# Traffic and Light Rail Transit: Methods of Analysis for DART's North Central Corridor

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Since 1986 three methods have been used to evaluate the traffic effects of at-grade light rail transit (LRT) operations in Dallas' North Central Corridor. The objective was to determine the need for and location of any grade separations. The technical data was subsequently entered into the grade separation decision making process that included other factors such as aesthetics, ability to pay, and community opposition or support. The first of the methods calculates the decrease in cross street capacity resulting from the reduction in the progression band caused by preemptive LRT operations. The second method has four modules that estimate the reduction in cross street capacity, the impact of motor vehicle queuing, motor vehicle stopped delay, and reduction in cross street travel speeds resulting from preemptive at-grade LRT operations. The third method estimates the change in various measures of effectiveness by simulating traffic operations with and without priority at-grade LRT operations. The model used for this third method is the TRANSYT-7F traffic signal optimization and simulation model. In addition to these methods, the cost-benefit analysis used for the North Central Line is discussed, along with the potential application of the NETSIM and Traf-NETSIM models.

The Dallas Area Rapid Transit Authority (DART) was created by the voters of Dallas, Texas, and surrounding communities on August 13, 1983. The 20-mi starter system approved by the DART board of directors in June 1989 (see Figure 1) consists of four legs radiating from the Dallas central business district (CBD). On the Oak Cliff, West Oak Cliff, and South Oak Cliff lines, most of the street crossings of the LRT guideway will be isolated, midblock, at-grade crossings or within the median of a major arterial street. The North Central Line will be in a subway tunnel from the northeastern edge of the CBD to a point just north of Mockingbird Lane. The potential at-grade section of the North Central Line, which is the subject of this paper, traverses what is, and is expected to continue to be, one of the most congested corridors in Dallas. Bounded by Park Lane on the north, Greenville Avenue on the east, Mockingbird Lane on the south, and US-75 (North Central Expressway) on the west, DART's North Central Line will cross nine major east-west thoroughfares—five of these feed ramps serving US-75—and are expected to carry traffic volumes in excess of 20,000 vehicles per day (vpd).

To determine the technical need for and location of grade separations, it was necessary to estimate the effect of at-grade LRT operations on cross street motor vehicle traffic at each potential crossing. To do this, DART initiated a series of planning studies that, with the passage of time, have become more intense and refined. Between January 1986 and July 1991 three distinct methods of analysis were used:

1. The options analysis method—a method used by DART and Parsons Brinckerhoff/DeLeuw Cather (PBDC) planners from January 1986 through mid-1986 for a quick but intensive systemwide evaluation of a large number of alternative systems and alignments.
2. The grade separation analysis method—a refinement of the options analysis concept used for detailed planning between mid-1986 and July 1989. The method can be used by itself on simple crossings as an analysis tool or on more complex crossings as a screening process to determine potential problems and solutions.
3. The TRANSYT-7F evaluation method—a logical progression from the second method, it permits areawide traffic impact studies of at-grade LRT operations in complex corridors. TRANSYT-7F work on the North Central Line began in August 1989.

As a supplement to the TRANSYT-7F evaluation method, a benefit-cost analysis was performed for each potential at-grade crossing to determine the cost-effectiveness of constructing a grade separated facility.

## OPTIONS ANALYSIS METHOD

This method was developed to make quick estimates of the effect of fully preemptive LRT operations on motor vehicle traffic at potential at-grade crossings. Four major assumptions are made:

1. LRT operates with full, unconditional railroad-type preemption across crossings protected by flashing lights and railroad-type gates.
2. Close-by street intersections restrict, or meter, traffic flow on the roadway link containing the rail crossing.
3. The crossing is blocked by light rail vehicles (LRVs) for a percentage of time equal to the following:

