Design of Traffic Interface on the Banfield Light Rail Project

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Portland is the largest metropolitan area in Oregon with a population of approximately 1 million. Transit service is provided by the Tri-County Metropolitan Transportation District of Oregon, more commonly known as Tri-Met, using a fleet of some 600 buses that carry about 40 million passengers a year. Tri-Met is also constructing a light rail transit (LRT) line, known as the Banfield light rail project, which runs through the center of downtown Portland to the eastern suburban community of Gresham, a distance of some 15 mi. This line is intended to permit the restructuring of east-side transit service to provide better service at less cost.

Service will be provided by 26 light rail vehicles operated singly or in pairs with peak headways of about 5 min west of Gateway Station. Maximum speed will be 55 mph, and there will be 26 stations. End-to-end journey time will be about 50 min. The project cost will be about $213 million for the 15-mi light rail, and an additional $100 million is being spent on a 4-mi freeway improvement that forms an integral part of the overall east-side transportation improvements.

Throughout the preliminary planning and design of the line, it was clear that the project would be implemented with the available resources only if a tight lid was maintained on construction costs. Consequently, each section of the line had to be designed within the constraints imposed by the right-of-way available on that section. A variety of civil engineering and operational design solutions was necessary to enable the line to be constructed to operate efficiently at the least possible cost.

Over its 15 mi, the Banfield LRT has some 65 grade crossings and 20 pedestrian-only crossings, the design and control techniques of which form the subject of this paper. Figure 1 shows the general layout of the LRT alignment. Through downtown and on Holladay Street the line operates on reserved lanes in city streets, except where it crosses the Willamette River on the existing steel bridge. Here the LRT tracks run for about a quarter mile in traffic lanes. Continuing eastward the line runs for some 5 mi beside the Banfield (I-84) and I-205 freeways an exclusive, grade-separated right-of-way to East Burnside. Near the east end of this section a large at-grade transfer station is being built for bus-to-rail and bus-to-bus transfers.

The next 5 mi run in a newly constructed median in East Burnside, a county road. Minor cross streets are closed, and traffic signal controlled intersections are located at major cross streets and at stations.

The final 2 mi of the line occupy an old railroad right-of-way with a number of grade crossings. These have been improved and equipped with railroad-style drop gates.

By the summer of 1985 all design work had been completed, and all major construction contracts awarded. More than half the track had been built, and operational testing had begun on the eastern end of the line. Revenue service over the whole line is expected to start in the fall of 1986.

The traffic control systems described in this paper are presently being installed, following which a period of testing and adjustment will take place before the start of revenue service.

TRAFFIC CONTROL JURISDICTIONS AND GUIDELINES

The essence of effective LRT design is to allocate the available resources to secure the most favorable trade-offs between initial construction costs and operating efficiency. The widespread use of grade separation as an alternative to solving traffic interface problems is no longer affordable on new rail starts. At the same time, at-grade LRT operation will affect traffic capacity and introduce rail operating speed constraints that must be carefully considered on a site-specific basis.

The Banfield LRT line passes through four traffic jurisdictions that involve the Oregon Department of Transportation, Multnomah County, and the cities of Portland and Gresham. Each of these agencies was party to the decision to build the LRT, and their staffs work with Tri-Met and its engineers on the development of final designs and operating plans. Formal agreements with each jurisdiction lay down responsibilities for construction and maintenance, and all construction plans are approved by the local jurisdiction.

As are most metropolitan areas, the local traffic jurisdictions are concerned about not losing street capacity or delaying traffic for the benefit of the LRT system. Therefore a major guideline in system design has been to preserve traffic flow and capacity to the greatest extent possible. Where LRT requires changes in established traffic patterns, localized traffic studies were made to predict impacts and develop mitigating measures.

Safety is a particularly important consideration in designing for at-grade LRT operation. The need to

