For LRT, in addition to high-level platforms, there are two options for providing wheelchair access to the vehicles at low-level platforms. The first method is to install wheelchair lifts on each vehicle similar to the bus lifts (San Diego). The major disadvantages of this system are the time delays when operating the lift and the vehicle maintenance and reliability problems associated with on-board lifts. In addition, with double-ended cars, two lifts per car would be required. The second method is to provide a fixed-location wheelchair lift at each LRT station (Portland). The advantage to this system is simpler car design, the avoidance of interference with train operations due to lift failures, and less expensive capital and operating costs. Disadvantages include alignment of the front door of the LRV with the platform lift, time delays to operate the lift, vandalism and security problems in an exposed urban environment, and maintenance at a number of far-flung locations rather than all at the LRV maintenance yard.

- Fare Collection: The fare collection method along the downtown transit mall must be fast, convenient, and easily understandable. Options include self-service fare collection, a free-fare zone within the downtown, or the standard, pay-as-you-enter, front-door farebox system. The advantages of the self-service fare or the free-fare zone include speeding up boarding, reducing dwell times, and reducing the platform space required for passengers. The major disadvantage of the self-service fare is that fare collection machines would have to be installed in a hostile urban environment. The major disadvantage of the free-fare zone in downtown would be the loss of revenue to the transit district.

SUMMARY

In summary, it has been shown that there are a variety of factors that must be considered in the design of a bus and/or LRT transit mall. Analysis of these factors will often indicate the type of mall design that is appropriate for a given situation, and, as has been demonstrated by the diversity of mall designs for the cities mentioned in this paper, there is not a single mall design that can be universally accepted as best.

The proposed San Jose transit mall will use a unique design solution that is expected to provide the maximum transportation and land use benefits to downtown San Jose. This solution was arrived at after consideration of the same common design factors reviewed by the mall designers of San Diego, Buffalo, Calgary, Denver, Portland, and Sacramento. Because of the inherent differences among cities, however, each mall design is unique in its own way.

Once a mall design concept has been chosen, the designer is faced with the task of picking the individual elements. The selection of each mall building block should be done carefully and with a great deal of thought. There will be much community debate over the best paving material to use, lighting fixtures, street trees, etc., and the mall designer will do well to listen to everyone's input in order to tailor the mall to the city and people who will be using and paying for it.

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1. San Jose Transit Mall Technical Report. Santa Clara County Transportation Agency, City of San Jose, April 1981.

2. Streets for Pedestrians and Transit: An Evaluation of Three Transit Malls in the United States. UMTA-DOT Final Report, February 1979.

Traffic Impacts of Light Rail Transit

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In August 1981, the San Diego Metropolitan Transit Development Board (MTDB) began operation of light rail vehicle service from downtown San Diego southerly to the San Ysidro International Border. This 16-mile-long light rail system operates for most of its length in joint use with freight service in an at-grade, double-track operation (Figure 1). In the Centre City, trolleys operate at-grade on an exclusive path within city streets. The general alignment (Figure 2) includes C Street, which is ultimately planned as a transit and pedestrian way.

During the first 4 months of operation, the trolley system carried 1 854 000 passengers. Daily ridership averaged 11 500, with 14 000 to 17 000 passengers using the system on Saturday.

Even before the south line of the trolley was put into operation, MTDB began planning for an East Line extension. The general alignment for the East Line extension is shown in Figure 3. The extension includes 13 passenger stations spaced about 1.25 miles apart. The East Line extension is described in more detail in the Appendix to this paper.

Although the feasibility study for the East Line showed the extension to be practical in terms of patronage estimates, construction impacts, and overall environmental impacts, there were some questions regarding potential impacts of light rail vehicles on traffic operations in the downtown areas of the cities of Lemon Grove and La Mesa. In these two areas, the light rail vehicles would operate parallel to the major north-south streets serving the two business districts. In Lemon Grove (Figure 4) the light rail tracks would actually be located between Imperial Avenue (a citywide arterial street) and Main Street (a business district collector street). The light rail vehicles through La Mesa (Figure 5) would operate at-grade between Spring Street (an arterial street) and Nebo (a local collector street).

