At-Grade or Not At-Grade

The Early Traffic Question in Light Rail Transit Route Planning

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The planning, design, and construction of a light rail transit (LRT) line require that a wide range of complex issues be resolved. Understanding the degree to which individual issues can be addressed at each stage of the process can significantly reduce effort and time needed to gain community acceptance and to implement the LRT program. Important tools are effective methods for dealing with traffic issues in the feasibility and planning stages of LRT lines where early decisions need to be made between horizontal and vertical route alignment alternatives. Traffic issues play a critical part in making these decisions, and transit planners and traffic engineers need to know the potential magnitude of LRT impacts on traffic circulation, parking, and the degree of LRT priority or grade separation for which to plan. The grade separation issue is particularly critical, as it directly affects the operational, economic, and political viability of an LRT line. Traffic analysis and evaluation techniques can be used effectively to make early decisions on vertical and horizontal LRT alignments, to both guide LRT planning policy and focus subsequent LRT design efforts.

THE PLANNING, DESIGN, AND construction of a light rail transit (LRT) line involve several stages. The first stage is the identification of an LRT service area and corridor, usually in the context of a regional plan or sales tax proposition. The second stage is a route refinement study that identifies alternative alignments within the service corridor. These studies typically evaluate the feasibility and the pros and cons of the alternatives and estimated costs and recommend a preferred LRT alignment. The route refinement

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study, although including some concept or preliminary engineering, is largely focused at the planning level.

The third stage is usually preliminary engineering and environmental clearance. Based on a preferred alignment, specific alignment details are defined, more detailed engineering is conducted, LRT impacts are evaluated, and mitigation solutions are identified. Some of this work may be included in the route refinement studies. The fourth stage is final engineering, in which design details are resolved, the project is approved, and construction of the LRT line is accomplished.

ISSUES AND PERSPECTIVES

This paper focuses on the route refinement stage of LRT planning and design in which the objective is to define potential alignments, identify the impacts and feasibility of each, evaluate alternatives, and select a preferred route for more detailed study and engineering. The principal issues of concern regarding LRT impacts are usually community effects, traffic impacts, safety, land values, residential intrusion, cost, noise and vibration, adjacent land uses, and other environmental concerns.

The key issue transportation planners and traffic engineers have to face directly is traffic impacts (and their relationship to associated areas of concern). Traffic impacts are among the most prominent and controversial of issues, as they are highly visible and affect or are perceived to affect most people in the vicinity of the proposed routings. Key traffic issues include impact of at-grade or aerial LRT on traffic, traffic queues and delay due to LRT, safety of mixed operations, turn restrictions, access controls, on-street parking removal, traffic at stations, and parking at stations.

The numerous interest groups involved—including system planners and engineers, transit operators, government agencies, politicians, and local communities—bring many different perspectives to these issues.

Planners and engineers have a technical perspective. They are concerned with mitigating impacts and design solutions within the philosophy of LRT, which implies low-cost and at-grade operations wherever possible. System operators share this philosophy but are also concerned with system speed and performance, which implies that LRT takes priority over automobile traffic.

Government agencies sometimes differ and may be in conflict with these goals. Affected jurisdictions (usually cities and counties) are concerned with minimizing their costs and LRT impacts on the street system and traffic operations. Hence, they often favor minimal LRT priority over automobile traffic or grade separation of LRT.

Communities are understandably concerned with LRT's effect on their local environments. LRT is often perceived as a threat as well as a benefit.

Although this is often due to misconceptions or lack of knowledge about what LRT is and how it can operate, legitimate concerns exist regarding safety, traffic congestion, parking overflows at stations, and environmental intrusion.

The success of any LRT system requires consensus and support from all these groups, as well as from the political arena. It is therefore necessary to address issues early, share information, refine plans, and educate people about system performance and impacts.

The vertical alignment of a light rail line is perhaps the single most important issue in that it largely determines the cost of the project. An at-grade line is considerably less expensive to build, but may lower operational efficiency and increase impacts due to conflicts with automobile traffic. Although LRT is ideally suited for mixed traffic operations, in many western U.S. cities LRT operations over long route lengths with no priority over automobile traffic often result in slow run times, unreliable schedules, and consequently poor operational performance. Underground and elevated alignments, on the other hand, raise costs significantly and fail to capitalize on the flexibility of LRT technology. If the LRT line is all grade-separated, then it becomes a typical rapid transit heavy rail system and the cost may be prohibitive.

