Designing At-Grade Light Rail Transit

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The ability to operate at grade, interfacing with traffic and pedestrians, is a key characteristic of light rail transit (LRT). It can reduce construction costs, improve access to important trip generators, and justify rail development in corridors where more costly construction may not be warranted. It can also reduce transit reliability, interfere with traffic movements, and reduce operating speed. Effective intersection control and traffic interface design are the key elements in successful at-grade LRT design. Yet experience in this field is still limited, and beset with misconceptions that can distort, or even foreclose, a project in the planning stages, before potential problem resolution can occur. This paper discusses some of the commonly perceived problems that confront at-grade LRT designers and outlines some of the potential design responses, some of which were used on Portland's recently opened LRT.

ONE OF LIGHT RAIL'S strong points is its ability to operate at grade, interfacing with traffic and pedestrians. This can reduce construction costs, improve access to important trip generators, and justify rail development in corridors where more costly construction may not be warranted. But it also can present system designers with serious problems.

Although minimizing cost is almost sacred, when it comes down to details, its constituency is rather less solid, particularly as the project progresses from a proposal to a commitment. For instance, operating staff prefers as much grade separation as they can get. It makes a line easier and cheaper to operate. Designers may feel no compelling urge to promote the least costly option. Less cost may mean more risk and, after all, design fees are usually tied to project cost.

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Furthermore, the purveyors of proprietary expensive transit systems (PEPS) have a vital interest in not minimizing light rail transit (LRT) costs. More costly alternative systems appear more competitive if the cost of LRT can be kept as high as possible. For their part, local agencies like to piggyback other improvements, such as utility upgrading, street redevelopment, etc., onto LRT projects. These may be excellent programs, but they may not be true costs of the LRT construction. And people like to hear, and readily believe, that their city is different, as in "It might be good enough for Portland (or Zurich, or San Francisco), but it won't work here."

This paper discusses some of the commonly perceived problems that confront designers of at-grade LRT and outlines some of the potential design responses, many of which were considered or used on Portland's recently opened LRT.

Experience in at-grade LRT design is still limited and beset with misconceptions that can distort development of an LRT project before analysis has even begun. Most commonly at-grade operation is considered to have "unacceptable" impact on traffic, or to lead to excessive delays to LRT operation. Grade separation is often proposed before the trade-offs and alternatives have been properly analyzed. How to solve a problem is sometimes addressed, and included in the design of a system, before the problem is defined and before any determination is made about whether it needs to be solved. But the development of an effective at-grade design profoundly affects the cost, performance, and feasibility of an LRT project and is therefore a central element in developing transit alternatives.

DESIGN PHILOSOPHY

The design philosophy of a transit agency is pivotal to the success of the development of a low-cost LRT system. It must be actively supported by the agency staff and is best reinforced by reference to other operating systems, or elements of them. Fortunately there are a growing number of North American and European "reference systems."

A low-cost design philosophy is the product of several design principles. Keeping things simple is a principle that calls for constant vigilance. Use existing technology, do not invent new solutions to a technical problem where solutions already exist, and always ask first whether a problem needs to be solved before asking how to solve it.

Another important design goal is to maintain service when a component of the system fails, with as little delay and inconvenience as possible. Hence "How does it work when it doesn't work?" becomes a key question. Most elements in a transit system will periodically fail, particularly vehicles, fare equipment, traffic control equipment, and power supply elements.

The potential to upgrade LRT in the future can be a major inference for current design. It is usually not necessary to solve the problem of what happens when the ridership is 10 times higher and traffic levels are 5 times higher in 30 years' time. First, predictions may not happen and, second, if they do, the system's success will be so great that further expenditure will be readily justified. Trying to solve all these potential problems initially may lead to not being able to afford any system at all. Then there are the "might-as-wells." This is an insidious situation in which a decision to improve one element of a system is taken as a justification to improve another element. This approach can rapidly lead to escalating costs and is a frequent threat to cost-effective design.