Because of the potential effect of light rail vehicle operations on the east-west streets crossing the tracks, the businessmen and city councils of both cities expressed serious concerns over downtown traffic operations that might result from implementation of the East Line trolley extension. The purpose of this paper is to review the existing and potential operations of the streets within the downtown areas of Lemon Grove and La Mesa to evaluate

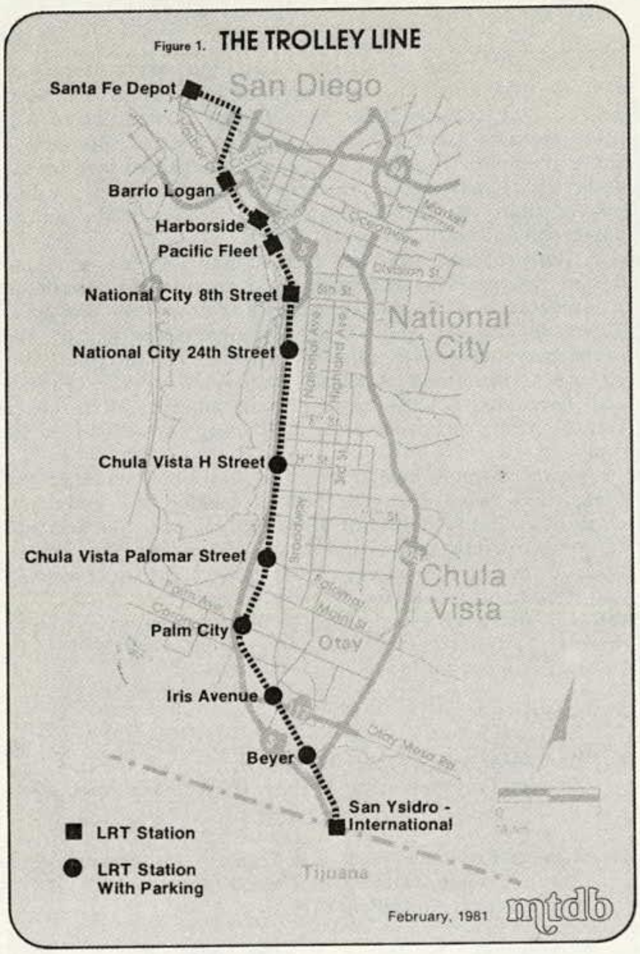


Figure 1. THE TROLLEY LINE

the potential impacts of the trolley at-grade operations.

EXISTING CONDITIONS

Within the City of La Mesa, Spring Street is a 4-lane street providing additional roadway width for left-turn pockets at major intersections. Spring Street carries approximately 2 400 total vehicles in the afternoon peak hour.

In Lemon Grove, Imperial Avenue serves as the main north-south artery, also providing a general 4-lane cross section with left-turn lanes at major intersections. Imperial Avenue carries approximately 2 000 vehicles in the afternoon peak hour.

Analysis of traffic operations during the afternoon peak hours showed that each downtown area had one intersection operating at level of service D, with the remaining intersections all working at more acceptable levels of service.

TRAFFIC IMPACT ANALYSIS

Duration of LRT At-Grade Crossing

The time needed for the LRT train to cross the at-grade intersections is based on several variables. The LRT and gate operating characteristics and the intersection geometrics generally influence the duration of LRT at-grade crossings.

The duration analysis was conducted using a "worst-case" condition. The LRT will travel at various speeds and dwell for different times as necessary for passenger operations. Moreover, the duration of the trolley stop will depend on the number of passengers boarding and alighting during a certain period of time. As shown in Table 1, the "worst-case" condition was established to reflect the peak demand during the afternoon peak hour on weekdays. The travel speed was estimated to be 20 percent slower than the usual speed in the downtown area to give conservative consideration to the gate blockade. Other operating characteristics of the "worst-case" condition (which match the South Bay LRT operations) are also shown in Table 1.

For those LRT vehicles going through the intersections, the intersections would be blocked for the 25-second lead time, plus the time it takes to proceed through the intersections, plus the time it takes to raise the gates. For those LRTs dwelling at the intersections for passenger operations, another 20 seconds for passenger boarding and alighting and 6 seconds for LRT acceleration and deceleration would be added to the gate blockade. As shown in Table 2, the resultant durations of gate blockade at the 11 major intersections range from 48 seconds to 74 seconds. It should be noted that these durations represent the "worst-case" condition. If the trolleys travel faster (for example, 30 mph), the durations could be reduced accordingly.

Estimation of Vehicular Queue at LRT Crossing

In urbanized areas, the traffic flow is usually controlled by the traffic signal system. As a result of this control system, the traffic arrives at intersections "cluster by cluster." The flow characteristics would be described by the equation of the Poisson distribution in general:

$$f(x; \lambda) = e^{-\lambda} \frac{\lambda^x}{x!} \text{ for } x = 0, 1, 2, \ldots$$

where λ is the arrival rate.