Grade separation is thus often an early and controversial issue in LRT route planning and is particularly critical because it directly affects the operational, economic, and political viability of a proposed LRT line.

The flexibility of LRT provides opportunities for compromise between system cost and operating speeds. The early identification of grade separation needs and of an LRT/automobile control strategy is important in the definition and evaluation of mitigation measures, and for the development of a realistic LRT operating plan and patronage forecasts. There is a wide range of traffic engineering strategies for LRT/traffic control. The key areas with respect to traffic decisions in LRT route planning are midblock alignment, alignment at intersections, and station locations.

At the planning stage, both qualitative and quantitative traffic evaluations can help assess the opportunities, constraints, and impacts of light rail operation. It is therefore important to understand what evaluation criteria are most appropriate and what analytical methods are best suited to the LRT route planning process.

TRAFFIC ISSUES IN MIDBLOCK ALIGNMENTS

Midblock sections between major roadways compose most of the length of LRT alignments. The principal traffic issues for midblock alignments thus primarily address the horizontal alignment. The key alignment options are in-street versus off-street. There are two in-street options, median running or side running, and two off-street options, adjacent to street or away from street.

For LRT to operate within the existing roadway right-of-way (either at grade or grade separated), roadway space available for automobile traffic is normally displaced. A number of opportunities usually exist for mitigation. If the reduced roadway space may be adequately absorbed through reduced lane widths, then the LRT will have no direct impact. Where this is not possible, additional roadway space may be obtained by either removing parking or widening minor roadways, which involves curb relocations. Alternatively, where traffic volumes permit, the dropping of a traffic lane or prohibition of turning movements at minor intersections and driveways may be viable.

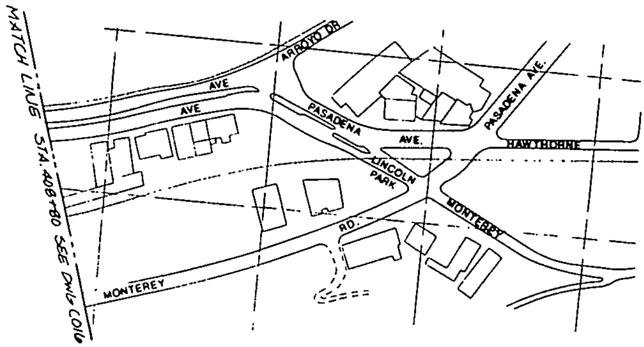
Criteria and Methodologies

LRT operations, particularly at grade, have the following potential impacts: reduced roadway space, reduced parking spaces, reduced accessibility to adjacent land uses, and increased automobile travel time and delays. With respect to midblock LRT impacts on traffic operations, the key criteria are available roadway and right-of-way widths, roadway geometrics, traffic volumes and operations, traffic controls, driveway locations and property access, on-street parking, and adjacent land uses.

The route planning process and the refinement process may involve many miles of potential LRT alignments, thereby precluding detailed quantitative analysis. A more prototypical approach can effectively address many midblock traffic issues, primarily by qualitative analysis. At the route refinement stage, the focus of traffic analysis is often more on the comparative impacts of various alignment alternatives than on the absolute impact. Geometric requirements for LRT, both at-grade and elevated LRT, and the need for lane modifications or eliminations are easily identified. Matrix evaluation techniques using the criteria listed above will often provide decision-makers with sufficient information to narrow down alternatives.

For example, in a route refinement study for the downtown Los Angeles-to-Pasadena corridor, a qualitative matrix format was utilized to evaluate impacts on roadway width, roadway geometry, traffic controls, parking, and adjacent land uses by LRT line segments. The matrix (see Figure 1) was presented adjacent to strip maps of LRT alignments for easy reference. This technique was used to make recommendations for median or side running and at-grade or elevated configurations for a preferred LRT alignment, as well as to focus on problem areas requiring subsequent quantitative analysis.

