Table 1. Annual cost of cars by length.

Car		Annual Cost ($)				
Length (m)	Number	Power[a]	Capital	Maintenance	Operating	Total
12.2	259	3 600 000	3 400 000	600 000	1 200 000	8 800 000
18.3	192	6 300 000	2 700 000	1 900 000	1 200 000	11 100 000
22.9	142	7 000 000	2 400 000	2 900 000	1 200 000	13 500 000
25.9	108	8 300 000	2 300 000	3 600 000	1 200 000	15 400 000

Note: 1 m = 3.3 ft.

[a]As the total number of cars decreases, the cost of power will also decrease; however, these decreases are not at the same rate. As the length and mass of the car increase, the power consumption also increases.

be a 25.9-m (85-ft) car length. Thus, the important car features would be as follows (1 m = 3.3 ft; 1 kg = 2.2 lb; 1 kW = 1.4 hp; 1 m/s^2 = 3.3 ft/s^2; and 1 MJ = 0.3 kW·h).

Feature	Dimension or Description
LENGTH	25.9 m
WIDTH	3.2 m
CAR WT	60.8 Mg/empty car
CAPACITY	280 passengers/84-seat car
PM	97 kW/motor
MAX VEL	80.5 km/h
AVGVEL	32.2 km/h
STA SPAC	0.8 km
DWELL	30 s
ACC	1.1 m/s^2
DEC	1.1 m/s^2
CAR COST	$224 000/car in 1972 dollars
POWER CONSUMPTION	
TRACT	27.3 MJ/car·km
AUX	5.4 MJ/car·km
Total	32.7 MJ/car·km

In addition to the above, a total of 644 cars is needed to operate this route. This total accounts for 22 percent of the cars being out of service for maintenance at any time. During rush hour, trains having six cars each would be used (6 cars × 280 people/car = 1680 people/train).

The total annual costs for this solution are as follows (1 MJ = 0.3 kW·h and 1 km = 0.6 mile).

Item	Annual Amount ($)
Capital cost for 644 cars, 35 years and 7 percent	11 000 000
Power cost, 0.6 cent/MJ and 53 100 000 car·km	6 600 000
Operating cost, 2 crewmen/train and $8/h; including fringe benefits	3 200 000
Maintenance cost for 644 cars and 53 100 000 car·km; $6/h, including fringe benefits	1 300 000
Total	22 100 000

In many cases, the length of a car is predetermined. The upper limit may be determined by tunnel clearances, or an operating authority may desire to order new cars that match existing cars for mating purposes. In this case, it is interesting to examine the difference in total costs between the optimum length and the desired length.

For a system in which 12.2 m (40 ft) was determined as the best solution, the values of 18.3, 22.9, and 25.9 m (60, 75, and 85 ft) were fixed respectively. The resulting annual costs are given in Table 1.

SUMMARY

There are many possibilities for using this methodology. Sensitivity analyses have shown that the program operates realistically, that is, a slight change in the maintenance life of a wheel bearing will not affect car length or any other major design feature. Cost comparisons may be made for cars of different lengths, various interest rates on capital investment, and various system parameters such as headway, demand, and system length. The program may be updated for new data and new costs to account for inflation, changing technology, and other factors.

ACKNOWLEDGMENT

This study was conducted under a research and training grant from the Urban Mass Transportation Administration of the U.S. Department of Transportation. The opinions and findings expressed or implied in this paper are ours and are not necessarily those of the sponsor. This paper is taken from Huss' dissertation submitted to the faculty of the Polytechnic Institute of New York in partial fulfillment of the requirements for the degree of doctor of philosophy in transportation planning and engineering.

Publication of this paper sponsored by Committee on Rail Systems Planning and Development.

