the intersection, vehicles may still be able to flow during a portion of the time the intersection is being prepared for LRT arrival. The intent of this analysis is to show the amount of time that normal intersection operations are disrupted by the implementation of LRT. In many cases, the study results will not necessarily show the lost intersec-

tion capacity created by LRT. Intersection capacity losses may result from a portion or all of the LRT clearance time, depending on the specific operating characteristics of the intersection.

ALTERNATIVE OPERATIONAL CONDITIONS

The first step of the analysis of LRT clearance time is to determine what types of crossing conditions a light rail vehicle might encounter on arrival at an intersection. In general, there are six possible operational conditions:

1. The light rail vehicle approaches the intersection at a constant speed and, because of either preemption of the traffic signal or light rail progression, the light rail vehicle is able to proceed without interruption.
2. Again, the light rail vehicle is able to proceed at a constant speed. However, as a safety precaution, the time for a light rail vehicle to make a full emergency stop is accommodated after cross-street traffic has been halted and before LRT arrival at the intersection. The emergency stop time provision assures that the LRT vehicle operator can stop the train if an intersection blockage occurs. Without this provision, an LRT vehicle will arrive at the intersection the instant that cross-street traffic receives a stop condition.
3. The light rail vehicle is required to stop at the near side of an intersection and then must accelerate back to its operational speed. This condition will occur if a near-side station platform is present or if the light rail vehicle is stopped by the traffic signal (i.e., no LRT priority).
4. The light rail vehicle is able to cross the intersection uninterrupted, but deceleration occurs due to a station platform at the far side of the intersection. No emergency stop considerations are provided. For this analysis, the deceleration condition has been combined with the acceleration case (Condition 3) because acceleration and deceleration rates are assumed to be similar.
5. Again, the light rail vehicle is able to cross the intersection without interruption and then decelerates into a far-side station. However, it is assumed that, as a safety precaution, a full emergency stop from the operational speed is accounted for before a light rail vehicle arrives at the crossing.
6. No priority is granted to the light rail vehicle and, as a result, the vehicle is forced to stop at the near side of an intersection where far-side station platforms are present. This means that the light rail vehicle, after stopping, will have to accelerate as close as possible to the operational speed and then decelerate into the station.

For each of these six conditions, equations were derived for estimating LRT clearance time. Critical factors entering into the equations were light rail speed; train length; width of crossings; and, in some cases, acceleration, deceleration, and emergency braking. The equations derived in this study are expressed by general variables. However, examples and graphs presented herein are calculated by inserting typical values for LRT vehicle length, service acceleration rate, service deceleration rate, and emergency deceleration rate. Although the value of these parameters may vary from one vehicle model to the next, the analysis presented here makes use of values considered typical of new light rail systems. The values used are as follows:

- Vehicle length = 90 ft,
- Service acceleration = 4 ft/sec^2,
- Service deceleration = 4 ft/sec^2, and
- Emergency deceleration rate = 7.3 ft/sec^2.

DERIVATION OF LRT INTERSECTION CLEARANCE TIME

Condition 1

The condition where vehicle speed is constant is best described using the uniform rectilinear motion equation:

$$t = (x - x_o)/s$$

where

x = final position coordinate,
x_o = initial position coordinate,
s = operating speed (a constant), and
t = time to cover the distance from x_o to x.

In the case where LRT crosses an intersection, $(x - x_o)$ can be simplified to x to denote the total distance covered in crossing the intersection. This distance (x), referred to as the effective crossing distance, can further be defined as the intersection width (w) plus the length of the train (L). The train length is determined by multiplying the vehicle length (c) by the number of vehicles (V) forming the train. Therefore, the LRT clearance time can be determined by

$$t = (w + cV)/s \qquad (1)$$

where w and c are expressed in feet, s is expressed in feet per second, and t is in seconds.

Equation 1 has been solved for speeds ranging between 10 and 50 mph, intersection widths between 40 and 160 ft, and train lengths of one-, three-, and five-car trains, as shown in Figure 1. Not all possible values for the various factors have been computed, but values not shown can be interpolated from the lines on the graph or by using Equation 1. This graph should give a good indication of how modifications would affect light rail clearance time.

The obvious conclusion that can be drawn from Figure 1 is that as speed increases the total light rail clearance time decreases. At low speeds, particularly when train lengths are long and intersections are wide, a small change in speed results in a significant reduction in clearance time. However, with high speeds, short trains, and narrow intersections, the crossing time is hardly affected at all. For example, a five-car train traveling across a 160-ft intersection at 12 mph would save about 7 sec over a 10-mph speed under the same conditions. Conversely, a one-car train crossing a 40-ft intersection at a speed increased from 40 to 50 mph would save less than half a second. Other conclusions that become apparent by studying Figure 1 are that at slow speeds a change in train length or a change in intersection width can result in a fairly significant change in light rail clearance time. At high speeds, however, changes of this nature have a relatively minor impact.