Graphical illustrations, particularly cross-sections, are also extremely effective in identifying the need for reduced lane widths, on-street parking



Segment	Santa Fe right-of-way	Lincoln Park	Monterey Place	Santa Fe right-of-way
ADT		14,000	14,000	
Roadway Width		60' with islands	60'	
Lanes		2 lanes each way with left-turn lane	2 lanes each way	
Traffic Controls		R.R. gates and signal	R.R. gates and signal, STOP signs on EB Pasadena, Hawthorne	
Land Use	Residential	Commercial	Commercial	Residential
Recommended LRT Alignment	Santa Fe right-of-way	At grade with gates.	At grade with gates.	At grade
Comments	No traffic impact	Existing geometry OK. Gated control with signal preemption. Detailed analysis required.	Existing geometry OK. Gated control with signal preemption. Detailed analysis required.	No traffic impact, provided that station does not reduce width of Hawthorne Street.

FIGURE 1 Example of qualitative matrix evaluation.

removal, left turn restrictions, shared through/right curb lanes, and lane removals. For example, the cross-sections in Figure 2 illustrate the comparative effects on lane widths, parking, turn lanes, and through lane capacity of at-grade versus aerial alignments. The cross-sections in Figure 3 were used in a route selection study in the San Fernando Valley to illustrate two options for accommodating an aerial LRT alignment along a major street through a regional activity center.

At midblock locations, LRT impacts are usually reflected through restrictions or loss of parking and loss of access to adjacent land uses. Simple

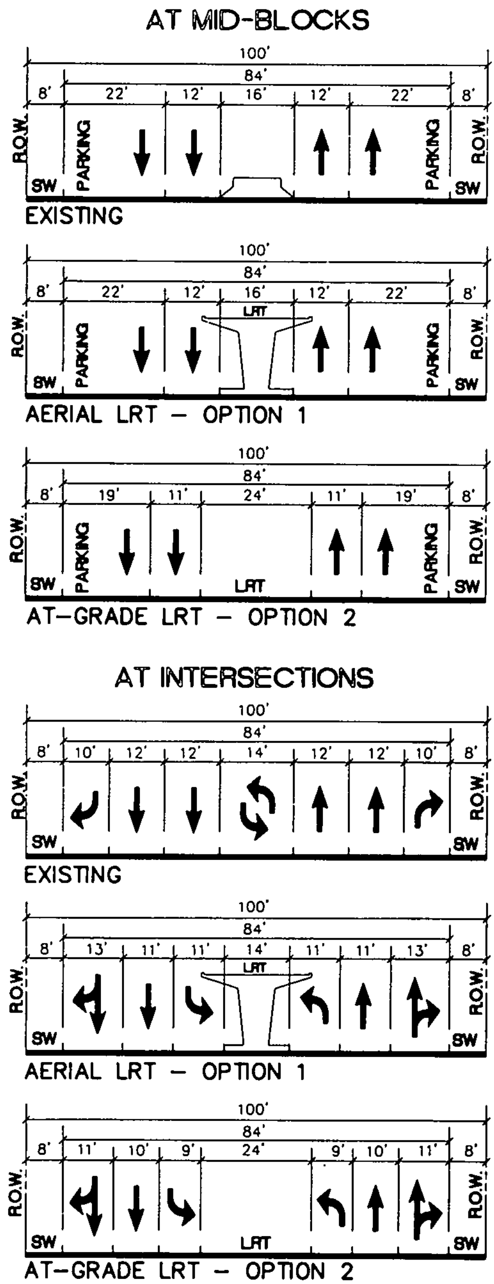


FIGURE 2 Prototypical highway: aerial versus at-grade LRT impacts.

quantification of the loss of parking will identify the need for mitigation measures such as on-street control and provision of off-street parking. Identification of critical access locations will also show the need for signals at certain minor intersections, for turn or access restrictions, or for improving geometric conditions at major intersections to compensate for access loss at the minor ones. The impacts of left-turn restrictions, modification to property access, closures of side streets, or diversion of traffic to parallel arterials can be further evaluated with conventional traffic impact techniques.