For the purposes of this analysis, the statistical significance of the 95 percent confidence level was used. Therefore, the Poisson distribution equation could be expressed as follows:

$$F(x; \lambda) = \sum_{k=0}^{x} e^{-\lambda} \frac{\lambda^k}{k!} = 95\%$$

The traffic characteristics mentioned earlier were used to estimate the vehicular queues for different approaches at the 11 intersections. The results of these analyses are summarized in Table 3.

Estimation of Time for the Queue to Dissipate

The first phase after the LRT leaves the intersection is always given to the traffic movement with the longest queue. The signal timing for this movement is based on the time needed to dissipate the queue.

The times needed for the vehicular queues to dissipate were estimated using Greenshields's model: Time needed to dissipate = 3.7 seconds + 2.1 seconds $x(n - 1)$, where n is the number of vehicles in the queue. Although it is known that Greenshield's estimation on the starting delay is fairly conservative (especially since the first vehicle in the queue would not need 3.7 seconds to leave after a 50-second gate blockade), it was used because of the safety consideration. The resulting times for the queues to leave the intersection are summarized in Table 4.

TRAFFIC SIGNAL COORDINATION AT LRT CROSSING

Preemption-Period Clearance

When the LRT is approaching the intersection and giving the preemption signal, the traffic signal should have a certain period of time to clear the LRT route. The preemption-period clearance would contain a 4-second amber to clear the intersection, a 6-second flashing red to move the vehicles on the LRT route, a 4-second amber to clear the LRT route, and a 2-second all red to prepare for the nonconflicting traffic movements. This 16-second

Figure 2.