Condition 2

The clearance time equation developed for this condition is similar to that for Condition 1, except that emergency stop considerations must be added. The suggested emergency stop time (E) is

$$E = (s/e) + 4 \text{ sec}$$

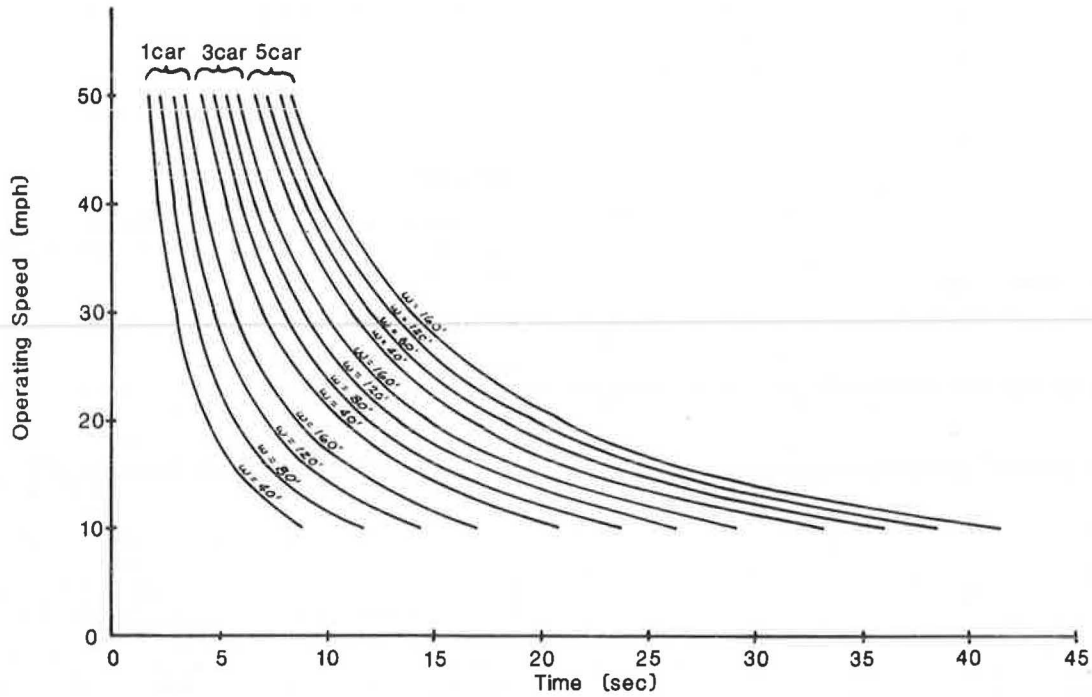

FIGURE 1 Light rail transit clearance time—constant speed.

where E is in seconds, e is the emergency braking rate in feet per second^2, and 4 sec is a factor added to allow driver reaction time and jerk considerations. This equation is added to the clearance time provided by Equation 1 and results in an overall light rail clearance time for this condition as follows:

$$t = [(w + cV)/s] + (s/e) + 4 \quad (2)$$

The emergency stop time is smallest at low speeds and becomes significantly larger as speeds increase.

Again, as was done for Condition 1, Equation 2 was solved for a range of values for each factor as shown in Figure 2. Unlike the graph for Condition 1, there is an optimum speed (s_{opt}) for each of the curves where light rail crossing time can be minimized; s_{opt} is derived by taking the derivative of Equation 2 and setting it equal to zero:

$$s_{opt} = [e(w + cV)]^{1/2} \quad (3)$$

For a given train length and intersection width, it is then possible to determine the corresponding