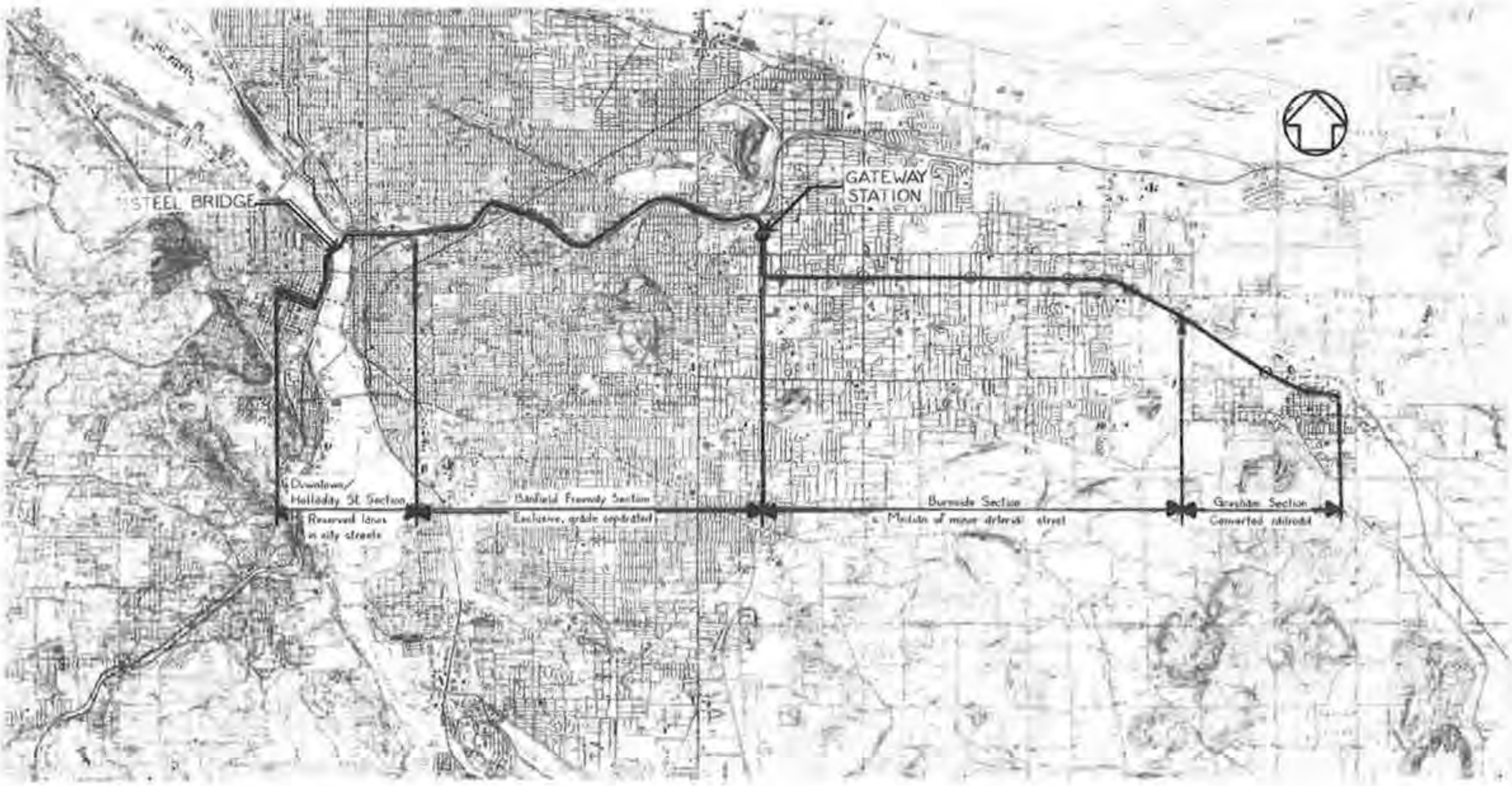

FIGURE 1 Banfield light rail project—principal right-of-way types.

achieve the safest possible operation lies behind several design guidelines:

- The use of standard, familiar traffic devices such as traffic signals or railroad gates without modifications that might confuse other road users;
- A Tri-Met policy that all public vehicular crossings of LRT tracks shall be equipped with active control devices that clearly assign right-of-way between the conflicting movements (i.e., traffic signals or railroad gates);
- The placement of fences, particularly between tracks in stations, and in some cases the nonplacement of fences (such as at locations where persons might be trapped on the right-of-way); and
- Avoidance of obstructions to sight distance, particularly from stations; signs; or large landscaping in at-grade right-of-way.

Other considerations in developing the traffic interface design have included adapting existing proven traffic control equipment and techniques to the needs of LRT; the siting and layout of stations to suit operating needs and minimize traffic impacts; and consideration of the special operating characteristics of the light rail vehicle, particularly with regard to braking, in intersection design and control.

Maximum speed on each segment of the line is set with due consideration of local conditions such as track geometry, station spacing, sight distance, train protection, parallel traffic speed, and type of crossing control. Speed limits are posted at each speed change to assist operators.

As outlined previously, there are five different types of right-of-way on the Banfield LRT:

- Downtown streets with reserved transit lanes,
- Lanes shared with traffic on a major bridge,
- Grade-separated exclusive right-of-way,
- Median operation on an arterial street, and
- Railroad right-of-way with grade crossings.

The application of the design guidelines to these various types of right-of-way provides an interesting illustration of the versatility of LRT.

DOWNTOWN-HOLLADAY STREET SECTION

This section of the line is some 2 mi in length and passes through the downtown retail center, across the bus mall, through two historic districts, and, after crossing the river, along the Holladay Street commercial district. Figure 2 shows the layout of the Downtown-Holladay Street section.

On this section the LRT is located entirely on city streets with paved tracks separated from traffic by a curb or painted line. Traffic is controlled by traffic signals at all intersections.

Because of the small size of the city blocks in Portland (200 ft) and a one-way street grid, it is possible to set up traffic signal progressions that provide uninterrupted traffic flow in all four directions. Each traffic signal is timed a quarter cycle before or after its neighbor. Speed of traffic flow may be adjusted by changing the traffic signal cycle length. Light rail trains will operate within this progression, moving at the same speed as traffic between LRT stops. At stops, trains slip one cycle, waiting through the red phase to resume running on the next green wave, approximately 30 to 45 sec later.

Where the LRT operates two ways on a single street, one of the LRT directions must run against the signal progression. Where this occurs, the train