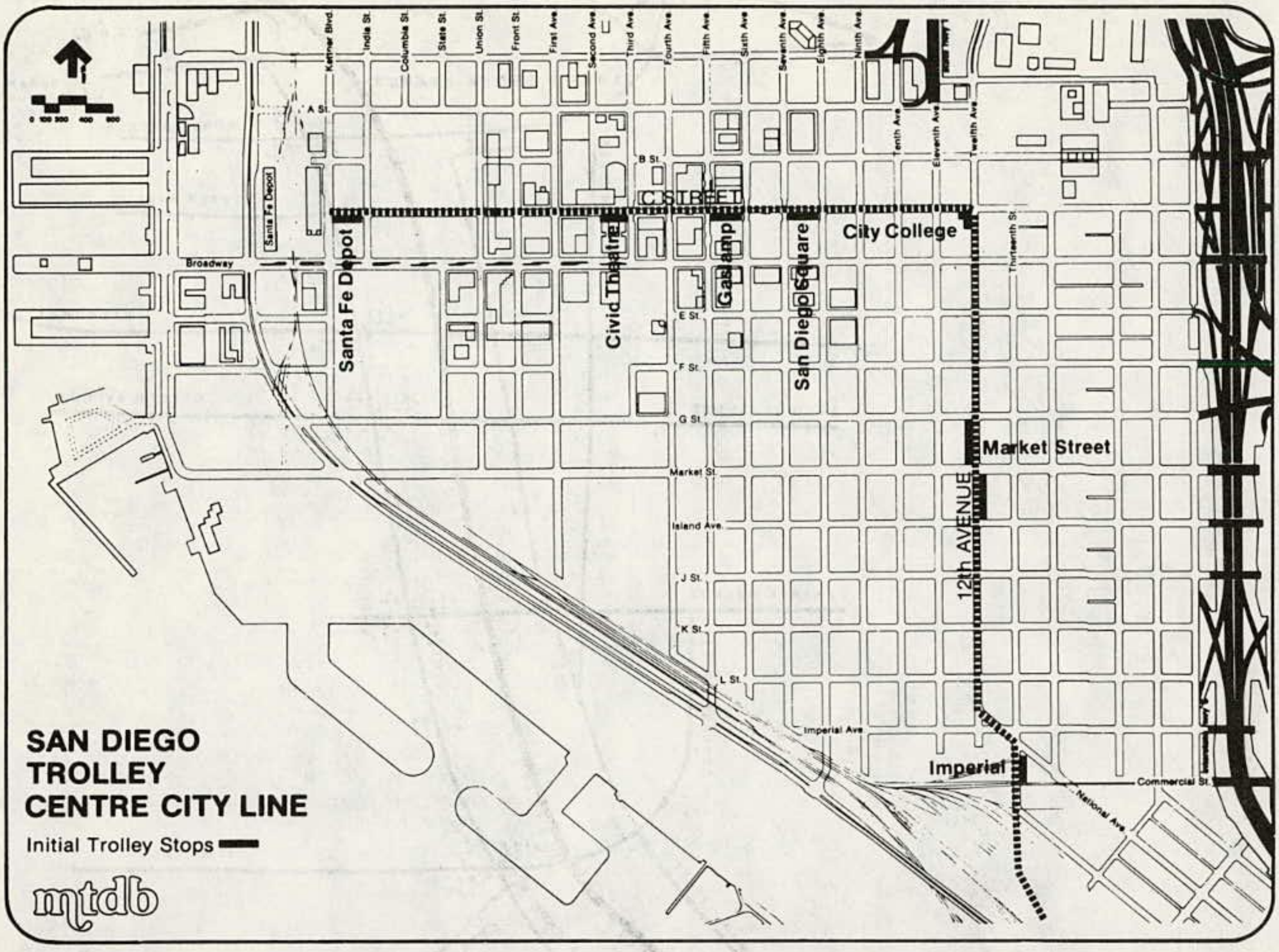


Figure 3.

Figure 4. Area roadway system and lane configurations, City of Lemon Grove.

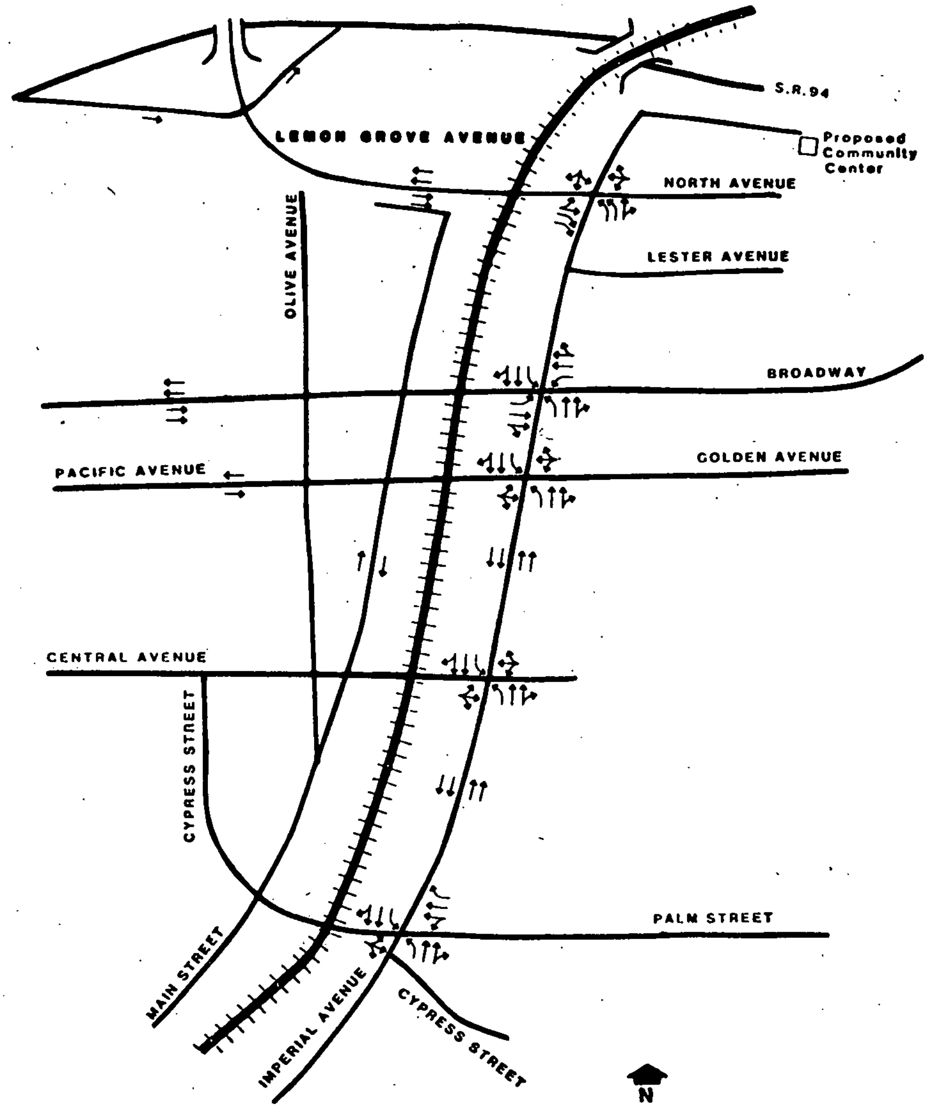


Table 1. Time required for at-grade crossing.