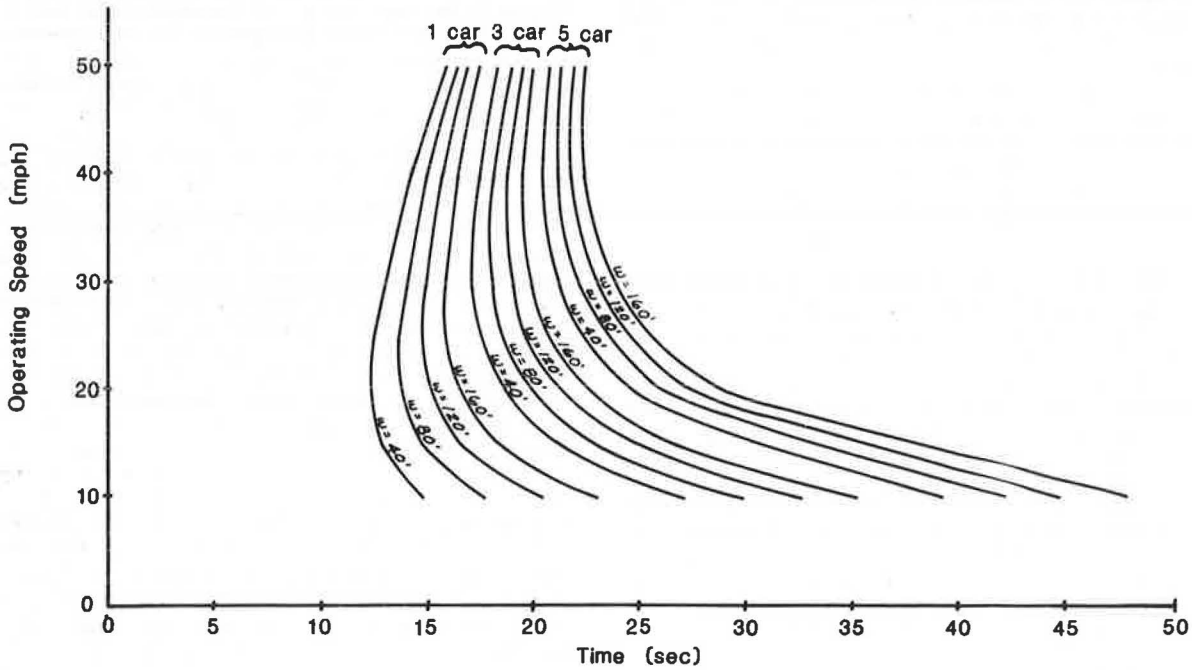

FIGURE 2 Light rail transit clearance time—constant speed including emergency stop.

s_{opt} by using Equation 3. This speed is then inserted into Equation 2 to determine the minimum clearance time.

It can be concluded from Figure 2 that optimum speed increases with increasing train length and intersection width. In addition, as optimum speed is increased, clearance time also becomes longer. Therefore, the least amount of intersection disruption would be at moderate speeds with short train lengths and narrow intersections. At low speeds the intersection clearance time is increased due to the amount of time the light rail vehicle is blocking the intersection, and at high speeds the clearance time is again increased due to the increased emergency stop time required before vehicle arrival at the intersection. Figure 2 also shows that changes in train length or intersection width create more of an impact at slower speeds. Also, speed is more of a delay factor at lower speeds when intersections are wide and trains are long.

Conditions 3 and 4

As mentioned earlier, the cases of acceleration from a near-side stop and deceleration into a far-side stop have been combined in this analysis because a common rate of acceleration and deceleration is used. Therefore, the equations will be identical, but signs will be reversed (negative rate for deceleration, positive rate for acceleration). The discussion that follows will refer to acceleration, but deceleration can be calculated by changing signs.

There are two circumstances that can occur for the conditions depending on the value of the factors involved. The first possibility is for a light rail vehicle to reach operating speed before clearing the intersection. Under this circumstance, a portion of the intersection would be traversed with the vehicle accelerating and the remainder of the intersection would be crossed at a constant speed. The second possibility is for the light rail vehicle to accelerate through the entire intersection without reaching full operating speed. Separate equations have been developed for each of these conditions.

The first step is to determine if the light rail vehicle would be able to cross a portion of the intersection at full operating speed. This is done by subtracting the distance to accelerate to operating speed from the total width of the intersection plus the train length. The distance to accelerate is found by using the uniformly accelerated rectilinear motion equation:

$$x_a = \left(s_f^2 - s_o^2\right)/2a$$

where

x_a = acceleration distance,
s_f = final speed,
s_o = initial speed, and
a = acceleration.

Because either the initial or the final speed will be zero, depending on whether the vehicle is accelerating or decelerating, this equation can be modified with the value for operating speed (s^2) replacing $s_f^2 - s_o^2$. Thus, the equation is further simplified to

$$x_a = s^2/2a$$

where x_a is in feet, s is in feet per second, and a is in feet per second^2. The total effective crossing width is w + cV as defined for Condition 1. Therefore, the distance across an intersection that a light rail vehicle is able to travel at full speed (R) is

$$R = (w + cV) - (s^2/2a) \quad (4)$$

If the value of R is greater than or equal to zero, the vehicle crosses at full speed for this distance and if R is less than zero, the vehicle is unable to attain operating speed in the distance covered by the effective crossing width.

For $R \geq 0$, the total clearance time is calculated by adding the time to accelerate plus the time the vehicle operates at a constant speed through the intersection. The acceleration time (t_a) is calculated by using the uniformly accelerated rectilinear motion equation:

$$s_f = s_o + at_a$$

This simplifies to

$$t_a = s/a$$

because either the final or the initial speed equals zero. The time at constant speed (t_c) is found by using the uniform rectilinear motion equation defined under Condition 1:

$$t_c = (x - x_o)/s$$

In this case $x - x_o$ is replaced by R and

$$t_c = (R/s) = [(w + cV) - (s^2/2a)]/s$$

The clearance time (t) becomes

$$t = t_a + t_c = (s/2a) + [(w + cV)/s] \quad (5)$$

For $R < 0$, the maximum velocity (s_m) attained by the light rail vehicle before clearing the intersection is again calculated by making use of a uniformly accelerated rectilinear motion equation simplified to

$$s_m = [2a(w + cV)]^{1/2}$$

The clearance time (t) is also found by using a uniformly accelerated rectilinear motion equation where

$$t = s_m/a = [2a(w + cV)]^{1/2}/a \quad (6)$$

Using Equations 5 and 6, the clearance times for various factor values have been calculated as shown in Figure 3.