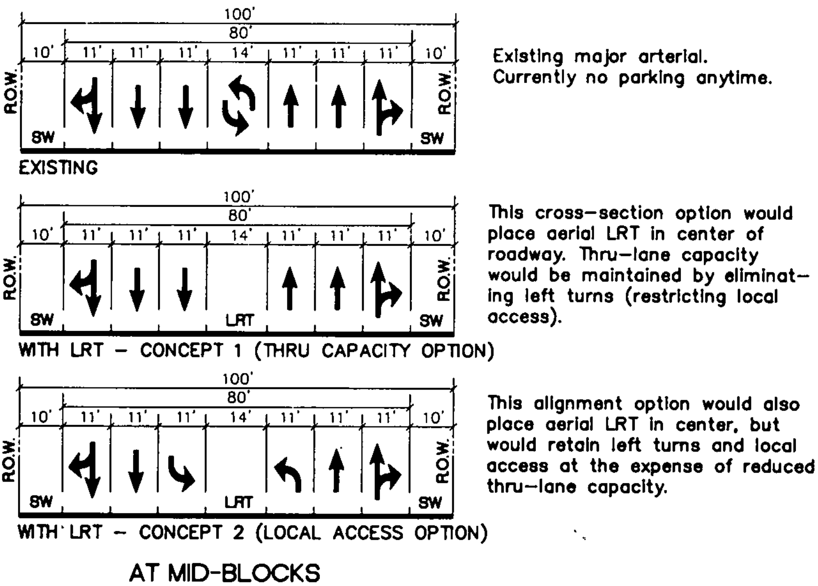


FIGURE 3 Examples of cross-section strategies for aerial LRT.

Analytical Approach

A qualitative approach is thus usually the most cost-effective way of dealing with midblock traffic issues early in the LRT route refinement process. Prototypical analyses can be used to illustrate likely LRT and traffic operating conditions under alternative scenarios (for example, at grade versus elevated, median versus side running). A qualitative overview, including matrix evaluations and illustrations, can rapidly identify general opportunities, constraints, and impacts of LRT operations, the appropriate type of mitigation strategies, and where they may need to be applied. This approach will also greatly assist in the educational process for decision-making, provide early input to civil engineers for alignment decisions, and provide the focus for more detailed analysis in the subsequent phases of the LRT planning and design process.

TRAFFIC ISSUES AT INTERSECTIONS

Traffic issues are often focused at intersections and where LRT crosses roadways, particularly with respect to the vertical LRT alignment. The key alignment choices to be made with respect to traffic are at-grade or grade separated. If at-grade alignment is chosen, the type and degree of LRT priority must then be decided. The traffic engineer has four strategies available to eliminate or reduce LRT impacts at intersections or midblock crossings:

- Separation of traffic flows in time (usually accomplished by traffic control signs or traffic signals that assign right-of-way to conflicting movements);
- Reduction in the number of traffic movements (converting one or both of the crossing streets to one-way operation or closing one or more of the approach legs);
- Separation of traffic flows in space at-grade (traffic and LRT can be separated at-grade by developing separate traffic lanes, by developing LRT medians, or by prohibiting or diverting certain movements); and
- Separation of traffic flows in space vertically (conflicts are totally eliminated by rail or highway grade separations).

Criteria and Methodologies

The evaluation of these traffic issues requires more quantitative analysis than do the midblock issues, as the traffic-LRT interface is more complex at intersections. LRT will generally have traffic operations impacts in both space and time, and the level of LRT impact will depend on the degree of priority that LRT receives over conflicting automobile traffic. The LRT may reduce roadway capacity (space impact) by taking roadway area previously used by automobiles, and may reduce signal capacity (time impact) by taking green time or adjusting the green splits due to preemption.

A considerable number of traffic engineering techniques can be used to mitigate the impacts of full LRT priority (preemption). If mitigation does not prove possible, then partial LRT priority is an option. Typically this involves the use of "window" techniques to obtain a more equitable balance of automobile and LRT performance and delay. LRT arrivals through linked signal systems may be timed to minimize disruption of automobile traffic. If partial priority does not work, then a decision must be made between no LRT priority at all or grade separation.

Thus one of the more important decisions in LRT planning is the degree of LRT priority and need for grade separation at intersections and roadway crossings. The principal criteria with respect to traffic issues at intersections are turn controls, intersection level of service, length of and dissipation of traffic queues, automobile delay, LRT delay, and impact on areawide signal systems.