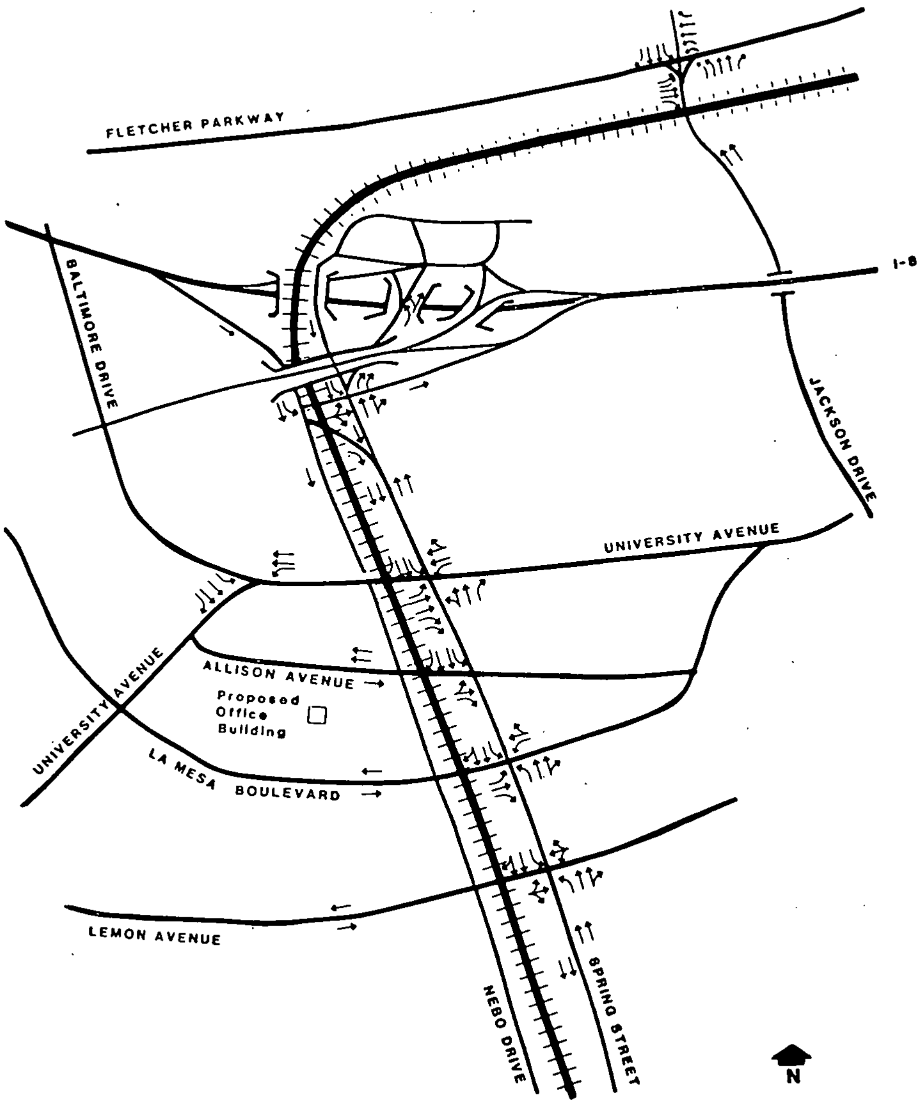
Operating Characteristics	Worst-Case Condition
LRT	
Passenger operations: 15-20 seconds[a]	20 seconds
Length: 2-car trolley (160 ft) during nonpeak period[a]	320 feet
4-car trolley (320 ft) during peak period[a]	
Travel speed: 25 mph in urbanized area, 28 mph average[a]	20 mph (29.3 fps)
Acceleration and deceleration: 3 mph per second[a]	3 mph/second
Frequency: every 15 minutes, each direction[a]	8 times/hour
Lead time (advance): 20-30 seconds[b]	25 seconds
Clearance (after): 50 feet[c]	50 feet
Gate	
Time for lowering or raising: 5-8 seconds[c]	8 seconds

[a]Source: MTDB

[b]Source: Public Utilities Commission Code 75-C, paragraph 7-2

[c]Source: Southern Pacific Railroad

Figure 5. Area roadway system and lane configurations, City of La Mesa.



preemption-period clearance could also be used for pedestrian crossings.