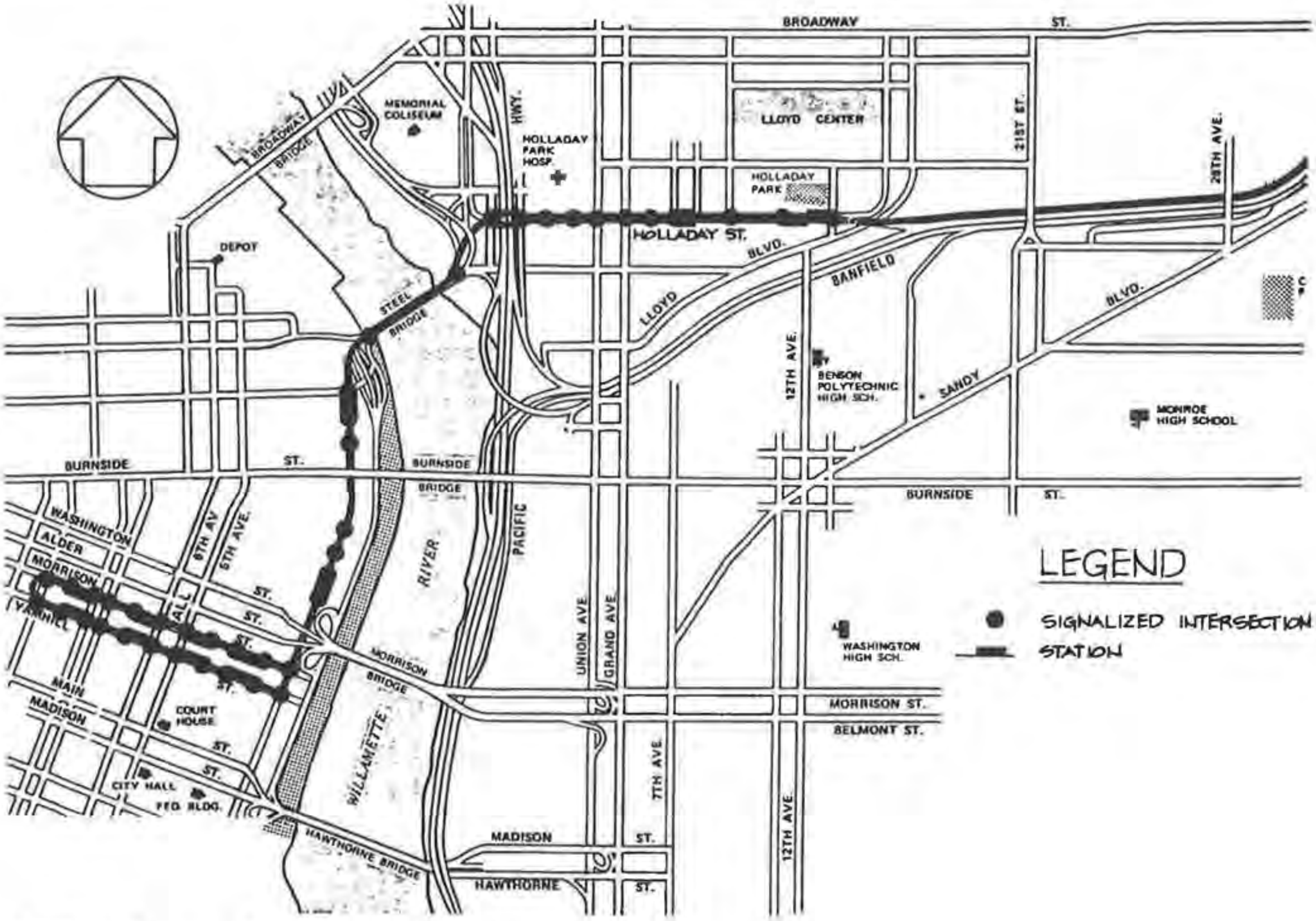

FIGURE 2 Downtown-Holladay Street traffic plan.

is detected by traffic loops, and certain predetermined cross streets lose part or all of a cycle to provide uninterrupted passage for LRT. This process is called green phase extension. It is not true preemption because it does not occur at random and bears a constant time relationship to the signal progression. Phase extension is less disruptive of pedestrian movements and works well with closely spaced, intertied traffic signals. Green phase extensions are used only at minor streets. Figure 3 shows how trains on Holladay Street can move both with and against the traffic signal progression without interfering with traffic on the arterial cross streets, Union and Grand Avenues.

On Morrison and Yamhill Streets, trains always follow the traffic signal progressions and, therefore, conflict with none of the arterial cross streets. A parallel lane of traffic on the right side of the LRT tracks is controlled by the same traffic signals. At three intersections where left turns are permitted across the LRT tracks a train-actuated turn prohibition signal is used to prevent conflicting movements when a train is approaching the intersection.

On First Avenue the LRT operates in two directions, and the traffic signals provide a southbound progression. The only major arterial streets that cross First Avenue are the approaches to the Burnside and Morrison Bridges, and these pass over First Avenue on existing bridges. Consequently, there are no arterial streets crossing First Avenue at grade and no significant restrictions on northbound trains (operating against the southbound traffic signal progression) extending the green phases at cross streets as required.

After crossing the Willamette River on the steel bridge, which is described in the next section, the LRT continues along Holladay Street, a minor arterial street, for another 13 blocks.

On Holladay Street the LRT tracks are constructed on the north side of an 80-ft right-of-way, which also includes two parallel traffic lanes, one-way westbound. Although normal design practice would have placed the tracks on the south side of this street, the existence of several commercial driveways on the south side of the street resulted in a north side LRT alignment.

The LRT tracks are paved with concrete throughout this section and separated from the traffic lanes on the south side by a curbed median and from the sidewalk on the north side by a curb. Intermittent plantings are used along the sidewalk curb to channel pedestrians toward the back of the sidewalk.

Traffic signals are used to control all intersections and are set up for a westbound progression tied to north-south progression at the two major intersecting arterials, Union and Grand Avenues, as shown in Figure 3.

In the westbound direction, the LRT operates within the existing signal progression. To provide for eastbound LRV travel, green phase extension is used at the minor intersections.

At certain LRT stops, there is no traffic signal to inform the LRT operator when to leave the station in order to enter the traffic signal progression. At these locations the standard LRT signals (described

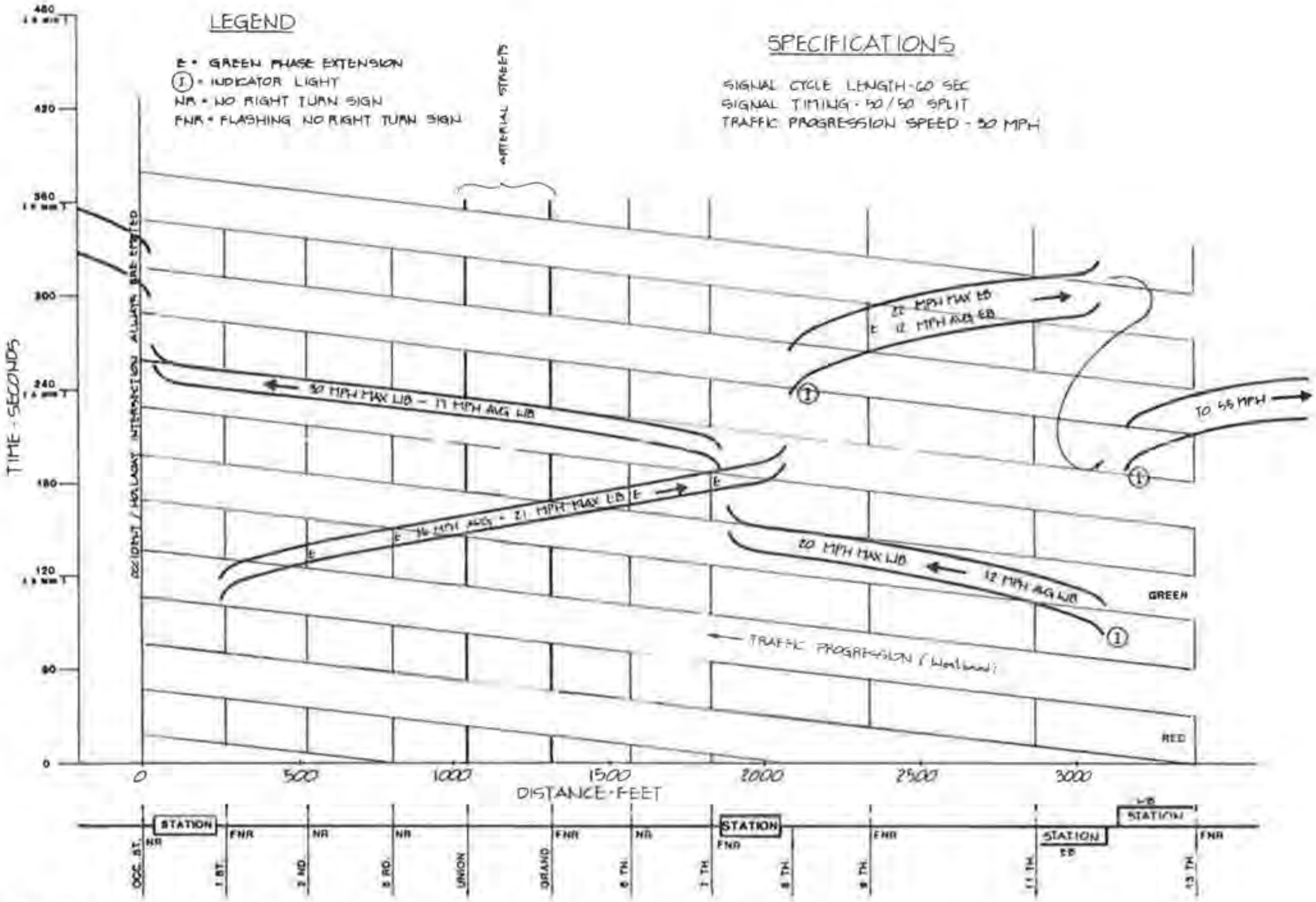

FIGURE 3 Holladay Street time-space diagram.