A wide range of analytical tools is available to evaluate LRT priority and grade separation. Some are simple and easy to use; others are complex, sophisticated, and very time-consuming. At the planning level of route refinement, simple techniques allowing comparative and screening-level analysis are preferable. A number of alternative alignments are usually being considered, with many intersection locations. It is therefore not practical to conduct detailed or in-depth analysis at all locations, particularly when the majority will not be on the preferred alignment. (For example, a study in the San Fernando Valley had five alternative alignments and a total of over 80 major roadway crossings to be addressed.) The following techniques are available to address the key criteria listed above.

Level of Service

The impact of LRT at intersections may be quantified through level of service (LOS) analysis, which is a measure familiar to many people and is relatively easy to use. Changes in roadway geometrics and green time, as well as potential shifts in traffic volumes due to LRT, can be readily evaluated. LOS analyses have historically used a volume/capacity (V/C) ratio as a measure of the traffic conditions at an intersection.

More recently, the 1985 Highway Capacity Manual recommended average vehicular delay as the determinant of LOS. However, our experience has led us to conclude that delay is not a valid method of assessing LOS at intersections where LRT priority over automobile traffic occurs. First, there is no simple and accurate way of estimating average vehicular delay over the peak period while accounting for discrete light rail preemptions. Equations shown in the Highway Capacity Manual are developed empirically for steady state average vehicular delay where operations are similar from cycle to cycle. Transient occurrences, such as rail preemptions that may affect numerous signal cycles, are not accounted for. Second, the capacity of an intersection is a real measure with a definable threshold beyond which oversaturation will result, whereas average delay is a subjective measure, with no currently defined thresholds or standards of what is and is not acceptable. Third, drivers' perceptions of delay at an intersection due to automobile traffic are likely to be different from those due to rail, and there are currently no empirical data to quantify such a difference.

The V/C ratio is thus preferred over average vehicular delay for the definition of LOS. Intersection V/C calculations are conventionally based on assessing the V/C of the critical phase(s) assuming an optimal green time allocation. The primary impact of full priority LRT operation is the disruption of this optimal green split. This can be evaluated through the following equation:

$$V/C = [\text{Sum of critical } (V - V_p)/s] \times \frac{C}{C - L} \times \frac{3{,}600}{3{,}600 - P}$$

where

- V = total traffic volume of a critical movement (vph),
- V_p = traffic volume moving during preemption (vph),
- s = saturation flow (vph),
- C = signal cycle length (sec),
- P = total preemption duration in an hour (sec), and
- L = sum of critical loss time (sec).

This formula is a derivation of standard volume/capacity analysis that allows for the consideration of LRT preemptions in two key respects. The impact of preemption on capacity is accounted for by subtracting the total preemption time (P) in the LOS calculations. Traffic volumes are then adjusted to account for traffic movements that can occur concurrently with the LRT phase (V_p). Movements that are blocked during preemption receive no adjustment.

This general approach to LOS analysis has been successfully used to evaluate LRT impacts in numerous route refinement studies in Los Angeles and San Diego. It has enabled the identification of geometric improvements at intersections necessary to mitigate impacts of LRT preemption to acceptable standards and the subsequent evaluations of the feasibility and cost-effectiveness of such measures. Where mitigation measures were not considered feasible, the crossing was considered a candidate for either LRT control (no or partial LRT priority) or grade separation. Table 1 illustrates this approach for the midcorridor segment of a preliminary study in the San Fernando Valley area of Los Angeles. Mitigation measures were considered necessary, or feasible, at all crossings except Reseda and Balboa, which were identified as grade-separation candidates.