Preemption Period Hold

When the LRT is 9 seconds away from the intersection, the traffic signal should turn green to those movements parallel to the LRT route.

When the LRT passes the 50-ft clearance point and the gate starts to raise, the traffic signal would turn yellow to clear the intersection and then another 2-second all reds to prepare for dissipating the vehicular queue built up during the gate blockade.

INTERSECTION CAPACITY

Because the LRT is crossing the intersection, the gate must be down for a certain period of time to control the conflicting traffic movements. During this gate blockade, the traffic signal gives the green to the traffic movements parallel to the LRT route. Thus, the actual time "loss" in terms of the overall intersection capacity would be only the preemption-period clearance, which is 16 seconds for each LRT crossing, as described in the previous section. The LRT is scheduled to run every 15 minutes for each direction. Thus, the overall intersection capacity will decrease by approximately 4 percent per hour.

Table 5 shows that the 4 percent decrease of the intersection capacity will not deteriorate the intersection level of service to an unacceptable level. Some intersections would operate at capacity because of the population and employment growth in those areas and the resultant background traffic, as opposed to the impacts of the LRT.

PREEMPTION SYSTEMS FOR LRT AND EMERGENCY VEHICLES

As stated previously, the LRT operation will have priority over other traffic. Also, emergency vehicles legitimately have priority over "all" vehicles. Obviously, a conflict exists when the LRT and the emergency vehicle approach the same intersection simultaneously.

It is impossible for emergency vehicles to travel as fast as they can in urbanized areas. "Normal" traveling speed would be 30 to 40 mph. If the emergency vehicles give the preemption signal to the traffic light 1000 ft away from the intersection, it would then take the emergency vehicles 17 to 23 seconds to reach the intersection. Thus, for a 50-second gate blockade, there would be no delay for the 40-mph approaching emergency vehicles if the LRT vehicle was past the 33rd second in its preemption cycle.

Table 2. Durations of gate blockade at intersections.

Intersection	Length of Track at Intersection (ft)	Loading and Unloading (seconds)	Acceleration and Deceleration (seconds)	Duration of Gate Blockade (seconds)
City of La Mesa				
Jackson Drive and Fletcher Parkway	100	-	-	49[a]
Spring Street and I-8 on-off ramps	330	-	-	57
Spring Street and University Avenue	200	-	-	52
Spring Street and Allison Avenue	80	-	-	48
Spring Street and La Mesa Boulevard[b]	80	-	3	51
Spring Street and Lemon Avenue[c]	60	20	6	74
City of Lemon Grove				
Imperial Avenue and Lemon Grove-North	100	-	-	49
Imperial Avenue and Broadway[b]	80	-	3	51
Imperial Avenue and Golden-Pacific Avenues[c]	80	20	6	74
Imperial Avenue and Central Avenue	60	-	-	48
Imperial Avenue and Palm-Cypress Streets	60	-	-	48

[a]As an example:
Duration of gate blockade at Jackson Drive and Fletcher Parkway
= 25 seconds + (100 ft + 50 ft)/29.3 fps + 8 seconds + 320 ft/29.3 fps
= 25 seconds + 5 seconds + 8 seconds + 11 seconds
= 49 seconds

[b]The gates will be raised at the intersections of Spring Street and La Mesa Boulevard and Imperial Avenue and Broadway for the passenger operations at the LRT stations.

[c]The gates remain down when loading and unloading passengers at the LRT stations at the intersections of Spring Street and Lemon Avenue and Imperial Avenue and Golden-Pacific Avenues.

If the LRT travels at 20 mph, it would take 7 seconds for it to come to a complete stop. The faster the LRT runs, the longer it would take to stop. Assuming that the LRT speed would not exceed 30 mph in the urbanized area, the maximum time needed for the LRT to stop would be 9 seconds.

Therefore, even in a conservative situation (a 40-mph emergency vehicle with a 30-mph LRT), there would be only a 16-second period over the 50-second gate blockade period that the emergency vehicle would be blocked by the LRT crossing. This yields a 32 percent chance for the LRT to block emergency vehicles. This percentage will be reduced if either the LRT or the emergency vehicle travels slower. If the emergency vehicle gives the preemption signal to the traffic light 1500 ft away from the intersection, there would be a 16 percent chance for the LRT to block the 40-mph approaching emergency vehicle. If the emergency vehicle travels at 30 mph, there would be no delay at all.