Figure 3 shows that, for higher operating speeds, the full speed is usually not attainable, particularly for shorter trains and narrow intersections. This means that the operating speed under these conditions is irrelevant to the clearance time. However, when slower operating speeds are used, these speeds have a significant impact on clearance time, especially as train length and intersection width increase.

It should be noted that, for the case of deceleration, the clearance times calculated correspond to a far-side stop that occurs as soon as the vehicle is clear of the intersection. If, for example, the platform is longer than the train, the clearance time would be slightly decreased if the train did not stop until it reached the end of the platform farthest away from the intersection. The reason the clearance time would be decreased for this configuration is that the light rail train would be able to continue at operating speed for longer than the times calculated in Figure 3.

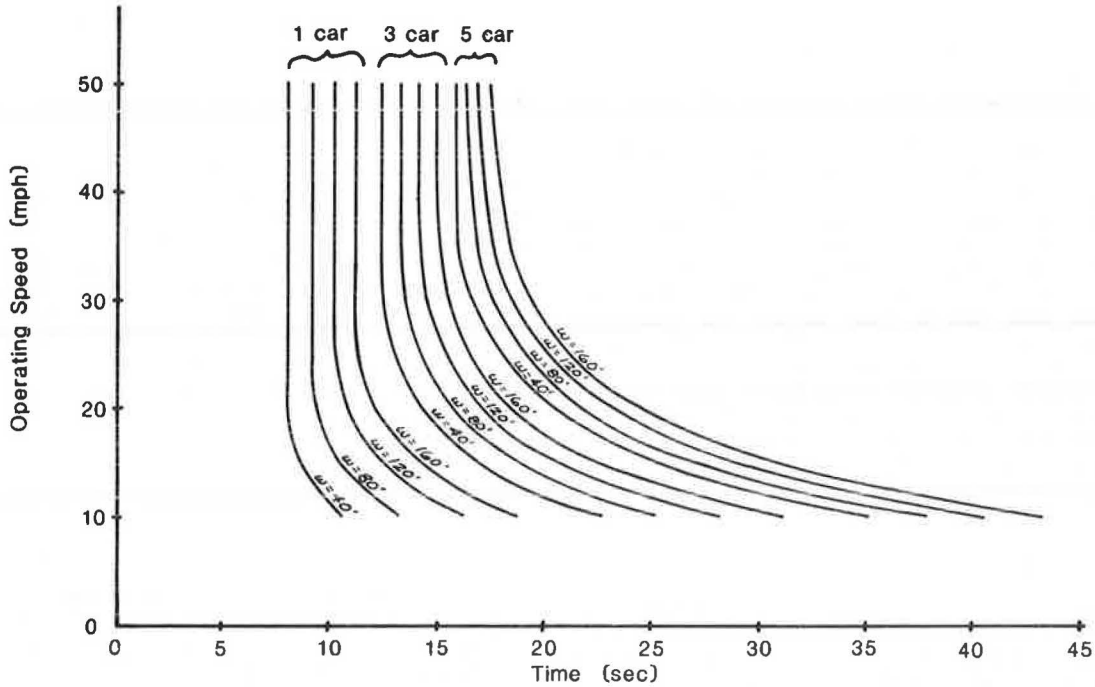

FIGURE 3 Light rail transit clearance time—deceleration to far-side stop or acceleration from near-side stop.

Condition 5

The condition of a far-side stop with emergency stopping considerations is similar to Condition 4 except that time for an emergency stop must be added to the total LRT clearance. The emergency stop factor is identical to that explained for Condition 2. Therefore, the equations for Condition 4 are modified as follows:

$$t = (s/2a) + [(w + cV)/s] + (s/e) + 4 \quad \text{for } R \geq 0 \quad (7)$$

$$t = \{[2a(w + cV)]^{1/2}/a\} + (s/e) + 4 \quad \text{for } R < 0 \quad (8)$$

Figure 4 shows the clearance times for various train lengths, intersection widths, and speeds. For any given train length and street width, there is an optimal operating speed at which crossing time is minimized. Speeds below this value create larger clearance times due to vehicle blockage of the intersection, and speeds above the optimum have greater clearance times due to consideration of emergency stop time. The optimum speed for given