later) are installed and timed with a suitable offset time to inform the operator when to depart from the station in order to enter the signal progression at the next intersection.

At a number of locations traffic is permitted to turn right from Holladay Street across the LRT tracks. At these intersections, as presently planned, LRT-actuated right-turn restriction signals will be used to prohibit right turns when trains are approaching.

Throughout the Downtown-Holladay section, the LRT tracks consist of Ri 59 girder rail placed on a concrete slab with gauge rods but no ties. The base and sides of the rails are encased in a polyurethane mastic to provide mechanical and electrical insulation, and the track is then paved in concrete or stone blocks. Train detection throughout this section is by means of inductive loops placed in the pavement between the rails. A continuous signaling conduit parallels the LRT tracks and provides connection between the detection loops and the traffic signal controllers.

Because of the turn restriction signals, preemptions, and other special features on the line, it was found that conventional traffic signal heads were not sufficient to show the LRT phase. To avoid confusing other traffic by adding more signal heads, European-style bar signals were adopted.

A white vertical bar is used as a "Proceed" indication, and a horizontal yellow bar for a "Stop" indication. The white vertical bar indicates to the LRV operator that the traffic signals at the intersection are set for LRT, and that no conflicting traffic movements are signaled. Such a condition means that the parallel traffic signal (if any) is green, and that conflicting turns are prohibited. Preemption, if any, is activated. The signal does not, of course, provide any guarantee against illegal traffic or pedestrian movements conflicting with LRT, and the operators of the light rail vehicles (LRVs) are trained accordingly.

A horizontal yellow bar is used for a "Stop" indication. The horizontal yellow bar means that the traffic signals are not set for LRT, and the LRV must stop. An LRV may proceed against a yellow bar signal after stopping if the operator deems it safe to do so. Such a condition will occur if the LRV is not detected, in which event the train, having stopped, may proceed on the next parallel green phase, giving audible warning and watching for conflicting traffic movements. Figure 4 shows the traffic signal configurations used for LRT and parallel automobile traffic at the Holladay Street intersections for both directions of LRT.

STEEL BRIDGE

LRT may be separated from traffic by location, such as reserved lanes or an exclusive right-of-way. Such facilities require space and that may not always be available. LRT can also be separated from traffic by time. Such is the case at the steel bridge, where the LRT shares two lanes with other traffic, and use of the lanes at any given moment is assigned either to LRT or to other traffic by traffic signals at the merge point.

Downtown Portland is bounded on the east side by the Willamette River, a major navigable waterway. To avoid the need to construct a new bridge, the LRT

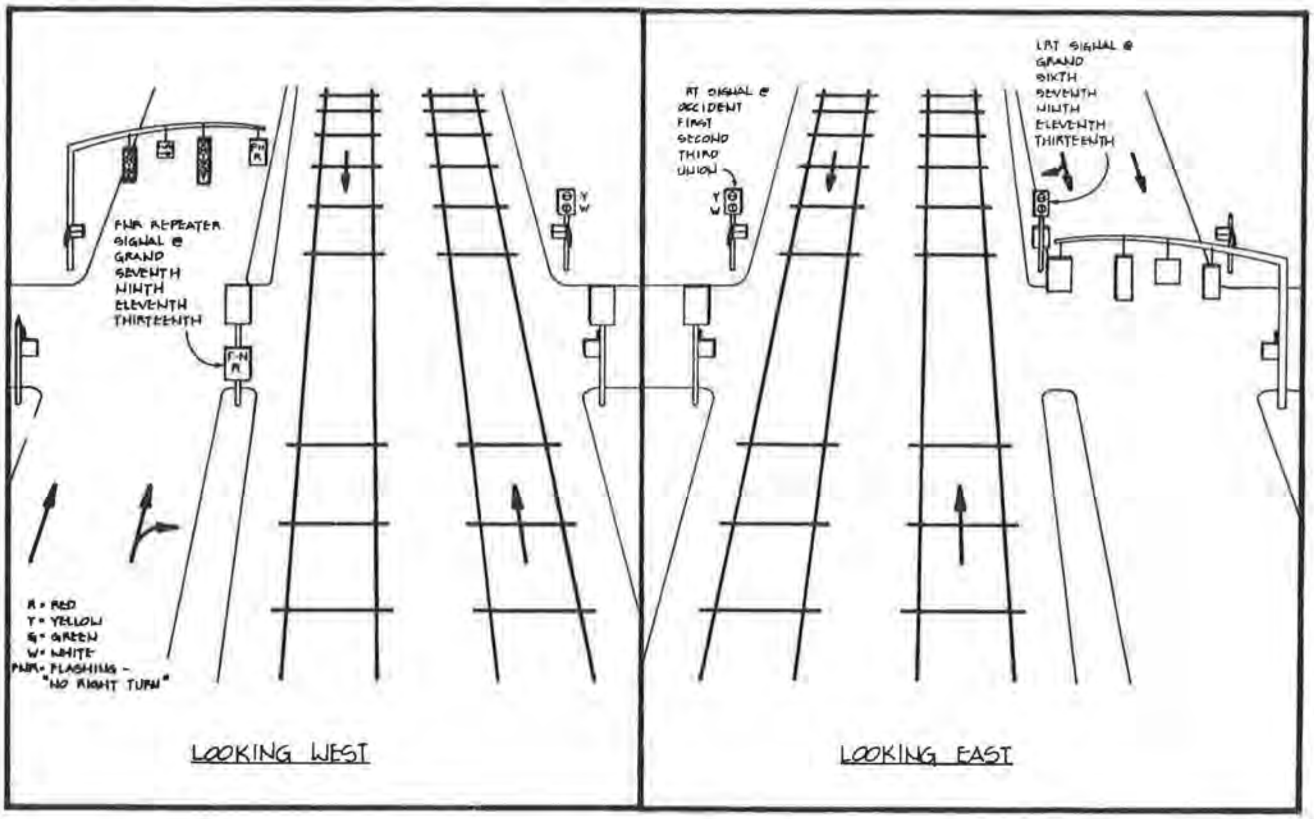

FIGURE 4 Holladay Street traffic signals—perspective.