Abridgment

At-Grade Crossings of Light Rail Transit

David Morag, De Leuw, Cather and Company

The growing interest in the performance characteristics of light rail transit (LRT) is primarily related to taking advantage of a wide variety of rights-of-way and employing a broad range of station configurations. Newly proposed light rail transit systems may be on an exclusive right-of-way (ROW), within existing streets, or on a semiexclusive ROW, which means that the transit line is on an exclusive ROW but has an at-grade, protected crossing at intersections with streets. The impact of semiexclusive lines on motor-vehicle traffic is analyzed in this paper.

A major concern for transportation planners in considering semiexclusive LRT lines is the potential impact these lines have on traffic at grade crossings where there is high-frequency and priority LRT operation. The purpose of this paper is to provide a methodology for analyzing and estimating the effect of semiexclusive LRT line on motor-vehicle traffic. The estimates of traffic volumes through at-grade crossings per lane per hour presented in this paper may be compared with actual traffic counts on city streets to provide a basis for comprehending the following major concerns of the planner:

1. The expected level of impact on traffic,
2. The restrictions required on the crossing approaches,
3. The improvements required in terms of added lanes, and
4. The minimum grade separation requirements.

BASIC OPERATIONAL DEFINITIONS

The wide variety of existing characteristics of light rail vehicles (LRVs) and the proposed operational philosophies for LRT that could affect this analysis require that this paper be restricted to discussing the following set of operational definitions that are common to many of the newly proposed LRT systems.

1. The operational characteristics of the standard LRV are used exclusively in numerical computations.
2. The average characteristics of motor vehicles are used.
3. The LRV is capable of crossing protection by preemption and of traversing the crossing at the average operating speed. (Preemption is actuated from a distance that is sufficient for safely stopping the LRV in the event of crossing protection failure.)
4. The crossing protection method assumed for this analysis is the conventional railroad gates (2).

In general, this analysis assumes that, for the achievement of adequate schedule speeds, an LRT system must be able to minimize the number of stops and acceleration-deceleration maneuvers per trip.

METHODOLOGY

Crossing Time Limitations

The number of motor vehicles per hour per lane at an at-grade crossing is limited by the total time per hour during which the crossing protection system is not actuated (open gates). In concept, this total time is equal to the total green signal time in conventional traffic signals. However, in the case in which the street crossing is preempted by the LRV and in which train arrivals are totally synchronized, the cycle time is equal to the headway of the operating train. For this case, the total green signal time for motor-vehicle crossings is equal to the headway of the LRV minus the time for the LRV to preempt, advance to, and clear the crossing and the time for the gates to reopen.

For totally synchronized LRV arrivals, the total crossing time per cycle available for motor vehicles [$G^*(\psi)$] is defined in Equation 1. The variables are defined in Table 1.

$$G^*(\psi) = h - [(b - 1)(KV/2d)] - [(\psi L + nW + C)/V] - [(\alpha + \gamma R)/S] - (S/2a) - (T + t + \phi) \quad (1)$$

For the general case in which bidirectional LRV operation is maintained on a dual-track facility, the total green signal time for motor-vehicle crossing will depend on the probability of synchronized LRV arrivals at the crossing. If it is assumed that there are three levels of options (totally synchronized, totally unsynchronized, and half synchronized) and the probability theory is used, then the expression for total crossing time per cycle available for motor vehicles [$G(\psi)$] is obtained as shown in Equation 2.

$$G(\psi) = G^*(\psi)^2/h \quad (2)$$

Therefore, the ratio of motor-vehicle crossing time to total cycle time (G/C) is

$$G/C = G(\psi)/h \quad (3)$$

The ratio G/C that is defined in Equation 4 assumes that the LRVs traverse the intersection at their operating line speed (V).

Locating LRT stops just before and after street crossings is common in the designs of many LRT systems. The crossing of an LRV that accelerates from a stop or decelerates to a stop on the far side of the crossing affects the crossing time available for motor vehicles in different ways. LRVs that accelerate from stops have the least impact, since LRVs are available at the crossing side and proceed once the protection system is actuated. The impact on crossing time for synchronized LRV arrivals [$g^*(\psi)$] is

$$g^*(\psi) = h - [(2/d_0)(\psi L + nW + C)]^{0.5} - (S/2a) - [(\alpha + \gamma R)/S] - (t + \phi) \quad (4)$$

To account for the probability of synchronized train acceleration from stops at both approaches, the ratio of motor-vehicle time to total cycle time (g/C) is used.

$$g/C = g(\psi)/h \quad (5)$$

The G/C and g/C ratios are used to compute traffic volumes.