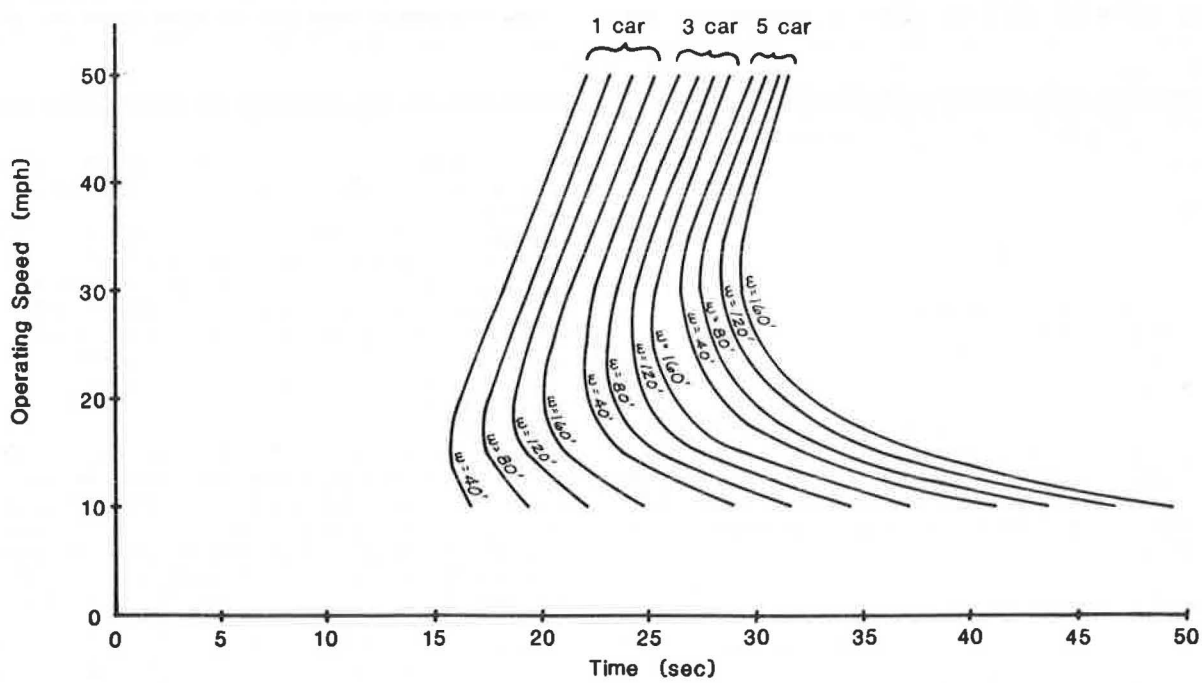

FIGURE 4 Light rail transit clearance time—deceleration to far-side stop including emergency stop.

conditions is calculated by taking the derivative of Equation 7 and setting this equal to zero to obtain:

$$s_{opt} = \{(w + cV)/[(1/2a) + (1/e)]\}^{1/2} \quad (9)$$

Equation 8 is not used for optimum speed calculations because the optimum speed is always attained before R becomes less than zero. As R becomes more negative, clearance time increases in a linear fashion.

Optimum speed increases with increasing train length and intersection width. At slow speeds, modifications in intersection width or train length create more noticeable time changes than they do at high speeds. Also, for slow speeds when train length and intersection width are large, a small change in speed can create a significant amount of change in clearance time.

Condition 6

The case where a light rail vehicle must first stop at the near side of an intersection and then stop again at the far side assumes that the vehicle will attempt to attain full operating speed, or the highest speed possible, before decelerating to a far-side stop. If the operating speed is attainable, the light rail vehicle will operate at this constant speed until it is necessary to begin deceleration from the service rate.

As for previously described conditions, the uniformly accelerated rectilinear motion equation is best used to determine light rail clearance time:

$$s_f^2 = s_o^2 + 2a(x - x_o)$$

This is similar to Condition 3 in that the value of R must first be calculated. For Condition 6 this is done by subtracting the distance required to accelerate to operating speed and then to decelerate back to zero (x_{ad}) from the effective crossing distance (w + cV). Because x_{ad} would be twice the acceleration distance (x_a) defined for Condition 3, x_{ad} can be expressed as

$$x_{ad} = 2x_a = 2(s^2/2a) = s^2/a$$

Therefore, the distance across the intersection that the light rail vehicle is able to travel at operating speed is

$$R = (w + cV) - (s^2/a) \quad (10)$$

If $R < 0$, the operating speed is unattainable for the given factor values.

For $R \geq 0$, the light rail clearance time is calculated by adding the time required for accelerating and then decelerating the vehicle (t_{ad}). The time t_{ad} is equal to twice the time to accelerate (t_a), assuming the service acceleration and deceleration rates are the same, and can be expressed as

$$t_{ad} = 2t_a = (2s/a)$$

The time at operating speed (t_c) is calculated by

$$t_c = R/s = \{[(w + cV) - (s^2/a)]/s\}$$

The clearance time (t) becomes

$$t = t_{ad} + t_c = (s/a) + [(w + cV)/s] \quad (11)$$

For $R < 0$, the maximum attainable speed (s_m) must be calculated using the uniformly accelerated rectilinear motion equation:

$$s_f^2 = s_o^2 + 2a(x - x_o)$$

In this case the vehicle can accelerate for only one-half the distance across the intersection before decelerating as shown in Figure 5. Therefore, $(x - x_o)$, by making substitutions, becomes