$$r/C_D = TPH \times BT/H \quad (1)$$

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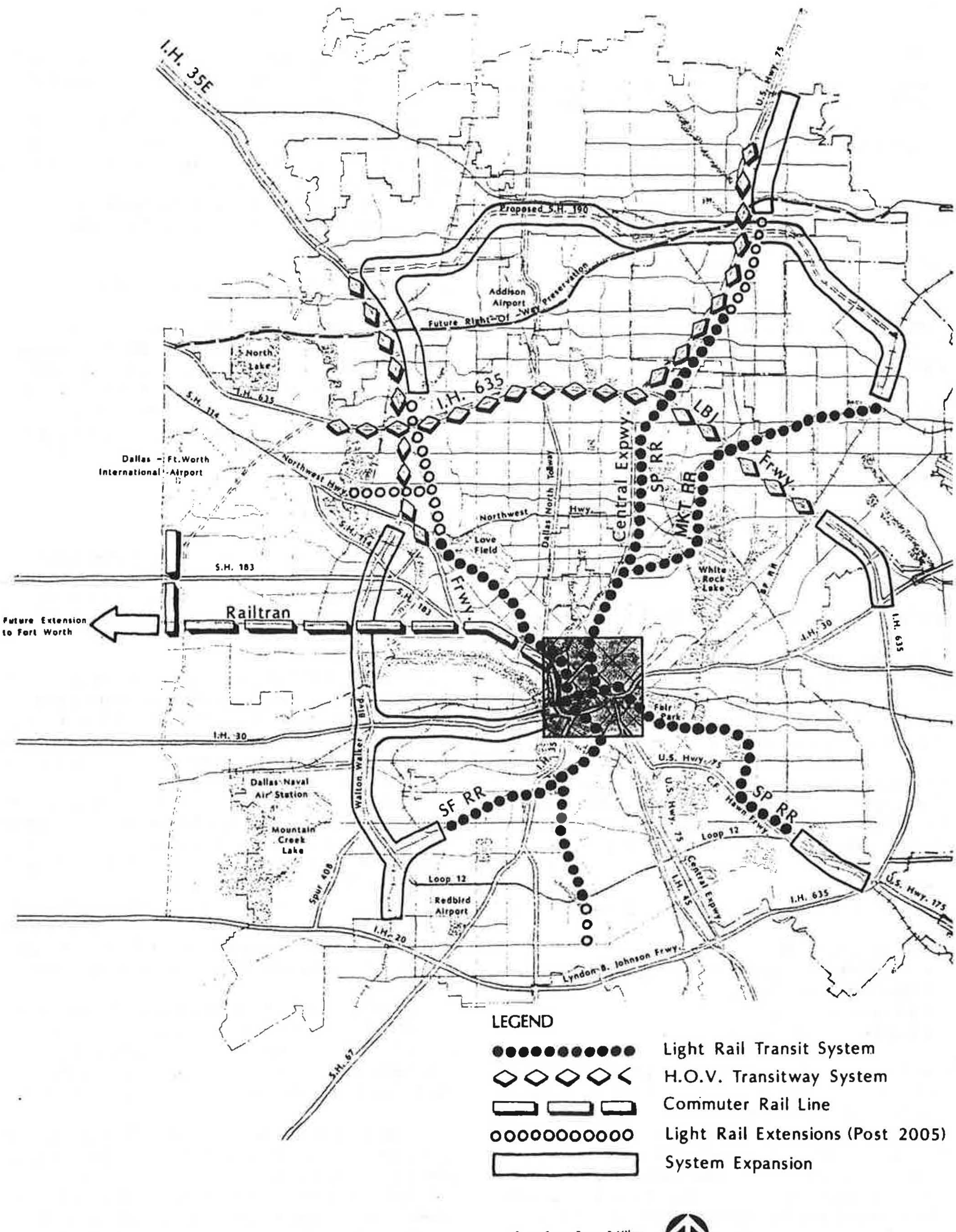


**FIGURE 1 Proposed DART system plan.**

where

$r/C_D$ = blockage ratio of the street by transit operations,
$TPH$ = trains per headway period (two-way operation = 2, one-way operation = 1),
$BT$ = time per train that the gate blocks the street (sec), and
$H$ = train headway time (sec).

example

$$r/C_D = 2 \text{ trains} \times 30 \text{ sec}/150 \text{ sec} = 0.40$$

4. The traffic service volumes on the link containing the at-grade crossing are reduced by the blockage ratio to reflect the additional delay resulting from the fully preemptive rail operations:

$$MSV = (1 - r/C_D) \times ISV \qquad (2)$$

where

$MSV$ = maximum service volume at a given level of service (LOS), and
$ISV$ = upstream intersection service volume at a given level of service.

example

$$MSV \text{ at LOS D} = (1 - 0.40) \times 2{,}115 \text{ vph} = 1{,}269 \text{ vph}$$

The options analysis method draws upon *Special Report 87: Highway Capacity Manual* (1965 edition) (*1*, Ch. 6)—in which levels of service (LOS) are defined by the load factor associated with the particular intersection approach under study. The load factor is the ratio of the number of green phases on an approach that are fully used (loaded) by traffic to the total number of green phases available. Graphs from *Special Report 87* were used to determine the approach volumes (*MSVs*) for the upstream intersections for each LOS. Key assumptions for the upstream intersections were as follows:

- No turns,
- Ratio of cross street green time to cycle length ($g/C$) of 0.42,
- 60-sec cycle length,
- 60/40 directional distribution of hourly demand volume,
- Peak hour factor of 0.85,
- 8 percent trucks, and
- 12-ft lanes and no parking.

Additional assumptions include a metropolitan area population of more than 1 million, location in the fringe or outlying area, and no local bus stops.

A table was constructed that showed maximum service volumes at each LOS for two-, four-, and six-lane cross streets versus 2.5-, 5.0-, 10.0-, and 20.0-min light rail headways. Two-way peak hour traffic volumes at each proposed grade crossing were compared with the appropriate maximum service volume to determine the LOS that will be provided by a crossing.

Although this method was appropriate for a quick analysis of a large number of alternative alignments, it has a number of limitations, including the following:

1. Use of fixed parameters such as the peak hour factor, the directional distribution of motor vehicle traffic, and the $g/C$ ratio of the upstream intersection,
2. Use of measures of effectiveness (MOEs) based on volume/capacity ratios rather than the average vehicle stopped delay values contained in *Special Report 209*, the third edition of *Highway Capacity Manual* (*2*),
3. No specific assessment of crossing capacity, and
4. No assessment of motor vehicle queue magnitudes.

## GRADE SEPARATION ANALYSIS METHOD

Engineers and planners from DART, the city of Dallas Department of Transportation (DOT), and DART's consultants recognized that the assumptions of the options analysis method were too restrictive for DART's more detailed project planning and design phase. Alternative methods with greater flexibility were evaluated, resulting in a series of spreadsheets referred to as the "grade separation analysis method."