Vehicle Flow Calculations

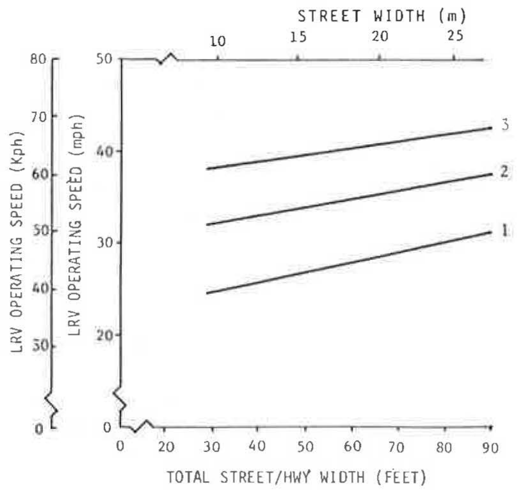
The calculations of vehicle flow through at-grade crossings are based on G/C, g/C, and a value for base flow per lane per hour (1). The base flow value used in this paper refers to an LRT system that operates in a location on the fringe of a metropolitan area that has a population of 1 million. Traffic operation during peak hour is at level of service D. The average flow includes trucks and buses (8 percent), and parking and turn movements on the crossing approaches are prohibited. The

Table 1. Typical parameter values.

Symbol	Variable	Value
K	Design safety factor of LRT for headway protection	1.35
T	Reaction time of LRV attendant and controls, s	2.5
t	Average reaction time of motor-vehicle driver, s	1.0
V	Operating line speed of LRV, km/h	8 to 48.3
S	Average speed of motor vehicle, km/h	40.3
R	Width of single LRT track and clearance, m	7.16
W	Width of single lane, m	
	Two-lane street	3.2
	Three-lane street	3.35
	Four-lane arterial street	3.5
	Six-lane divided highway	3.66
C	Width of curbs, medians, and clearances, m	
	Two to three-lane street curbs and clearances	2.44
	Four-lane arterial street and median	3.66
	Six-lane divided highway and median	5.49
γ	Number of LRT tracks at crossing	2
n	Number of traffic lanes of street or highway	2, 3, 4, 6
d	Deceleration rate of Boeing LRV, m/s^2	2.65
d_0	Acceleration rate of Boeing LRV, m/s^2	1.37
a	Average deceleration rate of motor vehicle, m/s^2	4.57
ϕ	Reaction and verification time of Webco gates, s	9
L	Length of single Boeing LRV, m	21.64
α	Average length of motor vehicle, m	6.1
b	Number of blocks in control design for LRT headway protection	2
ψ	Number of cars in LRT consist	—
h	Operating headway of LRV	—

Note: 1 km/h = 0.62 mph; 1 m = 3.28 ft; and 1 m/s^2 = 3.28 ft/s^2

Figure 1. Optimum LRV operating speed at an at-grade crossing to minimize impact on traffic.



maximum motor-vehicle flow (F) per peak hour per lane through at-grade crossings occurs at G/C = 1.0. This flow was determined to be

$$F = 740(0.85)(1.2)(1.3)(0.97)(1.14)(1.25) = 1356 \quad (6)$$

Optimum LRV Operating Speed

The expression derived in the previous section for motor-vehicle flow per hour per lane indicates that, for any given set of constant parameters that define the characteristics of street lane, track, and motor vehicle, there is an LRV operating speed (V) that will maximize the number of motor vehicles through the crossings. The optimum operating speed (V_{opt}) is obtained by taking the time derivative (dv/dt) and equating it to zero.

$$V_{opt} = \{[2d(\psi L + nW + C)]/[(b - 1)K]\}^{0.5} \quad (7)$$

LANE CAPACITY ESTIMATES

The variables used to calculate the estimated flow per

Figure 2. Motor-vehicle flow per hour per lane by LRV consist size and operating speed.