$$(x - x_o) = [(w + cV)/2]$$

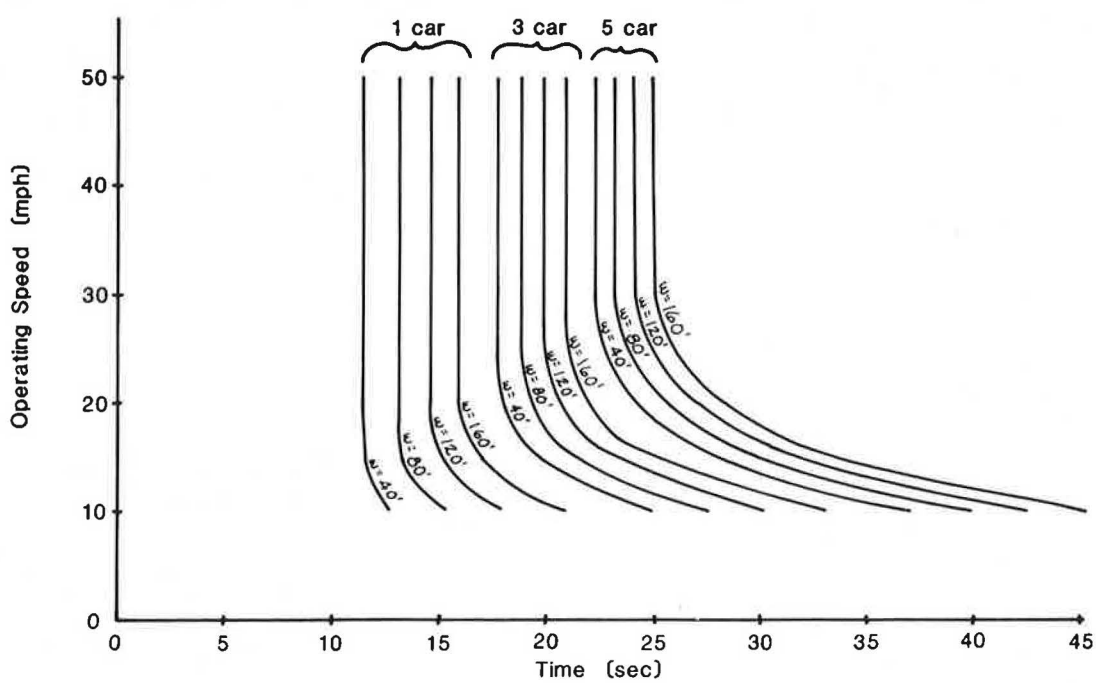

FIGURE 5 Light rail transit clearance time—acceleration from stop and then deceleration to a stop at far side of intersection.

TABLE 1 Summary of Equations

Description	Equation	Equation No.
Constant speed (Condition 1)	$t = (w + cV)/s$	(1)
Constant speed with emergency stop (Condition 2)	$t = [(w + cV)/s] + (s/e) + 4$	(2)
Acceleration or deceleration (Conditions 3, 4)	$R = (w + cV) - (s^2/2a)$	(4)
	for $R \geq 0$: $t = (s/2a) + [(w + cV)/s]$	(5)
	for $R < 0$: $t = [2a(w + cV)]^{1/2}/a$	(6)
Deceleration with emergency stop (Condition 5)	$R = (w + cV) - (s^2/2a)$	(4)
	for $R \geq 0$: $t = (s/2a) + [(w + cV)/s] + (s/e) + 4$	(7)
	for $R < 0$: $t = \{ [2a(w + cV)]^{1/2}/a \} + (s/e) + 4$	(8)
Acceleration then deceleration (Condition 6)	$R = (w + cV) - (s^2/a)$	(10)
	for $R \geq 0$: $t = (s/a) + [(w + cV)/s]$	(11)
	for $R < 0$: $t = 2[a(w + cV)]^{1/2}/a$	(12)

Substituting this and the speed components, the equation becomes

$$s_m^2 = 2a[(w + cV)/2] = a(w + cV)$$

$$s_m = [a(w + cV)]^{1/2}$$

The clearance time is then found by adding the time to accelerate (t_a) to the time to decelerate. Because acceleration and deceleration rates are equal for this analysis, $2t_a$ can be used, which becomes

$$t = 2t_a$$

$$t = 2(s_m/a) = 2[a(w + cV)]^{1/2}/a \quad (12)$$

Figure 5 shows the clearance times for varying street widths, operating speeds, and train lengths. The values calculated here, again, assume that the far-side stop occurs the instant the light rail vehicle is clear of the intersection (as explained for Condition 4).

Figure 5 shows that most higher operating speeds are unattainable regardless of the effective crossing distance and that the operating speed is only a factor in clearance time at slower speeds. Also, at slower speeds, the impact on clearance time becomes greater as speed decreases and train length and intersection width increase.

COMPARISON OF OPERATIONAL CONDITIONS

A summary of the equations that are critical in calculating clearance times for each of the six described conditions is given in Table 1.

For Conditions 2 and 5, in which emergency stop considerations are included, an optimum speed exists that minimizes overall clearance time. The optimum speed equations are given in Table 2.

The variables for all the equations given in Tables 1 and 2 are summarized as

- t = total clearance time (sec),
- w = intersection width (ft),
- c = LRT vehicle length (ft),
- V = number of vehicles in train,
- s = operating speed (ft/sec),
- e = emergency braking rate (ft/sec^2),
- R = distance light rail vehicle is able to travel across an intersection at operating speed (ft),
- a = acceleration (or deceleration) rate (ft/sec^2), and

TABLE 2 Optimum Speed Equations

Condition	Equation	Equation No.
2	$s_{opt} = [e(w + cV)]^{1/2}$	(3)
5	$s_{opt} = \{(w + cV)/[(1/2a) + (1/e)]\}^{1/2}$	(9)

- s_{opt} = optimum operating speed across intersection (ft/sec).