### Overview of Method

The grade separation analysis method is an iterative multiple analysis technique designed to assess peak hour traffic effects of LRT operations with and without specific traffic mitigation measures in place. The major elements of the process are as follows:

1. Identify candidate streets—Each street crossing the LRT line was initially examined. Major highway facilities currently grade separated from the proposed DART rail alignment were assumed to remain grade separated. Streets not on the Dallas thoroughfare plan as secondary thoroughfares (or higher classifications) were eliminated from the study by policy.
2. Data collection—Field data included roadway geometrics, traffic signal parameters near the crossings, 24-hr traffic volumes, peak hour directional distributions, and the percentage of the 24-hr traffic volumes occurring during the peak traffic hours (K factors).
3. Forecast of design year demand—estimates of 24-hr traffic volumes were forecast for the year 2010 using the MicroTRIPS traffic model developed by the city of Dallas with assistance from the North Central Texas Council of Governments (NCTCOG).
4. Preliminary analysis—The microcomputer spreadsheet estimated the a.m. and p.m. peak hour directional LOS of the roadway segments next to the proposed LRT crossing, as well as vehicle queues upstream and downstream of the crossing. Crossings were classified into one of three categories:

- At-grade crossing indicated—If the LOS estimates were A through C and the estimated vehicle queues did not exceed available storage, no further analysis was necessary.
- Grade separated crossing indicated—If the LOS estimates were F or the vehicle queues greatly exceeded the available vehicle storage or both, no further analysis was necessary.
- Crossing subject to further analysis—Where the LOS estimates for at least one approach during one of the peak

hours was D or E or the estimated queue length exceeded the available vehicle storage by less than 100 ft or both, a second level of study noted as "detailed analysis" was initiated.

5. Detailed analysis—Two evaluations were performed: first, an estimate of vehicle stopped delay at the LRT crossing to determine crossing LOS and, second, an estimate of cross street through travel speeds to determine arterial LOS. Comparing the arterial LOS with and without the at-grade crossing determined its relative impact. If queuing problems were found, solutions (auxiliary turning lanes, dual left turn lanes, channelization, and signal phasing modifications) were examined.

6. Findings—If, after examining a particular crossing at the various levels of detail noted above, the crossing operated at acceptable levels of service, it was not subject to further study. At those locations where the analysis indicated significant traffic impacts, a grade separation was considered if suitable traffic mitigation measures could not be found.

### Key Traffic Characteristics of Method

In applying this method, estimates were made of four key traffic characteristics: The *K*-factor, the directional distribution, the $g/C$ ratio for the upstream and downstream intersection approaches ($g/C_s$), and the ratio of green time to cycle length for the DART rail crossing ($g/C_D$). A consensus was reached with city of Dallas DOT staff that existing traffic characteristics would be used for projected conditions within the following limits:

1. *K*-factor—If the existing factor was less than 0.08, use a projected factor of 0.08; if the existing factor was greater than 0.10, use a projected factor of 0.10.
2. Directional distribution—If the existing directional distribution was between 85 percent/15 percent and 99 percent/1 percent, use a distribution of 85 percent/15 percent.

The $g/C_D$ of the cross street assumed the street was blocked by rail operations for 35 sec. This time approximates the time required for a 300-ft-long train to cross 100 ft of right-of-way at 20 mph with the advance warning requirements for fully gated railroad crossings contained in the *Texas Manual on Uniform Traffic Control Devices* (*3*). The following example illustrates the means of arriving at the $g/C_D$ value for each crossing.

given

DART vehicle headway = 5 min in each direction, and

gate down time = 35 sec.

let

number of hourly gate activations = $Nt$

gate blockage time (sec/hr) = $G_{Bl}$

effective $g/C$ ratio of crossing gate = $g/C_D$

then

$$\begin{aligned} Nt &= 2 \times \text{number of one-direction trains per hour} \\ &= 2 \times (60\ \text{min/hr}/5\ \text{min headway}) \\ &= 24\ \text{activations} \end{aligned} \tag{3}$$

$$G_{Bl}\ (\text{secs/hr}) = (35\ \text{secs/gate activation}) \times (24\ \text{activations in peak hour}) = 840\ \text{sec/hr} \tag{4}$$

$$r/C_D = (G_{Bl})/(3{,}600\ \text{sec/hr}) = (840\ \text{sec/hr})/(3{,}600\ \text{sec/hr}) = 0.233 \tag{5}$$

$$g/C_D = 1.0 - (r/C_D) = 0.767 \tag{6}$$

In this example, the gate is estimated to be up an average of 77 percent of the time. Conversely, the gate down time, or blockage time $r/C_D$, is estimated to affect traffic flow 23 percent of the time. The value for $g/C_D$ is dependent only on the train headways and the assumed gate down time.

### Street Capacity Estimation

The method used to estimate the capacity of streets crossing DART LRT guideways was the result of an evolutionary process beginning with the options analysis method. The most restrictive traffic flow constraint (either DART rail operations or the signal timings associated with signalized intersections on the cross street) was assumed to establish the capacity of the cross street.

A microcomputer spreadsheet was constructed to perform the calculations. Twenty-four-hour design year volumes were converted into directional peak hour demand estimates that could be compared with the most restrictive capacity constraint in the vicinity of the crossing—either an up- or downstream traffic signal, or the light rail crossing itself.

The capacity estimates for the cross street were based on the number of lanes indicated on the Dallas thoroughfare plan for a LOS E saturation flow rate. The spreadsheet provided capacity estimates for street cross sections of one to five lanes in each direction. Specific levels of service were related to the capacity of the segment using these relationships:

- LOS A—60 percent of capacity,
- LOS B—70 percent of capacity,
- LOS C—80 percent of capacity,
- LOS D—90 percent of capacity,
- LOS E—100 percent of capacity.