crosses the Willamette River using the existing steel bridge. This 70-year-old structure has two decks, the lower deck carrying two tracks of the Union Pacific, and the upper deck carrying four highway lanes. Both decks have a vertical lift span in midriver for shipping. The LRT tracks will share the center lanes of the upper deck with highway traffic as did the Portland streetcars 30 years ago. The merge of LRT into the traffic lanes at each end of the bridge is controlled by a train-actuated traffic signal. These signals provide traffic with uninterrupted access to the bridge except when a train is detected, in which case the traffic is stopped until the train has entered the traffic lane. When the train has passed the merge point traffic may follow it across the bridge. The diverge is not signal controlled but accomplished by signing and pavement markings. The track and roadway configuration on the steel bridge is shown in Figure 5.

In addition to the signals controlling the merge, there is an extra signal head at each end of the bridge controlled by the lift span interlocking. The bridge tracks are track circuited, so that the bridge cannot be raised when a train is on the bridge or its approaches. A red bar signal is shown on the merge point traffic signal when the bridge is raised. Unlike a yellow bar signal, a red bar signal requires an absolute stop.

Because the light rail will delay traffic entering the center lanes of the bridge for less than 30 sec every 5 min at most, the loss of bridge traffic capacity is only about 10 percent, which is similar to the capacity formerly taken by the buses that the LRT replaces and well within the available traffic capacity of the bridge.

One consequence that arises from use of the existing bridge is a severe grade entering downtown. Because of the need to minimize the length of the ramp descending from the bridge to city streets, the grade of the LRT ramp at the west end of the bridge is 7.5 percent, probably the steepest grade on any new LRT system, and the controlling grade for Tri-Met's LRT. The intersection at the foot of this grade is the only one preempted by LRT in the downtown area.

BANFIELD FREEWAY SECTION

Eastward from Holladay Street, the LRT line follows two freeways, the Banfield (I-84) and I-205, for almost 5 mi to East Burnside Street. Apart from Gateway Station, this section is fully grade separated. Operating speed will be 55 mph. The three intermediate stations have grade-separated access, with stairs and elevators, the only such stations on the line.

GATEWAY STATION

Toward the end of the Banfield section lies Gateway Station, the midpoint of the LRT line and a major transfer point with 12 connecting bus routes. The layout of Gateway Station is shown in Figure 6. Gateway Station is an excellent example of how LRT can offer major construction cost savings. By constructing this station at one grade, and by placing the bus loading bays at the back of the rail platforms, all major structural work is eliminated and there is no need for elevators or escalators. The distance between connecting buses and trains is as little as 15 ft in some locations. Pedestrian crossings of the tracks and bus roadways are by marked crosswalks, with fences used between the tracks to channel pedestrian flow into the crosswalk areas.

The bus roadway crossings of the LRT tracks at each end of the station are considered private cross-

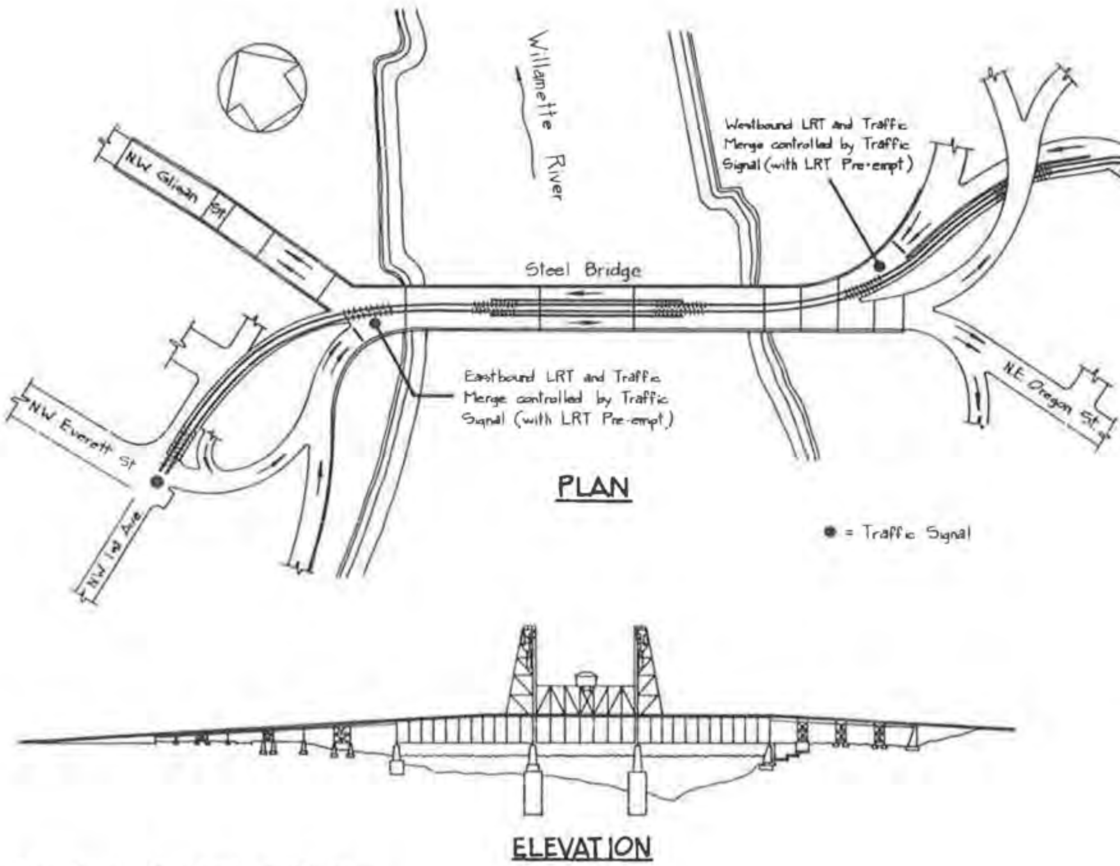

FIGURE 5 Steel bridge traffic plan.

