Operational Enhancements

Making the Most of Light Rail

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The at-grade light rail system between Long Beach and Los Angeles, a 22-mi double-track line, crosses 85 streets at grade. The five local jurisdictions involved in the system were understandably concerned about the traffic impact of light rail vehicles (LRVs) arriving at a peak headway of 6 min. The problems facing the designers were compounded by the adjacent Southern Pacific at-grade freight train operation, and by the proximity of major signalized intersections. The solution involved an assortment of integrated light rail and street traffic operational enhancements. In the exclusive right-of-way segments LRVs were given full priority over street traffic at all times at most major crossings. In the median alignment segments, special traffic signal software was designed to provide integrated LRV priority without the disruption of full preemption. All stations were designed with high-level platforms to minimize passenger loading times and to make handicapped access easier. Automatic overrun protection implemented via cab signaling allowed at-grade crossing gates to remain in the up position while LRVs dwell at nearside station platforms. At several locations streets were closed, turn movements prohibited, or streets converted to or from one-way operation to allow more efficient operation of automobiles or LRVs. The result of these operational features is an economical at-grade light rail system that meets the objectives of a reasonable LRV travel time and an acceptable level of service and safety for automobile traffic.

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THE ROLE OF TRANSIT as a primary means of personal transportation has been given increasing emphasis in recent years, due partly to the increasing financial and opportunity constraints of road building to meet ever-increasing transportation demands. Such a dominant need for transit in a modern city setting demands that great attention be given to the choice and form of this transportation mode.

Traditional forms of transit can be categorized as road-based or rail-based. The definition of road-based and rail-based transit cannot be interpreted literally. There exist today rubber tire "trains" running on a fixed guideway (i.e., Montreal, Paris) and also rail vehicles sharing roadway spaces with other automobiles. The classification here is intended to differentiate transit vehicles running on a fixed guideway (rail-based) versus transit vehicles operating freely on the road together with other traffic (road-based).

Whereas road-based transit, primarily buses and trolley buses, generally requires less capital investment, its rail-based counterpart is favored where its potential for higher capacity, lower travel time, or lower operation costs can be realized. Buses also offer more operational flexibility and can penetrate residential and business areas more effectively to provide a broader service area. Hence the common adoption of a rail-based system for regional transit services and a road-based system for local transit services.

Even within the rail-based transit mode, one has a wide choice of different systems for any urban environment. The spectrum of urban rail-based transit systems usually begins, at the lower end, with simple and relatively inexpensive systems such as streetcars, exemplified by San Francisco's Municipal Railway (Muni) system. They operate mainly in public roadways, sometimes within the same shared right-of-way. In many respects, these streetcar systems operate like buses. They therefore lose the speed advantage of a rail system.

On the other end of the spectrum is heavy rail transit, typically high-speed vehicles operating in a grade-separated environment, exemplified by the subway and metro systems in many large urban areas. Although heavy rail transit usually has a higher passenger-carrying capacity, it is also considered the most expensive form of transit in terms of capital costs. Its implementation is therefore confined mostly to corridors of very high demand.

Between these two ends of the spectrum lies the light rail transit (LRT) system. LRT can provide high-capacity, high-speed service where appropriate while still operating at grade in street rights-of-way where necessary. The flexibility of LRT is of great assistance to the transit system designer in achieving a compromise between cost and operating speed, in balancing efficiency versus safety, and, most important, in providing an attractive mode of transit operation at a reasonable cost.

The Long Beach-Los Angeles LRT Project strives to provide an appropriately balanced transit system design by making the most of LRT's flexibility.

This paper discusses the design features of the project, with emphasis on the variety of the methods employed to maximize the system's cost effectiveness. It also addresses some of the problems encountered and how the conflicting needs of different agencies were met.