Figure 6 shows selected curves for each of the previously discussed operating conditions. Only the curves for selected train lengths (one and five cars) and intersection widths (40 and 160 ft) have been included. This should give a feel for the range of impacts on clearance time without cluttering and confusing the graph.

The curves in Figure 6 show that constant light rail speed without emergency stop considerations obviously results in the lowest clearance times. However, in most cases, emergency stop time should be considered to allow a margin of safety. Given this, the acceleration condition (in which no emergency stop consideration is necessary) would create the least intersection impact. At slower speeds, or where intersection widths and train length are minimized, the condition under which the vehicle accelerates from a near-side stop and then decelerates to a far-side stop (Condition 6) would result in the next lowest intersection clearance times. In most cases, decelerating to a far-side stop with provision for emergency stopping results in the worst intersection clearance time.

LIGHT RAIL HEADWAYS

All light rail clearance times presented so far account only for an individual LRT vehicle interruption of an intersection. Most analyses involve the comparison of impacts on an hourly basis. Therefore, the light rail headways during a 1-hr period should be considered.

The hourly clearance time (T_h) required by LRT is the individual interruption clearance time (t) times the number of intersection interruptions per hour (i). The total number of intersection interruptions accounts for headways in both directions of travel and is normally figured as twice the frequency for one direction. The equation is

$$T_h = ti \quad (13)$$

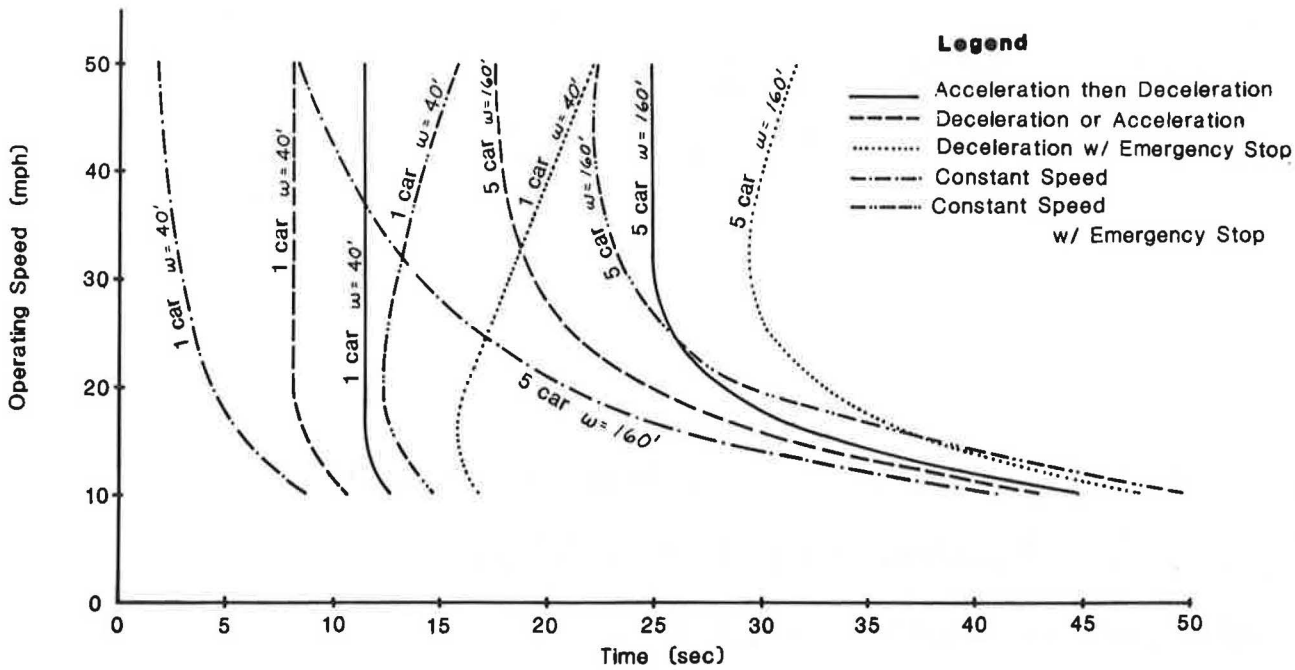

FIGURE 6 Comparison of clearance times under various operating conditions.

OTHER FACTORS AFFECTING CLEARANCE TIME

In addition to the interrelated factors discussed in the previous section, there are other factors that can cause clearance time to be added to the values calculated earlier. Two factors that will be discussed are railroad gates and clearance windows.

Railroad Gates

In some instances railroad gates are used to control traffic at light rail crossing locations. Gates are used either by themselves or in conjunction with traffic signals. The time to lower and raise gates varies somewhat from one railroad to the next, but a typical time would be about 22 sec (2). This includes about 10 sec to drop the gate and up to 12 sec to return the gate to an upright position.