Traffic signals near the North Central Line operate both as isolated signals and within coordinated signal systems. At the time this method was used, it was generally assumed that traffic signals were not coordinated if they were located more than 0.5 mi apart because of platoon dispersion. Because of this assumption, the treatment used for each crossing was dependent on the distance from the nearest signalized intersection and whether it was within a coordinated signal system. Crossings within 0.25 mi of a signalized intersection were assumed to be affected by the cross street traffic signals. To determine the most restrictive capacity constraint, the following rules were applied:

1. When adjacent traffic signals were within 0.25 mi of a crossing and operated as isolated signals or in two uncoordinated systems, the lane group saturation flow rate was reduced by the most restrictive $g/C$ of the cross street. Usually the high $g/C_D$ ratios of the at-grade crossings do not reduce cross street capacity and $g/C_{\text{eff}} = g/C_s$.
2. When adjacent traffic signals were within 0.25 mi of a crossing and operated in a coordinated traffic signal system, the lane group saturation flow rate was reduced by the product of the $g/C_D$ and the smallest $g/C_s$ for the through movement of the cross street. As time increases, the amount of reduction in average band width converges toward the product of $g/C_D$ and the smallest through movement $g/C_s$ value. Consequently $g/C_{\text{eff}} = (g/C_D) \times (g/C_s)$.
3. When adjacent traffic signals were more than 0.25 mi from the crossing, the lane group saturation flow rate was reduced by $g/C_D$. Therefore, $g/C_{\text{eff}} = g/C_D$.

The relationship between the demand volume and street segment capacity determined the LOS. Capacity and LOS were also calculated without an at-grade crossing to determine the incremental traffic impact of the crossing.

Although developed independently, the street capacity estimation procedure is similar to the method Gannett-Fleming/Schimpeler Corradino (*4*) used on the Bayside Line in San Diego, California.

### Queue Length Estimation—Signalized Intersections and DART Rail Crossings

Two cases of vehicle queuing are estimated by the method. In the first case LRT operations block the cross street for a period of time that causes motor vehicles to spill back into an upstream intersection. This case is dependent upon the gate blockage time at the crossing ($G_{Bl}$) and the average LRT cycle length ($C_D$). In the other case the queues at the downstream signalized intersection encroach on the at-grade rail crossing. They are directly related to the signal timing of the downstream intersection which is defined by the $g/C_s$ of street approach analyzed and the cycle length of the traffic signal. In either case the average number of vehicles arriving during the appropriate effective red period was estimated assuming constant vehicle arrivals. A factor of 1.5 was applied to this value to compensate for differences in the motor vehicle arrival patterns. This resulted in a probability estimate of being exceeded of 15 percent for low approach volumes and 5 percent for high volumes. The derived queue formula is as follows:

$$X_a = 1.5 \times (r/C_{\text{eff}}) \times \{[(PHV/\text{no. lanes})]/[(3{,}600\ \text{sec/hr})/C_{\text{eff}}]\} \times 25\ \text{ft/veh} \quad (7)$$

where

$X_a$ = queuing distance in feet rounded to the next highest multiple of 25 ft,
$r/C_{\text{eff}}$ = $(1.0 - g/C_{\text{eff}})$,
$C_{\text{eff}}$ = $C_D$ for Case I, where upstream intersection may be blocked because of DART operations,
= $C_s$ for Case II, where downstream intersection timing may cause the LRT crossing to be blocked, and
$PHV$ = total estimated directional peak hour demand volume for the design year.

Available queue storage distances were estimated from aerial photography and preliminary alignment studies. Comparisons were made between the anticipated queue lengths and storage distances to determine the adequacy of the storage area. Where turning movement counts were available, the estimated directional peak hour demand volumes were divided among the approach lanes in accordance with the percentage of turning movements, resulting in an improved estimate of projected queue length.

### Queue Length Estimation—Unsignalized Intersections

The method used to estimate motor vehicle queues at unsignalized intersections downstream from at-grade crossings used a combination of capacity analysis and queuing theory. Capacity analysis was used to estimate the available gaps in the conflicting traffic streams. Single channel queuing was then applied to estimate queue length on the minor street approach.

In the study area most low volume cross streets are subject to wide variations in traffic flow rates during the peak hour. In addition unsignalized intersections will not be subject to measures that can be used to clear vehicles from crossings. These factors suggested using a higher than average demand volume for study purposes to account for short term operational fluctuations. A poisson arrival distribution was therefore assumed. The average peak hour demand volumes were increased so that the probability of being exceeded was no greater than 15 percent. This adjusted demand volume was used as the arrival rate.

The capacity of the unsignalized intersection was estimated using unsignalized intersection capacity techniques (*2*). The sum of the demand volume and reserve capacity for a particular movement is the capacity of that specific approach movement and was used as the average service rate. The number of vehicles in the queue was estimated using a formula derived from work by Wohl and Martin (*5*, Eq. 11.51a):

$$x = \{\ln [1 - P(n < x)]/\ln(R_a/R_s)\} - 1$$

where

$x$ = estimated number of vehicles in queue,
$R_a$ = arrival rate in vehicles per hour,
$R_s$ = service rate in vehicles per hour,
$P(n < x)$ = probability of $x$ vehicles in queue exceeding $n$ vehicles in queue, and
$x$ = $n$ for study purposes.