CHARACTERISTICS OF THE SYSTEM

The Long Beach-Los Angeles LRT system represents the first line of what ultimately is to be a 150-mi rail transit system planned for Los Angeles County. It presently is a 22-mi double-track line between downtown Long Beach and downtown Los Angeles. Almost the whole line operates at grade within either existing street right-of-way or exclusive rail right-of-way shared with other tracks. The alignment passes through five different jurisdictions: the City of Los Angeles, Los Angeles County, the City of Compton, the City of Carson, and the City of Long Beach. It crosses 85 roadways at grade and will operate at a peak headway of 6 min through 20 stations. All station platforms are elevated to reduce passenger boarding time and to provide added convenience for the handicapped and elderly. Final design commenced in 1985. Revenue operation service is scheduled to begin in mid-1990.

This 22-mi light rail line can be divided into three segments: downtown Los Angeles, downtown Long Beach, and the "midcorridor" linking them. The two downtown segments, with their inherent urban characteristics, possess design and operational characteristics that are drastically different from those of the midcorridor segment. In the downtown segments, the light rail vehicles (LRVs) will operate in a street-running mode, whereas in the midcorridor they will operate in a high-speed exclusive right-of-way.

Exclusive Right-of-Way Operation

The LRT alignment through the midcorridor is an 18-mi segment, with light rail operating in the existing Southern Pacific Transportation Company (SPTC) right-of-way alongside active freight tracks.

The normal operating speed of LRVs through the midcorridor will be 55 mph. There are no grades, curves, or other factors that would limit the maximum speed to significantly less than that under normal conditions.

The LRV chosen for this project is representative of modern LRVs. Each articulated car is approximately 90 ft long. All facilities in the midcorridor are designed to accommodate three-car LRV consists. This segment is being fitted with cab signal-based train protection.

Road Traffic Impacts of At-Grade Operation

Along the 18-mi mid corridor, the line will traverse 38 street crossings at grade. These crossings range from minor residential collector streets to major highways carrying in excess of 30,000 average daily traffic (ADT). Table 1 lists the projected year 2000 ADT on some of the major and secondary crossings.

TABLE 1 DAILY TRAFFIC VOLUMES ON MAJOR AND SECONDARY STREETS

Street	ADT	Jurisdiction	Classifieation
Vernon Ave.	13,257[a]	City of LA	Major
Gage Ave.	29,000[b]	LA County	Major
Florence Ave.	39,000[b]	LA County	Major
Nadeau St.	15,000[b]	LA County	Secondary
103rd St.	17,000[b]	City of LA	Secondary
Imperial Hwy.	41,500[b]	City and County	Major
El Segundo Blvd.	25,956[a]	LA County	Major
Rosecrans Ave.	29,555[a]	Compton	Major
Compton Blvd.	22,500[b]	Compton	Major
Alondra Blvd.	20,477[a]	Compton	Major
Del Amo Blvd.	40,500[b]	LA County	Major
Wardlow Rd.	N/A	Long Beach	Major
Spring St.	N/A	Long Beach	Secondary

NOTE: ADT = average daily traffic in year 2000; N/A = not available.

[a] Source: SCAG's *San Pedro Bay Ports Access Study.*

[b] Estimate based on PB/KE's *LRT Traffic Impacts at Grade Crossings in Mid-Corridor.*

All 38 at-grade street crossings in the midcorridor are fitted with railroad-standard protection equipment in the form of gates, flashers, and bells. This is required by the California Public Utilities Commission (CPUC) because the LRT tracks will share the crossings with the SPTC track and because of the LRT's high speed of 55 mph. The gates and the associated bell and flashing lights will be automatically activated some 25 sec before the LRV arrives at the crossing. After the LRV has crossed the street, the gates will return to the upright position, and automobile traffic will be able to proceed. The total time from first activation of the flashing lights until the gates return to the upright position will be between 30 and 36 sec, depending on the location. In effect, by stopping the street traffic whenever an LRV approaches, the LRV can maintain a high speed of operation through the midcorridor.