Finally, don't solve nonproblems. During the design of an LRT system, numerous potential problems will be postulated. Not all of them will occur, and for those that do, there may be several solutions. Examples might include whether to fence a particular segment of LRT track, or whether stop sign control is adequate at a minor intersection.

AT-GRADE DESIGN ELEMENTS

At-grade design issues include parallel traffic capacity, cross traffic impacts, turning traffic, grade separation, crossing protection, and gated crossings.

Parallel Traffic Capacity

The issue here is the impact of LRT on parallel traffic capacity, which is created because the LRT occupies part of the street right-of-way. The first consideration is the amount of available right-of-way. In some cases the available right-of-way is sufficient to accommodate both LRT and the existing traffic. A further consideration is the relative importance of people-moving capacity versus automobile traffic capacity. Typically just two LRT trains an hour in a traffic lane will move more people than the traffic lane that they replace. The very concept of preserving existing automobile capacity has become more open to question in recent years as urban design goals have changed. The reduction of traffic capacity in central city streets to provide improved street amenities, pedestrian malls, and transit malls has become an increasingly successful central city strategy. LRT is highly consistent with such urban amenity improvement strategies, as is shown, for instance, by the new LRT malls in both North America and Europe.

A further consideration is that the traffic capacity on a street segment is usually limited by the adjoining intersections and not by the segment itself. A common LRT design response might be to widen the intersections only in order to match traffic capacity at both the intersections and the segment between.

A special parallel traffic condition is the merging of LRT into a traffic lane. Because LRT trains are too long to weave into traffic, LRT merges must be controlled by traffic signals, and such control seems to be a very effective design technique. In Portland the LRT is merged into traffic lanes to share use of a major bridge across the Willamette River. In Europe signal-controlled merges are often found that enable LRT trains to enter a mixed traffic lane after a station.

Cross Traffic Impacts

The impacts of LRT on cross traffic capacity will range from zero to significant, depending on the method of crossing control, the degree of preempt, and lane configurations. For instance, crossings may be controlled by gates, traffic signals, or passive devices such as stop signs. Gated crossings typically take longer to operate, and hence increase cross traffic delay. Gated crossings are most effective where LRT speeds are high or the crossing configuration is not readily controlled in a safe manner with traffic signals. Increased gate time arises from the actual operating time required to provide warning and lower the gates, as well as the regulatory "advanced warning" time (typically 20 sec) between the lowering of the gate and the arrival of the train. Traffic signals typically require less clearance time between the cross street red and train arrival time, the amount being a variable determined by train speed. Typical values range between 10 sec for 35-mph train speed and 5 sec for train speeds around 15 mph.

Then there are the existing upstream and downstream traffic constraints. There is no point in providing more capacity at an LRT crossing if traffic capacity is already constrained by the performance of upstream or downstream intersections. Furthermore, if LRT does not preempt an intersection, or moves within an existing signal progression, it will have little or no impact on cross traffic capacity. This fact provides an important starting point for LRT at-grade design, because not all intersections on an LRT line will have critical capacity problems. Thus the amount of preempts that may be possible can be varied according to the traffic requirements, starting at zero preempt and zero cross traffic capacity interference.

Stop location and preempt or lack thereof are closely related. For instance if a nearside stop is provided at a nonpreempt intersection, train delay will be minimized, and the greatest delay will be the length of the red cycle. If the train is moving with a signal progression, and stops at a nearside station, it will experience no delay at all if the stop duration matches the length of the red cycle.

Preempt can also be made conditional, for instance by a queue detector, which limits the preempt in the event that cross traffic reaches a certain queue length, or by a rulebook, which requires train operators to observe traffic conditions before calling for a preempt. Such systems provide considerable flexibility, allowing LRT priority except where this priority creates more than a given level of traffic congestion.