Note that $R_a$ divided by $R_s$ is equivalent to the $v/c$ ratio of the approach movement. The probability that $x$ will be greater than $n$ vehicles was set at 0.95. The final form of the equation was as follows:

$$X_a = 25 \text{ ft/veh} \times \{[\ln(0.05)/\ln(R_a/R_s)] - 1\} \qquad (10)$$

**Crossing Delay Estimation**

The method to estimate delay at DART rail crossings used the delay equation contained in the 1985 *Highway Capacity Manual* (*2*, Ch. 9). Factors in the equation were developed from estimates made for the street capacity estimation module and once again, a microcomputer spreadsheet was constructed to perform the calculations.

Total estimated directional peak hour demand volumes were calculated in the street capacity estimation module and used as input for the crossing delay calculations. These volumes were multiplied by the lane utilization factor to determine lane group volumes. The critical lane volume is the lane group volume divided by the number of travel lanes on the crossing approach. The saturation flow rate estimates used in this module were consistent with those of the street capacity estimation module. The crossing capacity per lane was calculated by multiplying the saturation flow rate estimate by the $g/C_D$. The $v/c$ ratio of the crossing was calculated by dividing the critical lane volume by the lane capacity. Average individual stopped delay was estimated using Equation 9-18 from the 1985 *Highway Capacity Manual* (*2*). Berry and Williams (*6*) validated use of this equation for LRT crossings. The equation is as follows:

$$d = \{0.38\, C[1 - g/C_D]^2/[1 - (g/C_D)(X)]\} + 173X^2\{(X - 1) + [(X - 1)^2 + (16\, X/c)]^{0.5}\} \qquad (11)$$

where

$d$ = average stopped delay per vehicle for the subject lane group (sec/veh),
$C$ = cycle length (sec),
$g/C_D$ = ratio of the estimated green time for motor vehicle traffic to average DART cycle lengths at a specific DART crossing,
$X$ = $v/c$ ratio for the subject lane group, and
$c$ = capacity of the through lane group.

The delay estimate is for an assumed random arrival condition. Where the arrival of an LRV could not be predicted in terms of a coordinated traffic signal system, the calculated delay was adjusted. It was multiplied by the progression factor for pretimed signal control and a Type 1 vehicle arrival type (*2*). This arrival type conservatively assumes that 50 percent to 100 percent of the vehicle platoons will arrive at the crossing just as the gate lowers for an LRV. The at-grade crossing LOS was estimated using the following criteria:

- LOS A—less than 5.0 sec of average individual stopped delay,
- LOS B—from 5.1 to 15.0 sec of average individual stopped delay,
- LOS C—from 15.1 to 25.0 sec of average individual stopped delay,
- LOS D—from 25.1 to 40.0 sec of average individual stopped delay,
- LOS E—from 40.1 to 60.0 sec of average individual stopped delay, and
- LOS F—over 60.0 sec of average individual stopped delay.

The total approach delay accounting for the deceleration/acceleration before and after a motor vehicle stops at an at-grade crossing was calculated as follows:

$$D = 1.3d \qquad (12)$$

where

$D$ = intersection approach delay (sec/veh), and
$d$ = intersection stopped delay (sec/veh).

**Travel Speed Estimation**

The method used to estimate travel speed impacts of DART rail crossings on motor vehicle traffic was taken directly from the 1985 *Highway Capacity Manual* (*2*). Each cross street studied included an at-grade crossing and the adjacent signalized intersections.

Intersection delay estimates were developed using projected intersection volumes. Overall intersection LOS was maximized by minimizing total intersection delay. The result was used to estimate the arterial LOS (*2*) with the FHWA highway capacity software (*7*). The arterial LOS was estimated with and without the additional vehicular delays resulting from DART rail operations. The LRT related delay was input as "other delay" and default values were used for initial speeds. A microcomputer spreadsheet was used to display the results of the analysis.

**Evaluation Criteria**

Street capacity level of service and queue length calculations were examined in the preliminary analysis stage and allowed the crossings under study to be classified as follows:

1. At-grade crossing indicated,
2. Grade separated crossing indicated, and
3. Crossing subject to further analysis.

Additional studies were identified for all crossings classified in the latter category. A summary of the evaluation criteria for each type of analysis is shown in Table 1 and represent the values used in the grade separation analysis method for assessing traffic effects of the DART rail crossings.

Portions of the grade separation analysis method were included in drafts of ITE Committee 6A-42's report on LRT grade separation guidelines (*8*). Although this method is su-

**TABLE 1 Evaluation Criteria for DART At-Grade Rail Crossings**

| Type of Analysis | Evaluation Criteria | | |
|---|---|---|---|
| | Finding for At-Grade Crossing | Detailed Study Needed | Finding for Grade Separation |
| Preliminary | | | |
| Street Capacity | LOS = A - C | LOS = D - E | LOS = F |
| Rail Crossing Queuing | Storage > Queue | Storage ~ Queue | Storage << Queue |
| Signalized Intersection Queuing | Storage > Queue | Storage ~ Queue | Storage << Queue |
| Unsignalized Intersection Queuing | Storage > Queue | Storage ~ Queue | Storage << Queue |
| Detailed Analysis | | | |
| Crossing Delay | LOS = A - D | Not Applicable | LOS = E - F |
| Travel Speed | LOS = A - D | Not Applicable | LOS = E - F |

perior to the options analysis method, it still had major limitations including the following:

1. No assessment of the effect of preemption on areawide traffic signal operation,
2. Limited assessment of the effect of cross street progression on LOS and queuing,
3. No assessment of the effect of train operations on diamond interchange operation,
4. No assessment of the effect of "late" trains on traffic signal operation, and
5. Serious deficiencies within the street capacity estimation module resulting from the reliance of level of service on the most restrictive $g/C$ ratio and not on at-grade crossing capacity and delay (*9*, Ch. 4).