IMPACT RESULTS

Because the LRT crossings are relatively short in duration (48 to 74 seconds), the traffic impacts of the LRT operation are not as severe as the city councils had feared. The short duration of the blockage means that the number of vehicles lined up during a crossing can always be cleared in one signal cycle after the gates go up. These conclusions are based on the assumption that the traffic signal system adjacent to the LRT crossings will be modified so that north-south traffic parallel to the LRT tracks can operate on a green signal indication when the gates across the east-west streets are down.

The traffic study found that the impact of the LRT operation on the downtown street systems of La Mesa and Lemon Grove would be very small as long as the following recommendations are implemented along with the LRT operation:

1. A traffic signal system with LRT preemption equipment must be implemented to detect the approaching LRT vehicles. The preemption detection would then begin a traffic signal sequence that cleared the east-west traffic off the LRT tracks, closed the railroad gates, gave north-south traffic a green indication as the LRT vehicle passed across the east-west street, raised the gates after the LRT vehicle passed, and finally gave the next green indication to the movement at that particular intersection with the longest back-up during the LRT crossing (either the east-west traffic or the northbound left turn).
2. All signalized intersections at LRT crossings should be restriped or widened to provide a southbound right-turn lane so that right-turning vehicles have a place to store while the gates are down. If this is accomplished, then two southbound lanes of through traffic can continue to operate while the gates are down.
3. Special emergency vehicle preemption equipment should be included in the LRT line so that, whenever possible, police and fire vehicles would be able to preempt the LRT vehicle. In fact, because of the higher operating

Table 3. Estimates of vehicular queues at LRT crossing.

Intersection	No. of Approaching Lanes	No. of Vehicles Queue for a 95 Percent Probability (per lane)
Jackson Drive and Fletcher Parkway		
Northbound	2	11
Southbound	2	8
Eastbound, right turn	1	9
Westbound, left turn	2	2
Spring Street and I-8 off ramp		
Southbound	1	17
Eastbound, left turn	1	4
Spring Street and University Avenue		
Northbound, left turn	1	9
Southbound, right turn	1	4
Eastbound	3	5
Westbound	2	4
Spring Street and Allison Avenue		
Northbound, left turn	1	7
Southbound, right turn	1	6
Eastbound	1	12
Westbound	1	11
Spring Street and La Mesa Boulevard		
Northbound, left turn	1	5
Southbound	1[a]	16 (6)
Eastbound	1	15
Westbound	1	7
Spring Street and Lemon Avenue		
Northbound, left turn	1	5
Southbound	1[a]	20 (3)
Eastbound	1	9
Westbound	1	9
Imperial Avenue and Lemon Grove Avenue		
Northbound, left turn	2	9
Southbound	1[a]	7 (5)
Eastbound	3	8
Westbound	1	6
Imperial Avenue and Broadway		
Northbound, left turn	1	9
Southbound	1[a]	12 (5)
Eastbound	3	7
Westbound	2	6
Imperial Avenue and Golden and Pacific Avenues		
Northbound, left turn	1	5
Southbound	1[a]	14 (5)
Eastbound	1	7
Westbound	1	5
Imperial Avenue and Central Avenue		
Northbound, left turn	1	2
Southbound	1[a]	10 (2)
Eastbound	1	6
Westbound	1	3
Imperial Avenue and Palm and Cypress Streets		
Northbound, left turn	1	3
Southbound	1[a]	11 (6)
Eastbound	1	11
Westbound	2	5

[a]There is no right-turn lane; this assumes the first vehicle in the curb lane is the right-turner, which would block the curb lane during the LRT crossing.

Note: If a right-turn lane is provided, the number in parentheses is the maximum queue in the right-turn lane (for a 95 percent probability).

Table 4. Estimates of time for queue to dissipate.