The amount of additional traffic delay caused by LRT varies from crossing to crossing and is highly dependent on the crossing's proximity to a major intersection and on traffic volumes. Where the crossing has adequate excess capacity, as is usually the case, the impact of LRT is light. Because the duration of each LRT passage, as discussed previously, is only 30 to 36 sec, the traffic queues formed as a result of an LRT preemption normally will be short. Where this is not the case, LRT impacts can be adequately mitigated by suitable geometric modifications, traffic management techniques, and fine tuning the traffic signal operation. Table 2 illustrates this through a comparison of the base case (without the project) traffic delay versus the "with LRT" traffic delay at the major crossings.

TABLE 2 YEAR 2000 AVERAGE DELAY PER VEHICLE AT MAJOR MIDCORRIDOR CROSSINGS

Crossing	Base Case (sec)	With LRT (sec)
Vernon Ave.	28	42
Gage Ave.	17	31
Florence Ave.	22	47
Imperial Hwy.	58	51[a]
El Segundo Blvd.	26	38[a]
Rosecrans Ave.	44	39[a]
Compton Blvd.	56	57[a]
Alondra Blvd.	35	50[a]
Wardlow Rd.	30	35[a]

NOTE: Assumed one freight train arrival per peak hour.

[a] Mitigated through roadway geometric modifications.

SOURCE: DKS' traffic impact analysis reports for midcorridor crossings.

LRT impacts can usually be mitigated adequately through minor roadway widening and prohibition of certain turning movements, without the need for expensive right-of-way acquisition or grade separation. Of all 38 crossings in the midcorridor, only one requires grade separation because of traffic, and there the problem is not light rail's impact on traffic but the impact of a nearby freeway ramp on light rail operation.

Minimizing LRT/Automobile Conflict

As discussed above, railroad grade crossings operate by stopping the street traffic whenever an LRV approaches. If there is a traffic signal at or close to the crossing, it is preempted, which means its normal operation is suspended and a special phase sequence introduced to clear the tracks and service nonconflicting movements until the LRV has passed. The same type of operation will be used for LRT at all of the 37 at-grade street crossings in the midcorridor.

At locations where the impact of signal preemption on road traffic is judged to be too severe, it is possible to control the LRV arrival time at a crossing so that, instead of arriving randomly, they arrive at selected times. All of the major streets crossed by LRT in the midcorridor have coordinated, signalized intersections at, or on either side of, the crossing. The traffic signals cause traffic to arrive at the tracks in bunches, rather than allowing it to be evenly distributed over time. The length of the traffic signal cycle is typically in the range of 60 to 90 sec, which means that similar bunches of traffic arrive at the LRT tracks every 60 to 90 sec. Because a crossing LRV requires the gates to be active for only 30 to 36 sec, one method of minimizing delay to street traffic at these crossings during periods of peak traffic is to make the arrival time of the LRVs coincide with that part of the traffic signal cycle when traffic at the crossing is at a minimum (the "window"). In this way most of the traffic will not be stopped by the lowered gates.

The most practical means of controlling the arrival time of an LRV is to hold the LRV at the upstream station. The LRV will pull into the station normally, but instead of closing the doors and moving off as soon possible, it will wait at the station until a signal indicates that the LRV should depart in order to arrive at the major crossing downstream at the optimum point in the traffic signal cycle. Once it moves off, the LRV travels at maximum speed to the next station. Figure 1 illustrates the window operation in a time-space diagram.

While the window concept is a form of low-cost mitigation for LRT impact, its implementation delays the LRVs. However, for LRVs and other traffic to share the same road space, the impacts must be balanced so that no one system suffers to the extent that it will negate the overall objective of moving people efficiently and expeditiously. The application of the window concept must be subject to careful scrutiny to assess the relative benefits enjoyed by road traffic versus the extra delay imposed upon LRV patrons. If the overall delay to all commuters—automobiles and LRV patrons together—is computed for the two scenarios, then the alternative causing the least overall delay can be identified.