## TRANSYT-7F EVALUATION METHOD

Following a review of the results of the grade separation analysis method, the city of Dallas requested additional detail on the effect of the proposed LRT operations on traffic operations. TRANSYT-7F was selected to simulate systemwide traffic signal operations under a condition of restricted on-demand traffic signal preemption in the corridor.

TRANSYT-7F can be used to account for systemwide traffic effects of nonpreemptive at-grade crossings and is especially useful for studying the nonrandom traffic flow often resulting from progressive traffic signal systems. Specific MOEs calculated by the TRANSYT-7F model and important to this effort included estimates of average vehicle delay for each intersection and "maximum back of queue" estimates for individual intersection approaches.

Initially a 50-node network was developed that encompassed most of the major traffic signals in the corridor. As at-grade crossings were removed from the network, the number of nodes was slightly reduced. At present the evaluation network (Figure 2) includes 25 signalized intersections, 9 diamond interchanges on US-75, and 5 at-grade crossings of the LRT guideway.

To date three TRANSYT-7F studies have been made, although the latter two were substantially the same and will be described as a single study. During the first TRANSYT-7F study the following steps were generally used to apply the optimization and simulation features of the model to the problem:

1. Study networks were identified and coded for base and light rail scenarios.
2. Initial traffic signal phase sequences for individual intersections were input as provided by the city of Dallas.
3. Diamond interchange traffic signal sequences were developed from PASSER III-88 optimization studies.
4. At the insistence of the city of Dallas no traffic signal preemption was allowed. Therefore train operations in the corridor were assumed to abide by a strict progressive green window operating concept.
5. At the time of the study, DART had not fully developed a train operations scenario. Therefore it was assumed that each train would operate through the corridor at 30 mph on 5-min headways, have a single 30-sec station stop at the Lovers Lane Station, and have a 2.5-min layover at the Park Lane Station. These assumptions resulted in a symmetrical time-space diagram through the corridor.
6. To regularly and predictably operate a train in the green window through the corridor, the traffic signal cycle length was set at 150 sec. There were two traffic signal cycles for each 5-min (300-sec) train headway.
7. The crossing blockages were modeled using two-phase traffic signal operations, a 40 sec blockage time, and a crossing saturation flow rate of 1,600 vphgpl (*9*). No clearance phases were provided.
8. Two simulations were made for each light rail scenario. One included train blockages at the Yale Boulevard, University Boulevard, and Blackwell Street crossings. The second included train blockages at the Southwestern Boulevard, Caruth Haven Lane, and Blackwell Street crossings. The symmetry of the proposed train operation simplified the study considerably. Except for the traffic signal timing at the light rail crossing nodes, both networks were identical. The first