Intersection control and its impact on traffic are also tied to stop platform locations. For instance at an intersection with full preempt, platforms should be located on the far side of the intersection, so that train arrival time can be accurately predicted. Traffic delay is then minimized. If the LRT system has stationary preempt capability (such as with pushbuttons, or cab-actuated preempt calls) nearside platforms can be used, and any range of preempt from full to conditional can be applied with equal facility.

A further consideration is the need to optimize street geometry, particularly the balancing of turn pockets with the placement of passenger platforms. One consequence of this consideration is the frequent use of offset platforms on at-grade LRT. Figure 1 illustrates some relationships among geometry, preempts, and platform locations.

TURNING TRAFFIC

Traffic turning across LRT tracks at intersections poses several special problems. If the LRT is in the median of a two-way street, a separate left turn phase must be provided if traffic is to go on the parallel green. A left turn lane or pocket is then needed to store traffic during the LRT phase. The left turn pocket increases the required right-of-way, and competes with a station platform if one is planned. Thus farside platforms often work better where left turns are planned. Where right-of-way is tight, a right turn loop may be used in lieu of left turns. This option increases intersection capacity by eliminating the left turn signal phase, and reduces right-of-way needs, but may not operate well for large turning volumes (depending on loop geometrics). Prevention of illegal left turns is an important safety element of this design, requiring close attention to signing, striping, and curb configuration.

Where LRT operates beside a street, the main problem is control of right turns. Unlike in Europe, where right turn on red is not permitted, LRT designers in the United States have to control right turns. "No right turn on red" signs are often insufficient, and train-activated protection is often needed. This may consist of audible warning, flashing "train" signs as used on Holladay Street in Portland, or even gates. The combination of nearside stops with stationary preempt is sometimes an effective way to control right turns safely.

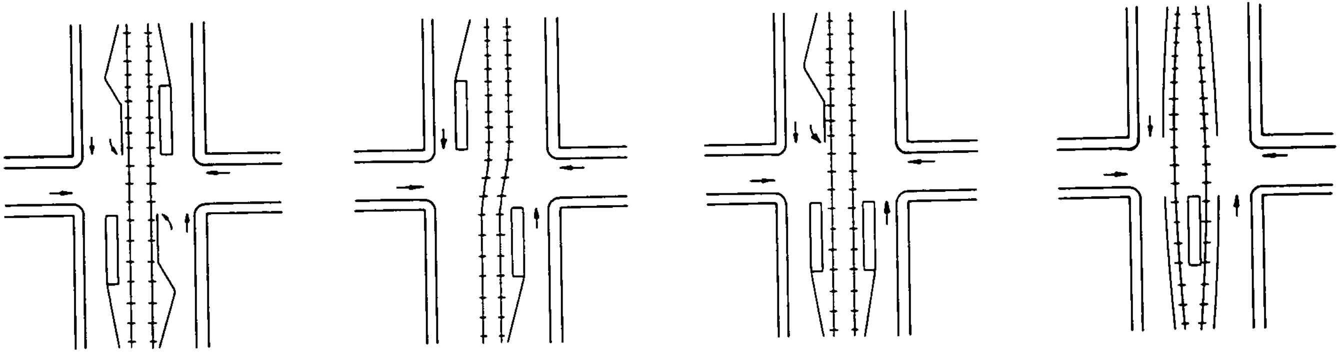

FIGURE 1 Geometry, preempts, and platforms.

Where LRT is to be placed on one-way streets, the tracks should, if possible, be to the left of the traffic. Turning movements conflicting with LRT then become left turns, which are more controllable, and track and lane configurations conform more closely to motorists' directional expectations. If a single LRT track is operated to the left of traffic in the counterflow direction, turning movements can be better accommodated at intersections, and uncontrolled turns into driveways can be permitted.

By contrast, if LRT is operated in the same direction as traffic on a one-way street, turn control becomes difficult. In downtown Portland, where a single track runs on a one-way street, turns across the track were initially prohibited at many intersections, and a high incidence of illegal turns resulted. The intersection control is now being changed to permit turns, requiring that trains pass through these intersections on their own "all red" phase.