Table 3 shows the overall delay to commuters under the two alternatives at major midcorridor crossings. It is evident that in all cases the no-window (referred to as "full preemption") is preferable to the isolated application of the window concept at any one crossing, because this would minimize the overall delay to all commuters. However, if two or more crossings are considered together as a system of coordinated windows, the benefits and

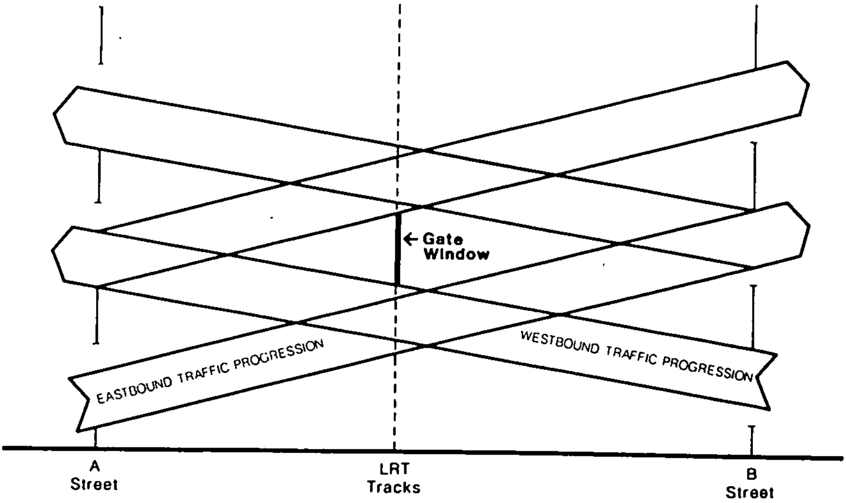

FIGURE 1 Time-space diagram showing gate window.

TABLE 3 OVERALL COMMUTER DELAY (MOTORISTS AND LRT PATRONS) AT MAJOR MIDCORRIDOR CROSSINGS

Crossing	Window Concept (person-hr)	Full Preemption (person-hr)
Vernon Ave.	48.1	30.6
Gage Ave.	52.2	30.8
Florence Ave.	78.1	62.7
Imperial Hwy.	209.0	122.0
El Segundo Blvd.	52.0	26.0
Rosecrans Ave.	72.5	39.2
Compton Blvd.	71.7	37.2
Alondra Blvd.	59.6	20.6
Wardlow Rd.	63.3	34.0

NOTE: Assumed one freight train arrival per peak hour.

SOURCE: DKS' traffic impact analysis reports for midcorridor crossings.

practicability of the window are enhanced. One coordinated window system that is considered most feasible is the Florence-Gage system. Due to the optimum distance between these two streets, the provision of a station at both ends, and traffic signals along both streets operating with the same cycle length, it is feasible to implement a system whereby LRVs leaving the station at one end will cross both streets at the optimum window. The same will apply for both directions of travel. Figure 2 shows how this is possible.

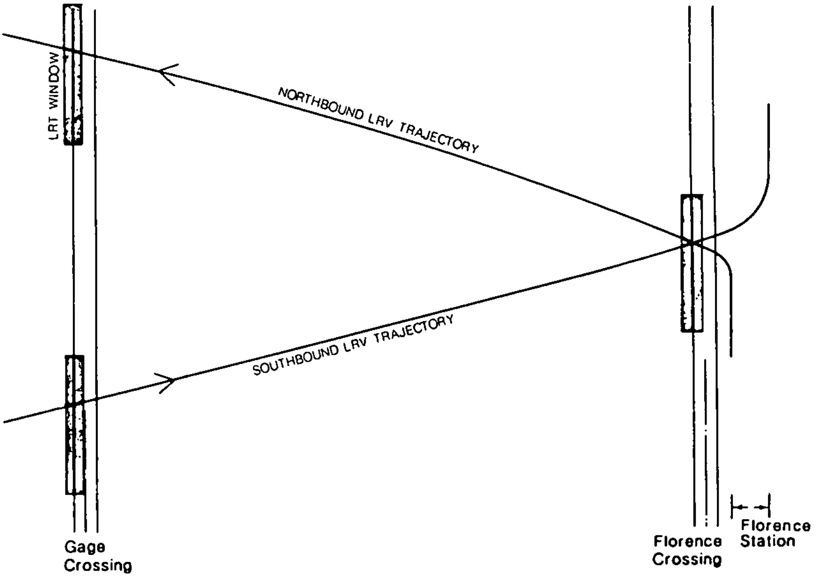

FIGURE 2 Gage and Florence signal coordination opportunities.