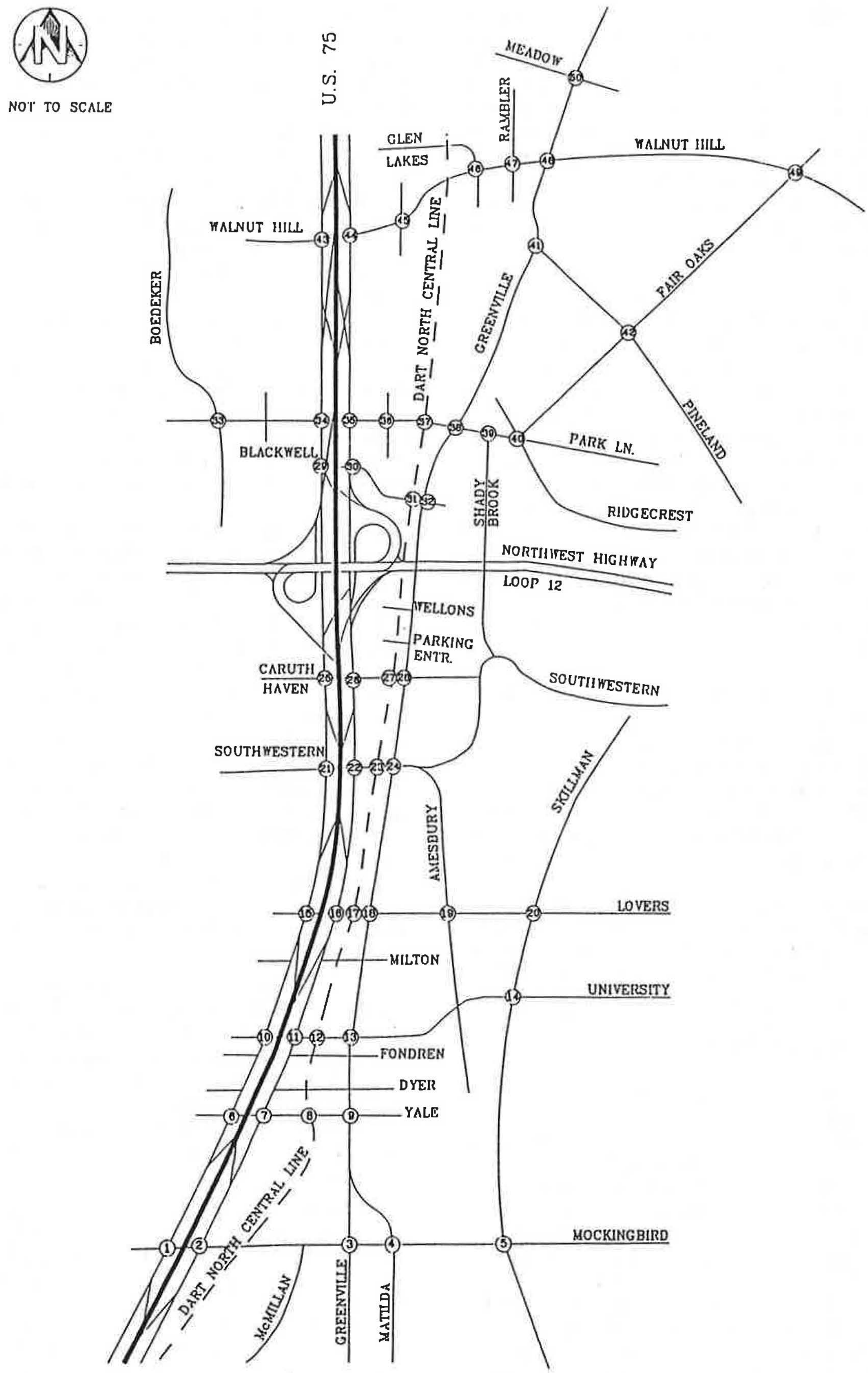


**FIGURE 2 DART North Central Line TRANSYT-7F network.**

network was optimized using TRANSYT-7F. Optimization of the second network would have resulted in conflicting traffic signal offsets. The second network therefore was not optimized. Instead the optimized timings from the first network were coded into the second network (except at the light rail crossing nodes) and simulation runs were made. Minor adjustments were made to both networks to balance the impacts of the LRT crossings on the traffic signal system.

9. Individual nodal MOEs were determined by either taking the largest value, averaging the results, or summing the results of the two networks, depending upon the MOE.

The technique was generally satisfactory. The resulting traffic simulations provided MOEs for traffic signal phase sequences that could accommodate LRT operations in every single traffic signal cycle. No priority or preemption was provided. However, both the city of Dallas and DART wanted to modify some of the key assumptions. Traffic volumes were modified at some locations, a second train headway option was introduced into the problem, clearance phases were added to the traffic signal sequences, and peak priority train operation was introduced. These changes resulted in a second, completely different, set of TRANSYT-7F runs. From the standpoint of applying TRANSYT-7F, three modifications were significant: the change in train headway, the addition of clearance phases, and the introduction of priority operation.

The change in train headway from 5-min to 10-min meant the following:

- The traffic signal cycle length did not have to be 150 sec—it could be optimized.
- The phase sequence in each traffic signal cycle did not have to be identical—they could be optimized.
- Many more combinations of train meets were available between northbound and southbound trains, and, consequently, the traffic signal phase sequence requirements were increased significantly.

The addition of clearance phases meant that flexibility would be lost during that one signal cycle. It also complicated the application of PASSER III-88. The introduction of priority operation in the peak direction added combinations of train meets, and hence, complexity.

For the second TRANSYT-7F study the following steps were used to apply TRANSYT-7F:

1. Study networks were identified and coded for base and light rail scenarios.
2. Initial traffic signal phase sequences for individual intersections were input based on PASSER II-87 optimizations.
3. Diamond interchange traffic signal sequences were developed from PASSER III-88 optimization studies.
4. A systemwide traffic signal cycle length was chosen for the base and light rail scenarios based on the PASSER II and III studies. The best MOEs were obtained for the base scenarios when eight of the nine diamond interchanges were double-cycled with respect to the remainder of the evaluation network. For the light rail scenarios, these interchanges were only double-cycled when clearance phases were not in the traffic signal sequence. Addition of the clearance phases in the phase sequences necessitated longer cycle lengths.
5. For this set of TRANSYT-7F studies DART reviewed a number of suggested train operations scenarios. Simulation studies by DART consultants indicated that the most reliable train operation in the corridor resulted from operating speeds between 35 and 45 mph on 10-min headways, with a single 35-sec station stop at the Lovers Lane Station and a 12-min layover at the Park Lane Station. This scenario resulted in a meet between northbound and southbound trains near the Lovers Lane Station. It is referred to as the "X" Case because of the pattern of its time-space diagrams. Five other scenarios with other meet locations were also studied.
6. The optimal systemwide traffic signal cycle length determined in the PASSER studies was 120 sec. This resulted in five traffic signal cycles for each 10-min (600-sec) train headway. Depending on the type of meet between northbound and southbound trains, one or two of the signal cycles in each five-cycle set had to accommodate LRT operations.
7. The crossing blockages were modeled using two-phase traffic signal operations, a 50-sec blockage time, and a crossing saturation flow rate of 1,600 vphgpl (*9*). Ten- to 15-sec clearance phases were provided at traffic signals adjacent to the crossings.
8. Two simulations were made for each of five scenarios. One included northbound train blockages and, if applicable, blockages from simultaneous crossings of north- and southbound trains at each of the five crossings. The second simulation included the southbound blockages. Except for the traffic signal timing at the crossing nodes, both networks were identical. The first network was optimized using TRANSYT-7F. The second network was not optimized. Instead the optimized timings from the first network were coded into the second network (except at the light rail crossing nodes) and simulation runs were made. After the initial traffic signal timings were determined, the clearance phases were manually fitted into the appropriate signal cycles at the affected locations. Minor adjustments were made to balance the effects of the crossings on the traffic signal system.
9. Individual nodal MOEs were determined by either taking the largest value, averaging the results, or summing the results of the five traffic signal cycles, depending upon the MOE.

This second technique was also generally satisfactory. The resulting traffic simulations provided MOEs for traffic signal phase sequences that included clearance phases that could accommodate LRT operations as necessary. The priority operation defined by these TRANSYT-7F simulations was accepted by the city of Dallas.