When emergency stopping is considered as part of the control strategy, the railroad gates would be completely down at the time the light rail vehicle would need to begin its emergency braking rate. This allows light rail vehicle operators to see if automobiles are stopped on the tracks after the gate is completely down. If the intersection is blocked, the rail vehicle would be able to stop short of the intersection by applying the emergency stopping rate.

Clearance Windows

When using certain types of control strategies, it may be desirable to add a few more seconds to the LRT clearance interval than what is required to clear the intersection. This time, referred to as a clearance window, allows for irregularities in light rail vehicle operations. This concept is particularly applicable to the strategy in which light rail vehicles are progressed through the corridor. If, for example, the light rail vehicle is unable to maintain the progression speed, a clearance window provides a greater probability that the vehicle will arrive at the intersection without having to stop. The amount of clearance window added to the clearance time depends on several factors including potential disruptions to cross-street traffic and the reliability of the light rail progression speed. The clearance window might typically be in the range of 5 to 10 sec.

CONCLUSIONS

Several factors that influence the performance of intersections when LRT is implemented have been identified in this study. These factors can be categorized as follows:

- Light rail vehicle operating characteristics,
- Prevailing intersection geometrics, and
- Traffic control methods.

The analysis performed here has demonstrated that light rail intersection clearance time varies considerably under different conditions. For the interrelated conditions analyzed, the clearance time ranged anywhere from 3 sec up to about 50 sec. Times would be even greater if a clearance window or railroad gates were provided. In general, it was found that clearance time increases with longer train lengths and greater intersection width. Clearance time is also increased as speeds decrease, as long as emergency stop considerations are not included. When provision is made for emergency stopping, an optimum speed can be computed. This optimum speed becomes higher as train length and intersection width are increased.

It is important to remember that LRT clearance time does not necessarily show the impacts on automobile capacity at an intersection. LRT clearance time is only one component of intersection capacity analysis. Further study is needed to determine an LRT analysis procedure that is compatible with the Highway Capacity Manual.

REFERENCES

1. T.F. Larwin and H. Rosenberg. Traffic Planning for Light Rail Transit. Institute of Transportation Engineers, Washington, D.C., 1978.
2. De Leuw, Cather and Company. Southeast Corridor Preliminary Engineering: Traffic Control. Draft. Denver Regional Transportation District, Denver, Colo., Aug. 1982.

Publication of this paper sponsored by Committee on Traffic Flow Theory and Characteristics.

Evaluation of Queue Dissipation Simulation Models for Analysis of Presence-Mode Full-Actuated Signal Control

FENG-BOR LIN

ABSTRACT

Full-actuated signal control may rely on long inductive loop detectors for detecting the presence of vehicles. The operation of this mode of control is governed primarily by the interactions between the detectors and queueing vehicles. To facilitate reliable simulation analyses of such a signal control, the queue dissipation characteristics in relation to the detectors should be properly modeled. The queue dissipation models used in the NETSIM program and the Value Iteration Process--Actuated Signals program are evaluated. These models are found to be capable of producing realistic departures of queueing vehicles from a detection area. The models are rather weak, however, in representing other aspects of vehicle-detector interactions. Possible modifications of the models are discussed.

Queue dissipation is a troublesome phenomenon that has to be dealt with in the simulation of traffic flows at a signalized intersection. Proper modeling of this phenomenon is imperative if a model is to be used for simulation analysis of presence-mode full-actuated signal control. The reason for this can be found in the logic of this mode of control.

The basic logic of presence-mode full-actuated control is rather simple. A vehicle can demand or hold the green light by occupying a detection area. The detection area is usually defined by a long inductive loop detector. After the vehicle leaves the detection area, the green is extended by a duration equal to a preset vehicle interval. To continue holding the green, another vehicle must enter one of the detection areas of the same signal phase before the vehicle interval expires. The phase duration is limited by a preset maximum green interval. The timing of this interval begins with the actuation of a detector by a vehicle in an opposing phase.

Because the vehicle interval is usually set at a value close to 0 sec, the queueing vehicles in a lane have a much better chance of holding the green than do those not in the queue. Consequently, the phase durations of this mode of control are governed by the queue dissipation characteristics in relation to the detectors. In a dissipating queue, vehicles enter and depart from a detection area in a dynamic and probabilistic manner. This results in a sequence of detector actuations and departures that determines whether the queueing vehicles can extend the green continuously. If such relationships are not properly modeled, the simulated operation of the signal control will deviate from reality.

The dynamic and probabilistic nature of the interactions between the queueing vehicles and the detectors is rather difficult to simulate adequately. To compound the problem, past efforts at modeling queue dissipation were focused on queue discharge headways (1). Not until recently have efforts been made to investigate the nature of the queue dissipation in relation to presence detectors (2). The lack of a comprehensive treatment of this subject is unsettling. It raises the issue of whether the queue dissipation models used in existing signal simulation programs are realistic.

The purpose of this paper is to explore this issue by evaluating two existing queue dissipation simulation models. These models are part of the microscopic simulation models used, respectively, in the Value Iteration Process--Actuated Signals program (3) and the NETSIM program (4). The evaluation