An LRV's travel time between the two crossings at normal operating speed is approximately half the cycle length of 80 sec at both streets. Two-way LRV progression through the LRV arrival windows can therefore be achieved by maintaining a time offset between the windows of approximately 40 sec. A southbound LRV will be held at the upstream station until it is time to leave for arriving at both the Gage and Florence crossings during the LRT window. The same is true for LRVs traveling in the opposite direction.

With this coordinated window concept, the impact of LRT operation on the major streets can be minimized while reducing the negative impacts to the LRT operation itself. At the Florence and Gage intersections the transit authority and local jurisdictions will evaluate LRT operational impact after revenue operations begin and decide whether to employ the window approach. Extension of the window concept to other crossings in the corridor is not practicable because of incompatibility of cycle length requirements and jurisdictional boundaries.

Street-Running Operation

In the downtown segments at either end of the light rail line, the tracks are located in the median of two-way streets and to the side of one-way streets. The LRT tracks pass through 47 street intersections in these segments. Railroad gates cannot be installed at these crossings because of space constraints and the excessive delays they would cause. Instead, conflicts between automobiles and LRVs are avoided either by prohibiting automobile movements across the tracks or by using traffic signals that control LRVs as well as automobiles. LRVs must be prepared to slow down and stop at signalized intersections just as any other vehicles would. LRVs are basically driven on sight and the drivers have to react to the environment and operate their vehicles like buses. LRVs will be subject to the normal rules of the road and will observe the same speed limits as automobiles running parallel. The highest speed limit in the downtown segments is 35 mph.

In both downtown Los Angeles and Long Beach, the LRV operates in a dedicated right-of-way within the roadway. Mountable curbs are installed on both sides to prevent general traffic from entering the LRT right-of-way. Only emergency vehicles are allowed to use the track area for emergency access. Except at intersections, the LRVs do not interact with other traffic.

In downtown Los Angeles, LRT interfaces with the metro station at Seventh Street. It then runs underground for approximately one-third mile, surfacing near 12th Street, and then continues at grade in a side-running alignment along one-way Flower Street. It turns into the median of Washington Boulevard and continues to Long Beach Avenue. At Long Beach Avenue, the tracks enter the midcorridor's exclusive right-of-way.

The choice of center-running versus side-running was given considerable attention. Generally, from a traffic point of view, center-running is more appropriate for two-way streets whereas side-running is best for one-way streets. A side-running LRT system on a two-way street poses serious access hazards from driveways and minor streets unless all uncontrolled intersections are either closed or signalized. In contrast, center-running LRT in a one-way street would cause access problems, because it is almost impossible to direct traffic to the proper side of the street should vehicles wish to turn at some downstream intersections. This is the rationale for selecting side-running operation along the one-way Flower Street and center-running operation along the two-way Washington Boulevard.

In downtown Long Beach, at the Willow Station near 27th Street, the LRT tracks leave exclusive right-of-way and enter the median of Long Beach Boulevard. The alignment follows Long Beach Boulevard for about 3 mi, and then forms a one-way clockwise loop round First Street, Pacific Avenue, and Eighth Street. On First Street the system operates in a transit mall where it interfaces with buses.

Traffic Signal Operation

Due to the location of the LRT tracks relative to the parallel running automobile traffic, the LRV conflicts with left-turning traffic. A separate traffic signal display therefore is required for LRVs. Likewise, all left-turning automobile movements must be protected with an exclusive left-turn phase.