TABLE 1 EXAMPLE LEVEL OF SERVICE ANALYSIS

Crossing	Level of Service: 1986	2010 No LRT[a]	2010 with LRT (A)[b]	2010 with LRT (B)[c]	Street Improvements Necessary by 2010 to Accommodate Traffic and LRT Full Preemption[d]	Street Restripe or Widening[e]
Tampa at Topham	0.75	0.66	0.73	0.73	(Add thru lane each direction on Tampa)	Restripe
					(Add thru lane each direction on Topham)	Widen
Reseda at Oxnard	0.65	0.90	0.99	0.82	Add thru lane each direction on Reseda	Restripe
Lindley at Oxnard	0.53	0.77	0.85	0.73	Add thru lane each direction on Lindley	Widen
White Oak at Oxnard	0.68	0.79	0.88	0.79	(Add thru lane each direction on White Oak)	Restripe
					Add thru lane each direction on Oxnard	Widen
Balboa at Victory	0.85	0.92	1.02	0.79	(Add right-turn lanes on Balboa)	Widen
					Add thru lane each direction on Victory	Widen
					Add thru lane each direction on Balboa	Widen

[a]Assumes street improvements where necessary to maintain Level of Service D (ICU 0.90 or lower).
[b]Assumes LRT preemption and no mitigating street improvements.
[c]Assumes street improvements detailed in remainder of table.
[d]Improvements necessary independent of LRT are shown in parentheses. Note that timing and phasing of and responsibility for street improvements will depend on when LRT line is constructed.
[e]Street improvements not requiring widening are restriping of existing roadway and removal of on-street parking.

Queue Length

Another useful parameter for the quantification of LRT impacts is queue length, particularly the maximum queue lengths under worst-case conditions. Whereas the LOS identifies the average operating condition over the peak period, the worst-case queue length indicates the impacts of a specific though-transient condition. The maximum vehicles in a queue may be estimated from the formula:

$$Q_m = q \times r$$

where

Q_m = maximum vehicles in queue,
q = vehicle arrival rate (sec), and
r = maximum red time (sec) due to preemption.

The key element of the analysis is the determination of r, red time due to preemption. The worse-case condition is typically two LRVs arriving back-to-back at the crossing. As the probability that such an event will occur is relatively slim, either the 85th percentile or an average of best case (single preemption) and worst case (back-to-back) can be used as a reasonably conservative measure of "worst case."

The maximum back of queue may be approximated and impacts may be categorized as minor (blocking driveways), moderate (blocking residential or minor roads), or major (blocking major streets). The need for and feasibility of mitigation measures to increase storage capacity can then be evaluated. Where such measures are not feasible, grade separation may need to be considered. Table 2 illustrates the application of such an analysis to the midcorridor segment of an alignment study in the San Fernando Valley in Los Angeles. The two crossings where queues could extend to adjacent major streets (Reseda Boulevard and Balboa Boulevard) were the two crossings targeted in Table 1 for potential grade separation.

Delay

More complex evaluations of queues (such as average queue length, dissipation times, and associated delays) are not recommended at the planning stage of route refinement, as they are significantly more complex, time consuming, and difficult to apply. Although the impacts of LRT on automobile delay are often of most interest to traffic engineers in affected jurisdictions, automobile delays are not considered a good general indicator of LRT impacts (as explained above). The preferred indicators of LOS and queue length are adequate for determining the effectiveness of mitigation measures, which, if feasible, make the further analysis of delay a moot point.

The real usefulness of delay calculations is thus at those locations where traffic engineering mitigations for full LRT priority are not considered feasible and the degree of LRT priority (none, partial, or full) is being considered. Both automobile delay and LRT delay can be computed and expressed as

TABLE 2 EXAMPLE QUEUE ANALYSIS

Crossing	Maximum Queue Length (ft)[a]	Queue Impacts: Driveway	Minor Street	Major Street
Tampa	400	Yes	Calvert	None
Reseda	380	Yes	Bessemer	Oxnard
Lindley	280	Yes	Topham	None
White Oak	400	Yes	Bullock Bessemer	None
Balboa	500	Yes	None	Victory

[a]Represents back of queue following LRT preemption. Average of best case (single LRT preemption) and worst case (back to back LRT preemption).

person hours of delay to assist in the determination of the optimal level of LRT priority and the overall minimization of delays in the transportation system. (A good example, comparing overall commuter delay for partial and full LRT priority at major crossings on the Long Beach-Los Angeles LRT line, is discussed by Taylor et al. in another paper in this report.)