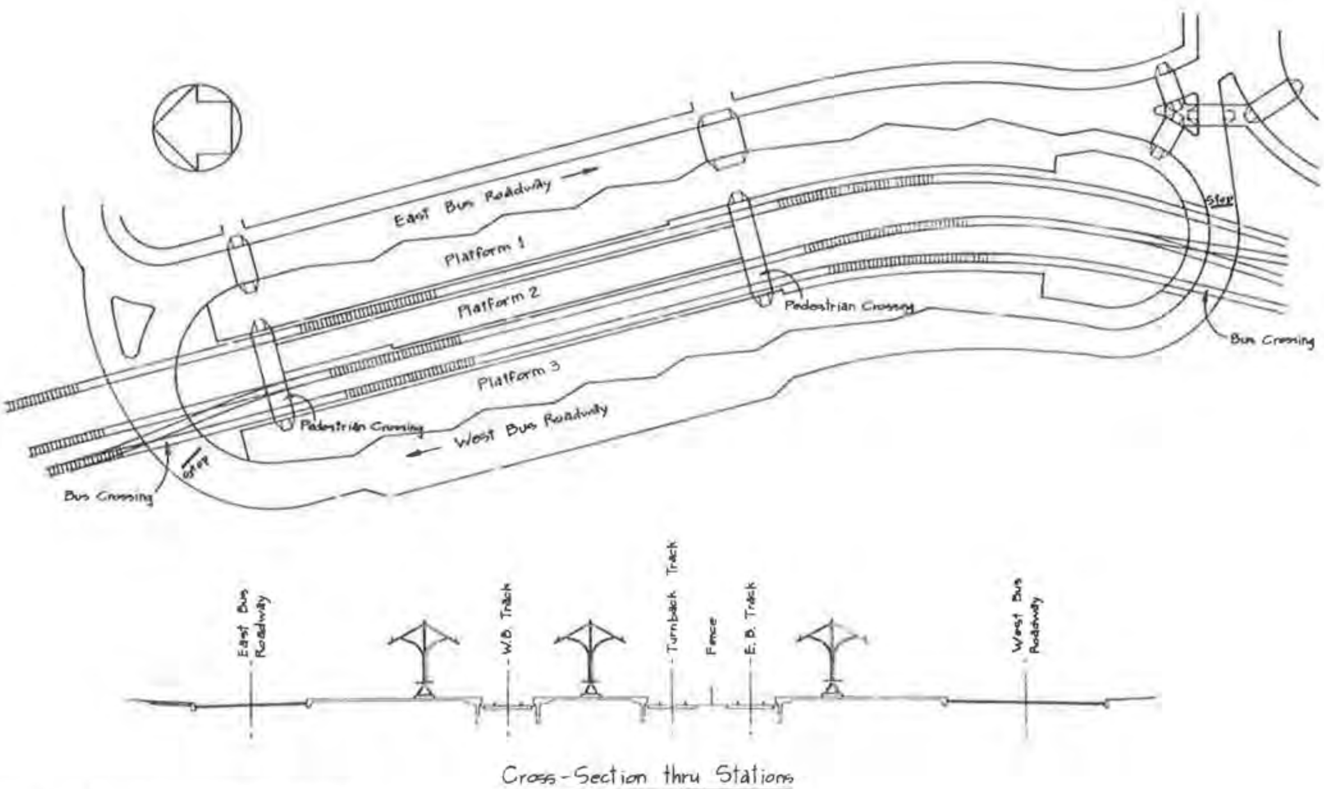

FIGURE 6 Gateway Station layout.

ings and are controlled by stop signs on the bus roadways, because these roadways are used only by Tri-Met drivers and are not open to public traffic.

BURNSIDE SECTION

South from Gateway Station, the LRT passes under the only new grade separation on the whole line and then turns east entering the median of Burnside, which it follows for the next 5 mi.

Burnside has an interesting history. From 1912 until 1928 Burnside was a railroad, which accounts for its unusually wide (100-ft) right-of-way. It then became a minor arterial street with two traffic lanes with shoulders over most of its length. After its most recent reconstruction, Burnside has one lane with a shoulder for each direction and a 28-ft median for the LRT. Extra traffic lanes are provided at intersections and east of 181st Avenue where Burnside is designated as US-26. Figure 7 shows the LRT layout on Burnside.

Construction of the LRT median in Burnside resulted in the closure of many minor side streets to traffic crossing Burnside and the concentration of cross traffic at major intersections.

There are 17 intersections along Burnside at which traffic can cross the tracks and make left turns and U-turns, all controlled by traffic signals. All the traffic signals are preempted by the LRT (1). There are also eight stations, all of them at intersections and all with far-side platforms. Far-side platforms provide the least traffic delay because the train arrival time is accurately predictable, and they have the best geometrics because the platforms balance the left-turn pockets. In addition, if a train overruns a platform, it does not enter a crossing.

Because Burnside has no train protection signals or track circuits, the preemption is accomplished by means of loop detectors that activate the preempt phase in the traffic signal controllers. When a train is detected, the controller goes to the clearance phase for conflicting movements and then enters the preempt phase while the train is still at least stopping distance plus 2 sec away from the intersection. The LRV operator is informed that the signal has entered the preempt phase by a preempt signal that uses the white vertical bar to indicate the preempt phase and a yellow horizontal bar to indicate all other phases. These signals are similar to those described previously. The Burnside version is shown in Figure 8. Four hundred feet short of the intersection stop line is a mark known as the decision point. An LRV moving at the design speed of 35 mph will reach the decision point 2 sec after the preempt signal indicates the traffic signal is in the preempt phase. When the preempt phase has been selected, it will remain until the train has cleared the intersection thereby releasing it or a preset time of about 30 sec has elapsed. Traffic parallel to the LRT is permitted to move on the same phase so that little overall intersection capacity is lost.

In the event an LRV is traveling faster than 35 mph, or the detector fails to detect the train, it will arrive at the decision point and not get the preempt signal. When this occurs, the train operator will apply brakes and stop at the traffic signal. After having stopped, the operator may then proceed when safe. In practice, this means on the next green phase of the parallel traffic.

This preempt system achieves three important design goals:

- It is simple with the minimum of special signals and no special signals for highway traffic (note that the train operator is not informed of detection but only of the preempt phase when it has begun);
- When the system fails to operate as intended, it creates no unsafe condition and does not require the LRV to make an emergency stop; and
- Failure of the traffic signal or preempt system shall not delay LRT operations for more than a minute or so.