LRV detectors located between the tracks send signals to the traffic signal controllers to request or cancel the LRT phase. In the absence of any request, the traffic signal controller would not provide a green display to LRVs, distributing all the green time to road traffic instead. An advance LRT call detector, usually located near the upstream intersection, detects the arrival of an LRV, and requests the controller to provide an LRT phase. With built-in software logic, the controller determines the most appropriate manner to provide the LRT green indication without causing excessive delay to traffic. At some busy intersections during peak hour this may mean that the LRV has to stop and wait for its turn without getting any priority. A call/release detector, usually located close to the LRT stop line, senses the LRV's departure and signals the controller to terminate the LRV phase. The call/release detector also serves to request another LRV phase should the advance call detector malfunction or should the LRV fail to clear the intersection due to some unusual occurrence.

Although LRVs will not be able to "preempt" the traffic signals in the street-running mode, they will be able to receive priority treatment at some intersections at some times of the day. This priority treatment could consist of two alternative forms: partial priority or full priority.

Partial priority widens the green window for LRVs at a coordinated traffic signal. (The green window is the amount of time in the signal cycle during which an LRV can pass through the intersection.) Along Flower Street, for example, the window coincides with the green time provided for southbound motorists. Along Washington Boulevard, the window occurs when both eastbound and westbound movements receive a green light. This window is widened beyond the normal length of the LRT-phase green time by allowing the LRT phase to start earlier than normal (early green), or by allowing the LRT phase to finish later than normal (extended green). In each case, the extra time given to the LRT phase must be taken from other phases within the fixed-length cycle. A wider window reduces the probability that an LRV would have to stop at the signal. Motor vehicles running parallel to the LRT tracks would also benefit from the extra green time of a wider window.

The partial priority proposed for implementation in the downtown Los Angeles and Long Beach segments attempts to minimize disruptive effects on road and pedestrian traffic. The extra length of the LRT phase would be limited, and no phase with a demand would be skipped in any cycle. The shortening of phases would not violate any minimum times preset in the controller, but pedestrian service could be suppressed if the signal operator permits it.

Full priority involves temporarily changing the normal signal operation in order to display an LRT green signal at, or soon after, the LRV arrival time. Full priority may result in shortening one phase or skipping one or more phases entirely. Full priority provides the optimum operating conditions for LRT but also can lead to intolerable automobile delay for side-street and left-turning traffic if used indiscriminately.

When full priority is used in a coordinated system, some signals often get out of step with the others. It can take several cycles to get them back into step. In fact, the traffic signals may not get back to coordinated mode during peak periods when 6-min LRV headways are used. Because the majority of intersections in the downtown segments will be operating at or near capacity during peak periods, full priority would cause excessive delay to side-street traffic. However, full priority may be appropriate at some intersections during off-peak periods when LRT headways are longer and vehicular traffic volumes are smaller.

Custom-designed software in the traffic controller will enable all intersections to provide full-, partial-, or no-priority operation. The type of priority can be adjusted in any of the following three ways:

- Time-of-Day—The degree of priority would vary by time of day. Little or no priority may be provided in the peak periods, whereas full or partial priority may be provided in off-peak periods.
- Vehicle Response—Vehicle detectors can be installed so that the level of priority can be reduced or deactivated once excessive traffic queues are detected.
- Manual—Level of priority treatment can be altered manually at the controller cabinet or from the traffic signal control center.

By providing different levels of priority, LRT operation efficiency can be maximized without excessive negative impact on road and pedestrian traffic. Such flexibility is further enhanced with the centralized traffic signal control system installed in downtown Los Angeles called ATSAC.

The ATSAC (Automated Traffic Surveillance and Control) System installed in Los Angeles is an enhanced form of the urban traffic control system (UTCS). In broad terms, ATSAC is a computer system that links and gathers information from all traffic signal controllers. It serves four major functions:

- Compilation of all traffic data collected from detectors in the streets,
- Optimization of traffic signal timings and coordination to minimize traffic delay,

- Fault monitoring, and
- Manual override at the central level.