However, the calculation of automobile delay is difficult and time consuming. A general formula for calculations of delay from discrete events such as LRT preemption is not available. Technical studies for the Long Beach-Los Angeles LRT line concluded that, where delay calculations were necessary, they were best obtained through simulation techniques. Unfortunately, traditional network models such as TRANSYT-7F and NETSIM do not provide the flexibility to accommodate LRT preemption sequences. For the Long Beach-Los Angeles LRT project, a microcomputer-based technique was developed based on a deterministic queueing model (similar to the description of deterministic queueing theory found in the ITE handbook, for example). The model evaluates successive signal cycles over a 10- or 15-min period, and was used to determine delays, queue lengths, and *V/C* ratios for various mitigating strategies.

While this approach yielded acceptable results, it was also extremely time consuming. It should also be noted that these studies were conducted during the design phase of the project to finalize design solutions for an already determined alignment. For the reasons outlined above, evaluations of delay are not recommended during the route refinement stage of LRT planning.

Analytical Approach

The emphasis in route refinement is on the evaluation of general feasibility, effectiveness, and costs of various LRT alignment alternatives. The traffic analysis should provide an indication of where at-grade crossings will work, what type of mitigations are appropriate, and what the relative levels of impact will be. It should also determine where grade separations may be necessary as inputs to cost estimating, fixing of vertical profiles, and preliminary physical (e.g., noise and visual) impact analysis.

A useful approach that has been adopted in studies in Los Angeles is to divide intersections and crossings into three categories during the early planning stages as follows:

- Category I: At-grade LRT priority should be feasible;
- Category II: Partial or no LRT priority, or grade separation, may be necessary; and
- Category III: Grade separation is probably necessary.

Although it should be clearly understood that every situation is different and that it is difficult to generalize, a number of sources do provide some general rules of thumb. These come from analytical work on LRT corridors in planning and design in Los Angeles County, from empirical data collected around the country, and from preliminary findings of ITE committee investigations. Generally these are as follows:

- For roadway crossings under 20,000 average daily traffic (ADT), at-grade crossings with LRT preemption should be workable.
- Between 20,000 and 30,000 ADT, at-grade may be workable, particularly if LRT is not accorded full priority. Depending on the operator's service needs, no or partial LRT priority or grade separation could be necessary.
- Over 30,000 ADT, grade separations should be seriously considered, although depending on site-specific circumstances, at-grade solutions may still be workable.

Clearly, factors such as roadway geometry, the number and configuration of traffic lanes, and peak hour traffic flows are important, and may cloud distinctions between these categories. Quantitative techniques such as LOS and queue analysis can be applied to validate and confirm such categorizations, and to further identify the level of mitigation required for at-grade solutions, particularly at Category II crossings. While "anything is possible" from the engineer's perspective in designing an at-grade solution, the "gray area" of 20,000 to 30,000 ADT crossings in Category II often becomes a matter of policy as well as technical feasibility.

It is in this category that the needs and resources of the operator, local jurisdiction, and community must be balanced. No LRT priority may produce no traffic impacts but may also be unacceptable from the operator or service point of view. Technical solutions may work for full LRT priority at-grade but may be too costly, unsafe, or politically unacceptable. Partial priority may thus be a satisfactory compromise between LRT operations and the affected jurisdiction.

Clearly all these trade-offs cannot be resolved at the planning stage because of the time and costs involved. The analytical strategy in route refinement should thus be to determine which intersections and crossings fall into Category I ("sure at-grade") and Category III ("probable grade separation") with a minimum of quantitative effort. The general level of mitigation required for Category II locations can be identified to assist decision-makers in evaluating the trade-offs between at-grade and grade separations. This approach allows the focusing of more detailed quantified analysis, particularly complex delay and queue evaluations on the much smaller number of Category II ("gray area") locations and on the subsequent design of mitigating strategies.

CONCLUSIONS

Early traffic analyses can be performed using both qualitative and quantitative techniques to assist in key decisions of LRT route planning. A generalized model for the types of traffic evaluation most appropriate to each stage of the LRT process is shown in Figure 4. In many cases qualitative evaluation can be used effectively to screen potential routes and alternatives, and is usually the most cost-effective way of dealing with midblock traffic issues early in the LRT route refinement process. A qualitative approach can rapidly identify opportunities, constraints, and likely impacts of LRT operations, and provide early input to civil engineers for alignment decisions.