Intersection	No. of Approaching Lanes	Time for Queue to Dissipate (Seconds)
Jackson Drive and Fletcher Parkway		
Northbound	2	25
Southbound	2	18
Eastbound, right turn	1	21
Westbound, left turn	2	6
Spring Street and I-8 off ramp		
Southbound	1	37
Eastbound, left turn	1	10
Spring Street and University Avenue		
Northbound, left turn	1	21
Southbound, right turn	1	10
Eastbound	3	12
Westbound	2	10
Spring Street and Allison Avenue		
Northbound, left turn	1	16
Southbound, right turn	1	14
Eastbound	1	27
Westbound	1	25
Spring Street and La Mesa Boulevard		
Northbound, left turn	1	12
Southbound	1[a]	14
Eastbound	1	33
Westbound	1	16
Spring Street and Lemon Avenue		
Northbound, left turn	1	12
Southbound	1[a]	8
Eastbound	1	21
Westbound	1	21
Imperial Avenue and Lemon Grove Avenue		
Northbound, left turn	2	21
Southbound	1[a]	12
Eastbound	3	18
Westbound	1	14
Imperial Avenue and Broadway		
Northbound, left turn	1	21
Southbound	1[a]	12
Eastbound	3	16
Westbound	2	14
Imperial Avenue and Golden and Pacific Avenues		
Northbound, left turn	1	12
Southbound	1[a]	12
Eastbound	1	16
Westbound	1	12
Imperial Avenue and Central Avenue		
Northbound, left turn	1	6
Southbound	1[a]	6
Eastbound	1	14
Westbound	1	8
Imperial Avenue and Palm and Cypress Streets		
Northbound, left turn	1	8
Southbound	1[a]	14
Eastbound	1	25
Westbound	1	12

[a] Assuming right-turn lane is provided.

Table 5. Intersection level of service.

	1980 Without LRT		1985 Without LRT		1985 With LRT			
Intersection	V/C[a]	Level of Service	V/C[a]	Level of Service	Preemption Clearance (seconds)	Percent in an hour	V/C[a]	Level of Service
City of La Mesa								
Jackson Drive and Fletcher Parkway	0.70	B/C	0.79	C/D	16 x 8 = 128	4	0.82	D
Spring Street and I-8 on-off ramps	0.49	A	0.55	A	16 x 8 = 128	4	0.57	A
Spring Street and University Avenue	0.79	C	0.89	D/E	16 x 8 = 128	4	0.93	E
Spring Street and Allison Avenue	0.73	C	0.82	D	16 x 8 = 128	4	0.85	D
Spring Street and La Mesa Boulevard	0.82	D	0.96	E	16 x 8 = 128	4	1.00	E/F
Spring Street and Lemon Avenue	0.52	A	0.65	B	16 x 8 = 128	4	0.68	B
City of Lemon Grove								
Imperial Avenue and Lemon Grove-North	0.57	A	0.75	C	16 x 8 = 128	4	0.78	C
Imperial Avenue and Broadway	0.88	D	1.00	E/F	16 x 8 = 128	4	1.04	E/F
Imperial Avenue and Golden-Pacific Avenues	0.57	A	0.65	B	16 x 8 = 128	4	0.68	B
Imperial Avenue and Central Avenue	0.51	A	0.57	A	16 x 8 = 128	4	0.59	A/B
Imperial Avenue and Palm-Cypress Streets	0.55	A	0.63	B	16 x 8 = 128	4	0.66	B

[a]Volume/Level of Service E capacity.

speed of the emergency vehicles, and because of the short stopping distance requirements for the LRT vehicle itself, the actual delays to emergency vehicles are likely to be very small. In most cases, the emergency vehicle can "signal" the crossing of its approach approximately 17 to 23 seconds before it arrives at the railroad crossing. An LRT vehicle traveling at 20 mph can stop in 7 seconds. Therefore, with emergency vehicle preemption added to the system, delays to emergency vehicles can be substantially minimized.

DEMONSTRATION PROJECT

On January 14, 1981, a demonstration project simulated LRT vehicles operating on a 15-minute schedule through La Mesa. This was done by simultaneously actuating the railroad crossing gates every 7.5 minutes across three adjacent La Mesa streets: University Avenue, Allison Avenue, and the Interstate 8 freeway off-ramp. The demonstration project was jointly conducted by MTDB, the California Department of Transportation, and City of La Mesa staff. The experiment was carried out over a 45-minute period (4:15 p.m. to 5:00 p.m.). The activity at the intersections was recorded on film through time-lapse photography.

The conclusion from this test project was that there was no significant adverse traffic impact resulting from the gates being lowered for a simulated light rail train crossing every 7.5 minutes. A review of the time-lapse filming reveals that all traffic queues were dissipated in one traffic cycle and there was no added congestion observed despite the fact that the recommendations described above are not in place. The longest backup observed during the test project was the northbound left turn onto University Avenue.