Currently ATSAC controls 120 signals in the so-called Coliseum System installed in the City of Los Angeles prior to the 1984 Olympic Games. When the LRT begins operation, the ATSAC system will be extended to control another 216 signals in downtown Los Angeles.

The LRT alignment traverses 11 intersections that would be under ATSAC control, from west of Los Angeles Street along Washington Boulevard and all of the Flower Street alignment. Due to the inherent benefits of ATSAC to both LRT and traffic operation, a cooperative agreement has been reached with the City of Los Angeles to extend ATSAC to cover the rest of the LRT alignment along Washington Boulevard east of Los Angeles Street. This will be implemented as part of the project. Special software will be developed at both the master and local levels so that all LRT control parameters are available within ATSAC.

Traffic Impacts and Mitigations

Although at-grade light rail operation requires less capital investment than a fully grade-separated system, it is generally true that the former creates a higher degree of negative traffic impacts. At-grade LRT operation on the Long Beach-Los Angeles system will have the following main impacts on street traffic:

- Reduced roadway space,
- Reduced parking space,
- Reduced accessibility to adjacent land uses, and
- Increased delay and travel times.

Where LRT will operate within the same right-of-way with other traffic, one obvious impact will be the loss of space available to automobiles and pedestrians. This loss will be compensated through reduced lane widths, reduced sidewalk widths, or through deletion of on-street parking.

For safe and reliable traffic control, all LRT/road intersections should be signalized. However, excessive signalization would increase vehicular traffic delay. Therefore, some minor intersections or driveways will be closed. In the center-running configuration, it is sufficient to close the median next to the tracks, so that a right-in/right-out configuration can be maintained for the side street. In the side-running configuration, minor crossings or driveways will be closed where possible and alternative access provided. Furthermore, due to the conflict between LRVs and left-turning movements, all left-turn phases will be protected. This will increase the number of signal phases in a cycle, increase the lost time involved in phase changes, and generally reduce the efficiency of traffic signal operation. Where such impacts would lead to an unacceptable level of service for motorists, additional traffic lanes are being added to compensate.

Other low-cost mitigation measures being employed on the project include:

- Roadway widening within the same right-of-way, at the expense of sidewalk widths, or with limited right-of-way acquisition;
- Geometric reconfiguration such as realigning curbs, relocating bus stops, converting from two-way to one-way streets, traffic rerouting, etc.;
- Restriping to provide adequate lanes within existing right-of-way;
- Signal redesign to increase operational efficiency; and
- Signal timing overhaul to increase coordination and reduce overall vehicular delay.

The impacts and extent of mitigation measures to be applied through the downtown segments of Los Angeles and Long Beach are listed as follows:

Downtown Los Angeles
- Loss of 316 parking spaces (64 percent of existing)
- Roadway widened at all locations along LRT alignment
- Medians closed at all nine unsignalized intersections
- Additional traffic signals at two locations
- Left-turn prohibition at two signalized intersections
- Traffic signal upgrades at all 20 traffic signals
- Driveway closed at three locations
- Driveway signals at all 10 open driveways

Downtown Long Beach
- Loss of 347 parking spaces (57 percent of existing)
- Approximately 80 percent of roadway widened along LRT alignment
- Medians closed at all 16 unsignalized intersections and 1 signalized intersection
- Additional traffic signals at three locations
- Left-turn prohibition at four signalized intersections
- Traffic signal upgrade at all 28 traffic signals
- No driveway closed

These mitigation measures were developed through extensive liaison and coordination with the local jurisdictions and responsible agencies, through compromise between various conflicting demands and design parameters, and through cooperation of all parties concerned with an aim toward providing an efficient and reliable transportation system at a reasonable cost.

Driveway Access Control

As discussed earlier, one problem of side-running operation is the control of driveway access. Whereas in the center-running configuration, medians can be closed and minor street and driveway access can be maintained, the side-running configuration can confront this problem only through active control, because some driveways do not have alternative access and cannot be closed. Full signalization is not warranted here due to the close spacing between driveways and the low volumes of traffic accessing these driveways. Some form of low-cost, effective active control measures need to be implemented.