Quantitative analysis is most useful for alignment issues at intersections to quantify LRT impacts, to identify the most feasible vertical LRT alignment in the traffic context, and to evaluate the degree of LRT priority necessary at particular roadway crossings. Quantitative methods are thus most effectively used after the initial screenings to determine impacts and, when applied to specific problem areas, to develop mitigation solutions.

Relatively straightforward criteria such as LOS and queue length will provide good early insights into the traffic issues of LRT route planning. Although these analyses will clearly not provide resolution of all the issues, they do provide a cost-effective way of focusing more complex subsequent evaluations. On the other hand, complex evaluation criteria involving automobile delay and impact on signal systems are not recommended at the LRT planning stage as they rarely need to be addressed to every location. Attention to these criteria can be focused on specific locations where decisions on the level of LRT priority must be made, and during the design phase when mitigating strategies are finalized.

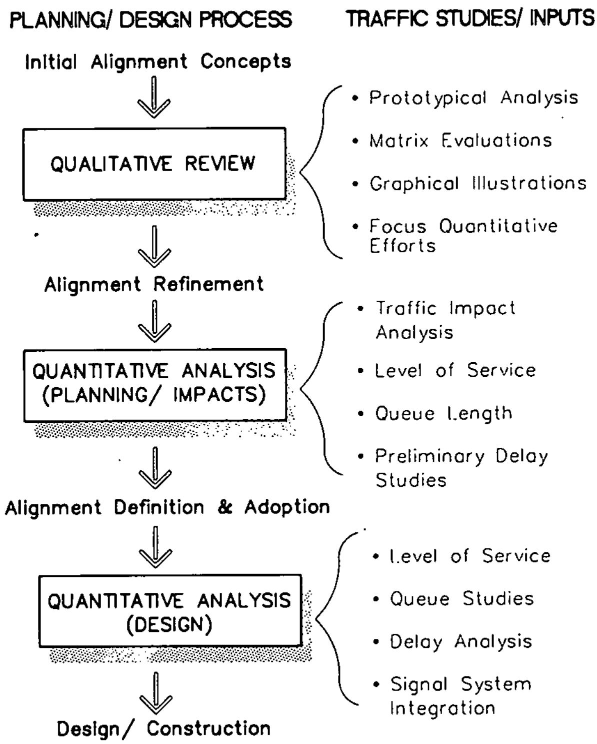


FIGURE 4 Generalized model for traffic study in LRT route planning.

In conclusion, the key decisions regarding traffic that can be made at the LRT route planning stage are as follows:

- Relative midblock impacts of horizontal alignment alternatives on traffic operations and on-street parking;
- Relative midblock impacts of at-grade versus elevated alignments on traffic operations and on-street parking;
- Potential grade separation needs;
- Potential for at-grade intersection solutions and likely techniques for LRT control and priority; and
- "Gray area" locations requiring trade-off decisions between level of LRT priority and grade separation.

Elements requiring more detailed analysis beyond the planning stage and throughout design of the LRT system are as follows:

- Impacts and delays associated with LRT priority, particularly at crossings requiring trade-off decisions between level of LRT priority and grade separation;
- Final grade separation decisions;
- Relative delays between automobile and LRT for at-grade strategies; and
- Final selection of preferred at-grade LRT control strategies and appropriate mitigating design solutions.

In the traffic context, many horizontal and vertical alignment and grade separation decisions can be made in the planning stages of the LRT route refinement process. The traffic evaluation techniques outlined in this paper will provide a good understanding of traffic issues at the early planning stages of LRT and focus subsequent LRT design efforts. Traffic studies are a key input to LRT alignment decisions, and the data provided on potential LRT control strategies, mitigations, grade separation needs, and impacts on costs can provide technicians, politicians, and communities with the traffic-related information necessary to make informed decisions between alternative alignments. Although significantly more complex levels of traffic analysis may often be necessary to determine final alignments and to finalize mitigating strategies for at-grade solutions during the design stage, the extent of such analyses can be effectively focused by application of appropriate traffic evaluation techniques in the early stages of LRT planning.

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