Figure 2 illustrates some common LRT turn relationships.

Grade Separation

Grade separation of LRT at major intersections or in downtown areas is often proposed to alleviate potential traffic impacts. However it is often proposed prematurely, without analysis of at-grade solutions first, and without appreciation of the potential negative consequences.

Preservation of traffic capacity is seldom, of itself, a sufficient reason for grade separation, particularly if LRT can use the same signal phase as parallel traffic. This cannot occur when LRT is turning across the traffic flow. Grade separation is particularly costly where a station is involved, because a grade-separated station usually involves elevators or escalators, and is constructed on a structure. Because the case for grade separation usually appears strongest at major cross streets, which is also where stations are located, this condition is a common design problem. Moreover, because a goal of grade separation is usually higher train speed, this goal is lost if a station is located at the same place. Look very hard at the cost/speed/capacity relationships for stations at arterial intersections. Placing the station with offset platforms on the approach side of the crossing without preempt can yield a low-cost design with little or no traffic impact, and only minor (half cycle length) train delay.

A second problem with grade separation is passenger access time, which is the time it takes passengers to get to a train. Frequent stations, surface operation, and barrier-free fare collection reduce access time. Grade-separated stations (which are also usually spaced further apart because of cost) increase access time. Because a passenger's trip time is the sum of access to the line, wait time, travel time, and access time to destination, access time is very important to passengers. Grade separation may make the