At locations where a station interferes with the predicted arrival time at a downstream intersection, the LRV is detected twice. The first detection is used to hold the conflicting pedestrian phase at the downstream intersection and hence reduce the required clearance interval. The second detection, which occurs after the train leaves the station, calls for the preempt phase to be initiated for which the shorter vehicle clearance interval is now required. Using this system, Tri-Met expects to get 100 percent preemption whenever required at all 17 intersections except for two where, in one direction, when a preemption is called for at the least favorable phase of the traffic signal cycle, a delay of up to 5 sec may occur. With the design adopted for Burnside, no additional signals or hardware are required at these two intersections.

In addition to the signalized vehicle intersections, there are also some 14 pedestrian crossings on Burnside that occur remote from an intersection. These crossings are all unsignalized "Z" crossings based on a design widely used in Europe. Figure 9 shows a typical "Z" crossing layout. This simple design provides a pedestrian refuge between the traffic and the LRT lanes and forces pedestrians to turn toward oncoming trains before they can cross the tracks. As an additional safety precaution, LRV operators will slow down when pedestrians are observed waiting in the "Z" crossing refuges.

The issue of whether to install fencing along the Burnside median was and continues to be the subject of much discussion. Tri-Met decided not to fence the median for several reasons:

- Additional right-of-way would be required to provide clearance for LRVs on one side and traffic on the other.
- If the fence were damaged it could cause an accident by fouling LRV clearance.
- Fencing would interfere with maintenance access.
- Fencing could trap people within the trackway.
- Fencing could reduce sight distance for both traffic and LRT.
- Fencing would create a physical and visual barrier through the neighborhood not justified by sufficient public benefit.
- Fencing or partial fencing can be added in the future if needed, perhaps between tracks. Because pedestrians will sometimes cross the trackway, operators will be instructed to slow the train where necessary for pedestrian safety. With the construction of street lighting and sidewalks throughout Burnside as part of the project, and taking account of the time it takes to access the trackway across the parallel street, pedestrians on the trackway are not expected to be a major problem.

PORTLAND TRACTION

The last 2 mi of the Banfield LRT line use the right-of-way of the former Portland Traction Company Interurban. This section of line uses single track with passing tracks at two of the three stations and has 9 grade crossings. Traffic signal control is not

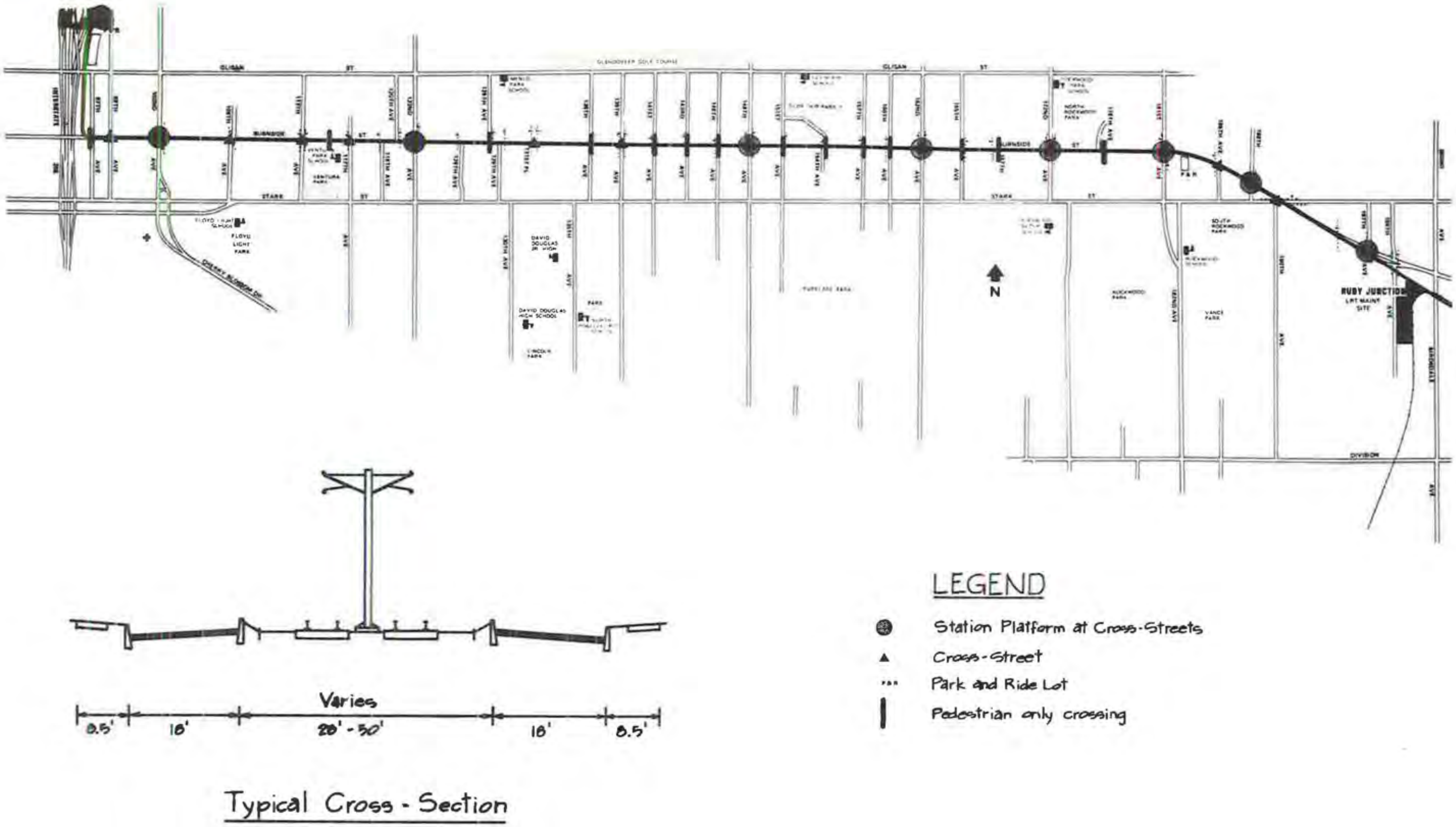

FIGURE 7 Burnside traffic plan.