The two TRANSYT-7F methods are not without shortcomings, however. The primary ones identified include the following:

1. This method is labor intensive for large networks. Significant time is spent setting up the networks, finding the optimal phase sequences and cycle lengths, adding the clearance phases, and compiling the composite results of the multiple runs.
2. TRANSYT-7F does not account for queue spill back into upstream intersections. The Stop line flow profiles and platoon progression diagrams should be inspected to ensure that the LOS of nearby upstream intersections is not compromised by queue spill back.

3. TRANSYT-7F does not provide the queue length at the end of the red phase. These data would be helpful in evaluating the adequacy of queue storage areas.
4. TRANSYT-7F does not always give results comparable to PASSER III-88 when modeling diamond interchanges. A wide disparity may exist between the results of each model even after the differences in the delay calculations are accounted for.
5. TRANSYT-7F does not allow for sufficient signal intervals to double-cycle a four-phase diamond interchange signal sequence. This limits the model's utility.
6. TRANSYT-7F cannot explicitly model the traffic signal preemption that typically occurs at light rail or railroad-highway grade crossings.

TRANSYT-7F is a powerful tool for evaluating the traffic effects of at-grade LRT crossings when time and funding are adequate, and a sophisticated analysis within a complex corridor is needed. It provides insight into the operation of a traffic signal system in much more detail than can be obtained with the options analysis or the grade separation analysis methods.

## GRADE SEPARATION BENEFIT-COST ANALYSIS

As a supplement to the TRANSYT-7F evaluation method, DART consultants used a benefit-cost model to determine the cost-effectiveness of grade separations at each potential at-grade crossing. The model, originally developed in 1986 and 1987 by staff of the NCTCOG (*10*), quantifies the point at which the benefits of a grade separation outweigh the costs. Benefits of grade separation included the annualized dollar value for reduced person-hours of delay, reduced accidents, and reduced automobile idling costs at grade crossings. Costs of grade separation included the annualized cost difference between an optimized and fully protected at-grade crossing and grade separation. When the benefits exceed the costs, grade separation may be warranted at a crossing.

## OTHER METHODS—NETSIM

Between 1986 and 1988, other methods of analysis were studied. NETSIM and Traf-NETSIM evaluations, for example, were used with limited success to evaluate the traffic effects of at-grade crossings in the North Central Corridor. Version 1.0 of NETSIM was used in 1987 to study isolated at-grade crossings modeled as two-phase pretimed intersections with no variability because of train operations. Studies by Cline et al. (*11*) suggested additional ways to model at-grade crossings using NETSIM. A validation study performed by Berry (*9*), however, casts some doubt on the validity of the regression model developed by Cline et al.

Traf-NETSIM has features that make it ideal for studying a priority operation such as the one developed in the second TRANSYT-7F study. The primary feature is the ability to transition from one traffic signal cycle type to the next. The at-grade crossing would have, again, been modeled by a two-phase traffic signal in the pretimed mode. Validation would have been performed using data contained in Berry (*9*). Although not implemented in the corridor, initial results looked promising. Potential shortcomings of NETSIM and Traf-NETSIM are as follows:

1. The limited number of vehicles, links, and nodes accommodated by the model,
2. The complexity of coding the model, and
3. The significant computational time—even using fast microcomputers.

## SUMMARY AND CONCLUSIONS

Since 1986 three methods representing an increasing level of effort have been used to evaluate traffic impacts of at-grade LRT operations in the North Central Corridor:

1. The options analysis method is useful for sketch planning studies in which traffic data are limited to 24-hour volumes. It will provide an indication of which cross streets may have capacity constraints.
2. The grade separation analysis method is useful for evaluating at-grade crossings where nearby traffic signals may create queues. It is also useful for midblock isolated grade crossings. Although the data requirements are more rigorous than for the options analysis method, the intersection capacity estimates are more refined. In addition this method also provides an indication of potential queue spill back and travel time and delay impacts. Judgment is required in its application, however, to ensure that spurious results are not obtained from the street capacity estimation module.
3. The TRANSYT-7F method provides the most detailed indication of traffic effects. It is, however, labor intensive and should be applied only when detailed results are necessary. This method provides a wide array of MOEs and consistency for one simulation to the next. It does not, however, explicitly provide for traffic signal preemption. Although this type of operation can be modeled with TRANSYT-7F, it is difficult.

NCTCOG's benefit-cost analysis model was used to determine the cost-effectiveness of constructing grade separations in the North Central Corridor in which many traffic mitigation measures were assumed to be in place. A benefit-cost analysis is useful when extensive mitigation measures affecting the cost of at-grade operations are expected. If extensive construction is not expected, this method may not be necessary because motor vehicle delay at grade crossings is seldom significant.

The Traf-NETSIM method was never fully applied to DART's North Central Line but does show great promise for the evaluation of complex crossing problems. The primary shortcomings of this method are the limited number of nodes and the limited traffic volume that the model can handle. For detailed analysis of small areas, however, this method should work well.

Any of the methods could be adapted to other LRT systems. The basic approach of starting at a sketch level of planning and continuing on in more detail is similar to the process ITE Committee 6A-42 has identified. Starting at the sketch level with a conservative method such as the options analysis method will usually result in an overestimation of the number of grade separations—which is not necessarily bad when initially setting capital budgets. As budget reductions occur, as they are prone to do, the additional levels of refinement provided by the more sophisticated methods typically will result in fewer grade separations and more mitigation measures at a lower capital cost.

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