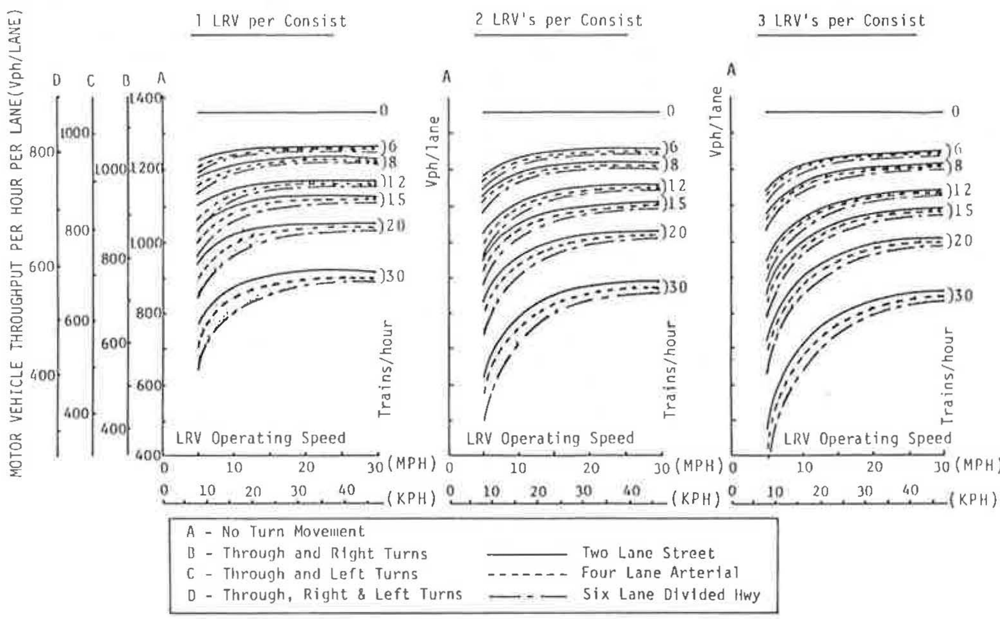
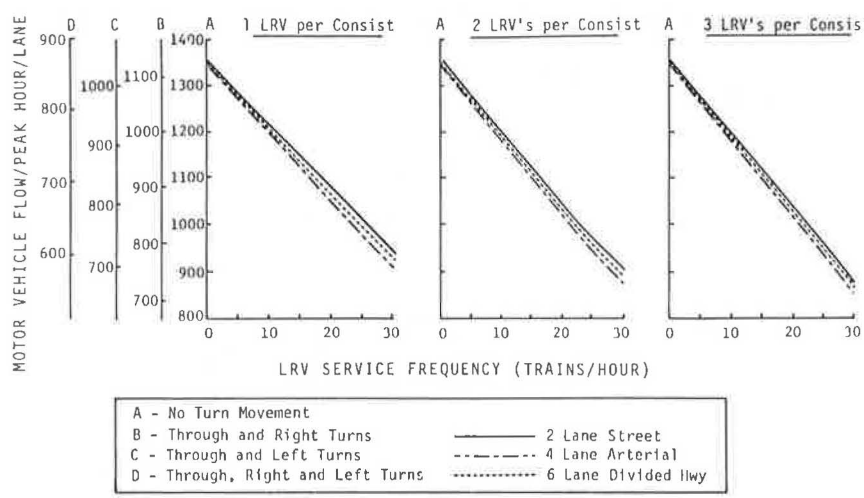


Figure 3. Motor-vehicle flow per hour per lane by LRV consist size and service frequency.



peak hour per lane through at-grade crossings on semiexclusive LRT line-street intersections are given in Table 1 and are typical for the average motor vehicle, LRT tracks, and street lanes. This analysis is based on the Boeing articulated LRV. Optimum LRV operating speed for minimum traffic impact is obtained by substituting the values given in Table 1 into Equation 7. The optimum LRV operating speed is shown in Figure 1.