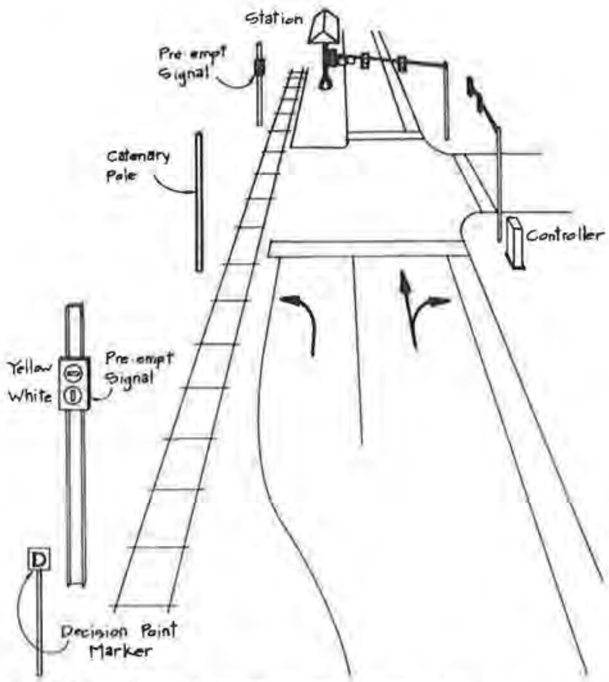

FIGURE 8 Burnside traffic signals—perspectives.

considered appropriate for these grade crossings because this right-of-way is not associated with a parallel street and because higher operating speeds are planned. Therefore, railroad-style drop gates are used at each crossing. These gates are actuated by LRVs by means of track circuits and are identical to the drop gates used by railroads elsewhere.

DETECTOR TESTS

The initial LRT plans featured overhead detectors for all train detection. However, overhead detectors have several drawbacks. They can only be installed where suitable traction electrification poles exist, which does not always meet traffic engineering needs. They are difficult to access for maintenance and adjustment. LRT systems in Europe, and all traffic engineering in the United States, have long since adopted inductive loops for vehicle detection. It was therefore decided to set up a test program to test certain common loop configurations and to compare these with the performance of the overhead detectors (2). The loops selected for testing were a rectangular loop used in San Diego, a "quadrupole" used in Buffalo, and the figure-8 loop widely used in Europe. These loops were installed on a completed section of line where LRVs were being test operated. Loops were tested at two levels, one of them deep, under the ballast, about 20 in. below top of tie,

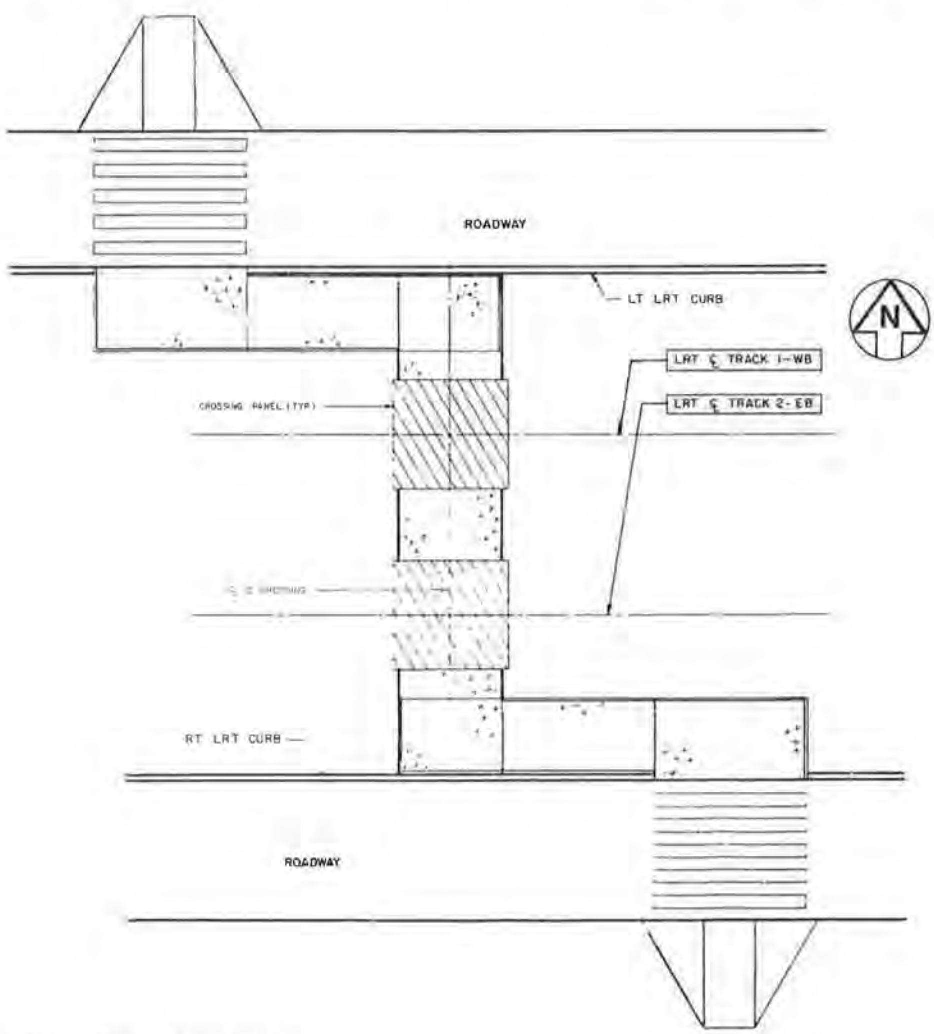

FIGURE 9 "Z" crossing plan.

and clear of track maintenance equipment; and the other shallow, on top of the ties, intended to simulate the position in paved track. An overhead detector was also installed, and all of the detectors were connected to an event recorder to measure their performance. After several weeks of testing, it was found that the deep rectangular loop did not perform reliably when train speed was less than 30 mph and that the overhead detector did not perform reliably when the train speed exceeded 30 mph. The shallow quadrupole occasionally picked up "ghost" signals. However, the deep quadrupole and the shallow rectangle and figure-8 loops performed reliably through the test period and were considered suitable for installation on the line.

CONCLUSIONS

The methods developed to handle the traffic interface are the key to effective low-cost LRT. LRT designers are often faced, in varying degrees, with the traditional opposition of traffic engineers to transit priority, with the massive bias against railroad crossings arising from many generations of railroad grade-crossing elimination programs, and with the residual memories of the shortcomings of the old-fashioned streetcars.

However, reviewing the LRT designs during the last decade, steady progress in low-cost design and traffic control techniques can be detected as successive projects have come into service. Tri-Met confidently expects that its Banfield line will be one further step in this process of evolution.

REFERENCES

1. Burnside Preempt Design Report. Tri-Met, Portland, Ore., 1983.
2. Loop/Detector Tests. Tri-Met, Portland, Ore., 1985.