Figure 3 illustrates the form of control designed for driveway access along Flower Street in downtown Los Angeles. Vehicles exiting from driveways usually have adequate sight distance on both sides to spot oncoming LRVs and they can stop and wait on the sidewalk. Stop sign control is adequate, augmented by a special sign to remind drivers to look both ways for LRVs even though they are entering a one-way street.

Drivers turning left into a driveway across the tracks do not have a good vantage position to determine whether LRVs are approaching from behind. The form of active control proposed here is a "secret" sign for the left-turning traffic. The sign is normally blank and left-turners can turn with usual caution. However, when an LRV approaches from either direction, the sign will show a no-left-turn symbol, advising drivers to wait to make the turn until the LRV has crossed. All signs along a block will be cabled directly to both of the upstream controllers so that the same signal that lit the LRT phase activates these signs. In this manner, an inexpensive, reliable, and effective method of active control will be provided to rectify the potentially unsafe condition.

CONCLUSION

The design of a light rail system, similar to all other engineering design work, requires a balance between cost and safety. Often, questions are posed about how safe is safe and how much money should be spent to further improve the safety of the system. The underlying principle behind all engineering design is to determine the safety threshold beyond which the marginal safety gain does not justify additional expense. A building may be designed to withstand an earthquake of scale 8, for example, or a storm drain system may be designed for a once-in-a-century storm. In light rail design, the additional

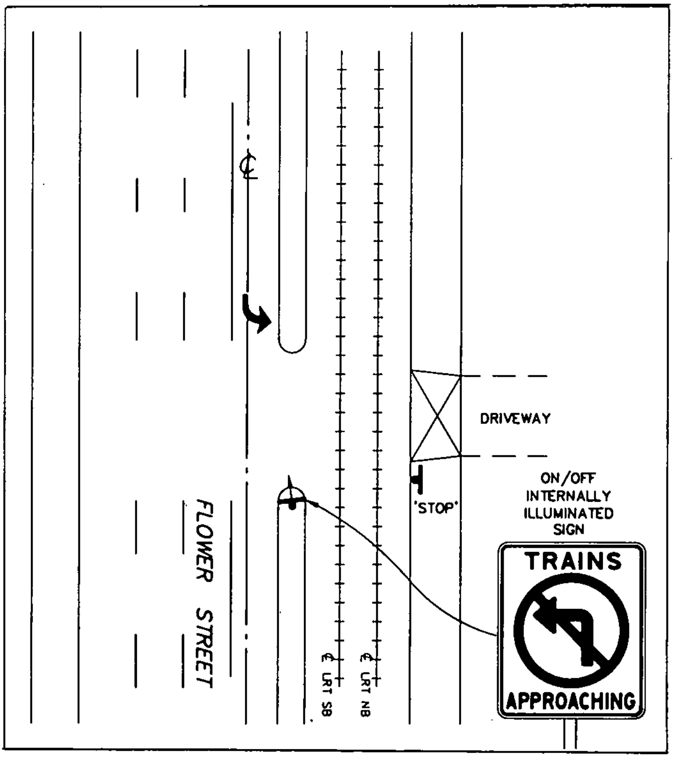

FIGURE 3 Typical driveway control on Flower Street.

expense is measured not only in terms of construction costs, but also in terms of reduced operating efficiency for LRT, automobiles, or pedestrians.

The design of the Long Beach-Los Angeles Rail Transit Project demonstrates the successful application of engineering techniques to make the most of LRT's flexibility. Special efforts are made to mitigate negative impacts on automobiles and pedestrians. Special efforts are also required in jurisdictional liaison, coordination, and communication. Through application of traffic engineering techniques, rigorous operational analysis, and close project coordination among designers and the local jurisdictions, a truly safe, reliable system can be provided at a reasonable cost, without resorting to expensive grade separation or creating a myriad of safety control mechanisms.