Case 1 Flow Estimates

Case 1 applies to the LRV that traverses intersections at its average operating speed. By substituting the values given in Table 1 into Equation 6 and by using G/C as defined in Equation 4, the vehicle flows (vehicles per peak hour per lane) through an at-grade crossing for a two-lane street, a four-lane arterial, and a six-lane divided highway were computed. A summary of the flow estimates and a comparison of the sensitivity of traffic flow per peak hour per lane to LRV consist size and operating speed are shown in Figure 2. The traffic flow per hour per lane with fewer movement restrictions (B, C, and D scales) is also shown in Figure 2.

Case 2 Flow Estimates

The flow estimates for case 2 deal with the special case described in Equation 5 in which the LRV consist accelerates through an at-grade crossing from a transit stop that is located at the intersection approaches. By substituting the values given in Table 1 into Equation 6 and by using g/C as defined in Equation 5, the estimated volumes of motor-vehicle flow per peak hour per lane through an at-grade crossing for a two-lane street, a four-lane arterial, and a six-lane divided highway for various LRT service frequencies and consist sizes were computed. A comparison of flows by both throughput and sensitivity to street width, consist size, and service frequency is shown in Figure 3. The flow estimates for case 2 are independent of LRV speed, since continuous acceleration through the crossing is assumed. Once the train clears the crossing, the peak speeds achieved by the crossing LRVs were found to be well within the operational limits.

SUMMARY AND CONCLUSIONS

The methodology and lane capacity estimate developed in this paper are designed to aid the transportation planner in the analysis of traffic impact due to the implementation of semiexclusive LRT lines. This type of analysis may provide the planner with the tool by which the grade separation requirement could be minimized or staged to some future year for the cases in which the motor-vehicle flow that was estimated at the time of the analysis would exceed the crossing capacity, the additional ROW for crossing improvement was unavailable or too costly, or totally grade-separated intersection must be considered.

The results of this analysis indicate that the deployment of LRT semiexclusive lines in fringe areas is a feasible alternative to transit lines that are totally grade-separated, fixed guideways. This analysis also indicates that, for LRT systems planned for multicar consist operation at high service frequencies, locating transit stops at grade-crossing approaches is desirable to reduce traffic impact.

However, this analysis considered only independent at-grade crossing situations, and additional considerations would be required to analyze the impact of at-grade crossings on adjacent intersections with signals. These intersections may require synchronization with the preempted crossing protection system.

REFERENCES

1. Highway Capacity Manual. HRB, Special Rept. 87, 1965.
2. Railroad-Highway Grade Crossing Warning Systems. Association of American Railroads, Bulletin 7, 1974.

Publication of this paper sponsored by Committee on Rail Systems Planning and Development.

Abridgment

Impact of Transit Line Extension on Residential Land Use

Paul J. Ossenbruggen, College of Engineering and Physical Sciences, University of New Hampshire
Michael J. Fishman, Real Estate Department, J. C. Penney Company, Inc., New York

Land users can be defined as those members of society who continually weigh the characteristics of land sites to determine the suitability of each site for a particular social or economic need. If the characteristics are suitable, then one or more land users might exert pressure for changing or redeveloping a given site. To evaluate the impacts of new transportation systems on land development, transportation and land use planners must be able to identify the important physical, institutional, and transportation characteristics that are responsible for the change (2). One physical characteristic is the suitability of urban land for residential, recreational, industrial, or governmental uses. One transportation characteristic is the accessibility of a given site to employment, shopping, and recreation opportunities. A particular combination of physical and transportation characteristics will generate interest and action by certain land users to develop a given site. To control land