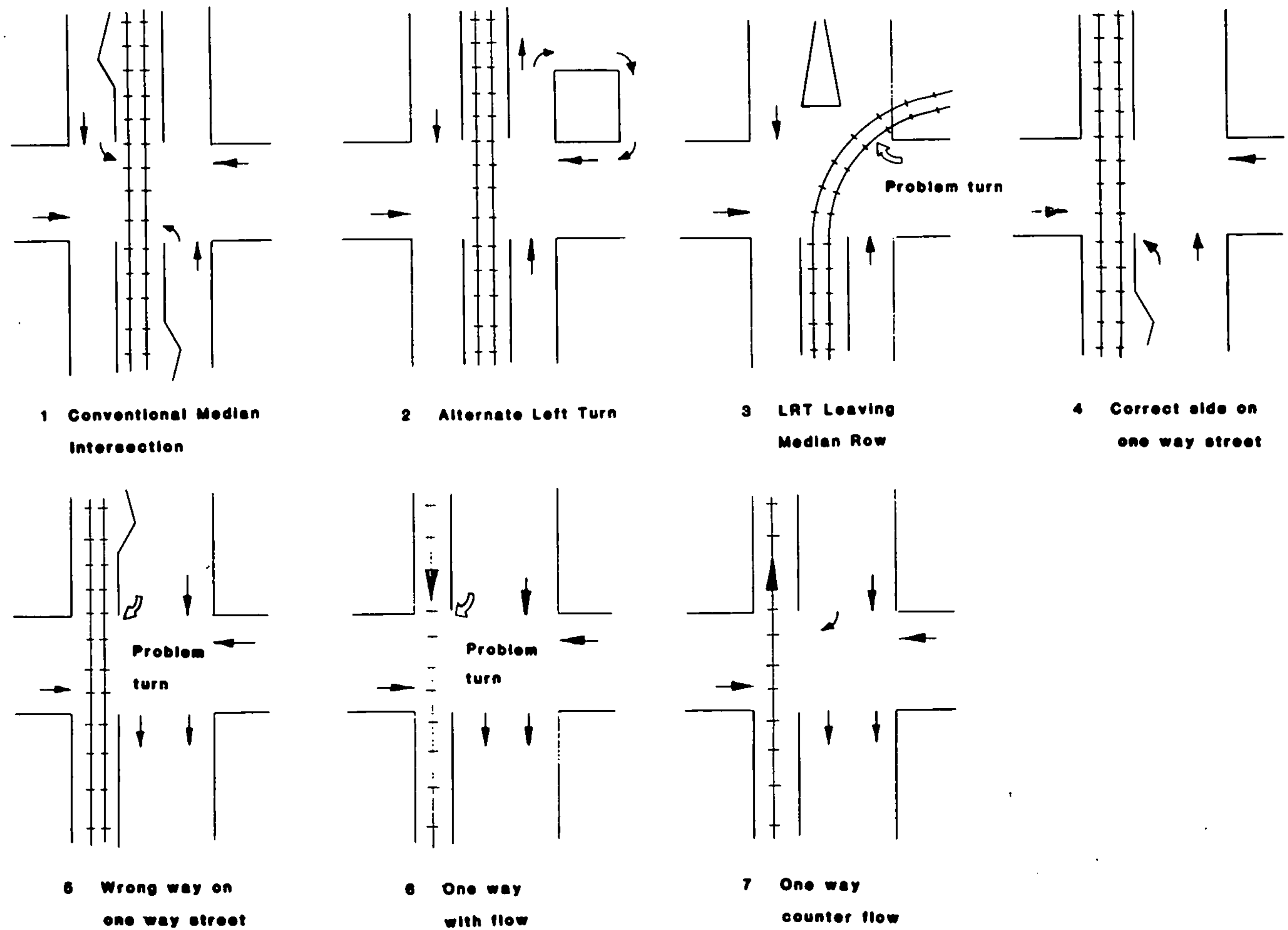

FIGURE 2 Some LRT/traffic turn relationships.

trains go faster, and the passenger go slower, all at considerably greater expense.

Related to this issue is the impact of station spacing on attainable speed. Figure 3 illustrates how station spacing affects average speed, and how maximum speed is of little importance when stations are closely spaced. Thus for stations spaced at 2,000 ft and a train limited to 20 mph [typical of LRT in a pedestrian or other central business district (CBD) situations], average speed will be 14 mph. A grade-separated system with a top speed of 50 mph will average about 18 mph. For that reason, when access time is also considered, the surface operation will compare well for all but the longest journeys.

Crossing Protection

The alternative types of crossing protection merit some comment. Where speeds are low, passive protection, such as stop signs, may be sufficient, depending on traffic conditions and street configurations. At one Tri-Met station, a four-way stop is used for both traffic and train control, with good effect, no delay to trains (which stop for the station), and no preempt. Where trains run on the edge of the street, stop signs on the nearside may not always be effective because of motorists' tendency to creep into the street.

The majority of LRT crossings at intersections are controlled by traffic signals. LRT may follow the signals, as does other traffic, or may have its own phase and signal aspects. Where LRT has its own phase, LRT signal aspects should be different from traffic signal heads, and should be designed to avoid confusing motorists who may see them. Thus certain colors, particularly green, should not be used, because motorists with poor vision may not distinguish between a T or X signal and a regular 0. Tri-Met has adopted the European bar signals, 1 for "go," – for "stop." Inclined bar signals may be used at junctions to indicate both "go" and position of a track switch.

The effectiveness of traffic signals for LRT crossings depends a lot on the intersection configuration. If the LRT is located in a median, or on the "correct" side of a one-way street, traffic signals work well, although speed is generally somewhat restricted. In Portland, traffic signals are not used if speed is over 35 mph. Raising this limit is currently under consideration. However because of station stops, the total time saved on a 5-mi section of line by raising top speed from 35 mph to 45 mph is only about 2 min.

Where unusual street configurations occur, traffic signal control is less effective, and higher levels of violation are found. Configurations in which turns are prohibited, or the LRT turns out of the right-of-way, or the streets are not perpendicular can all cause problems. Supplementary active protection in the form of flashing "TRAIN" lights is used by Tri-Met in such

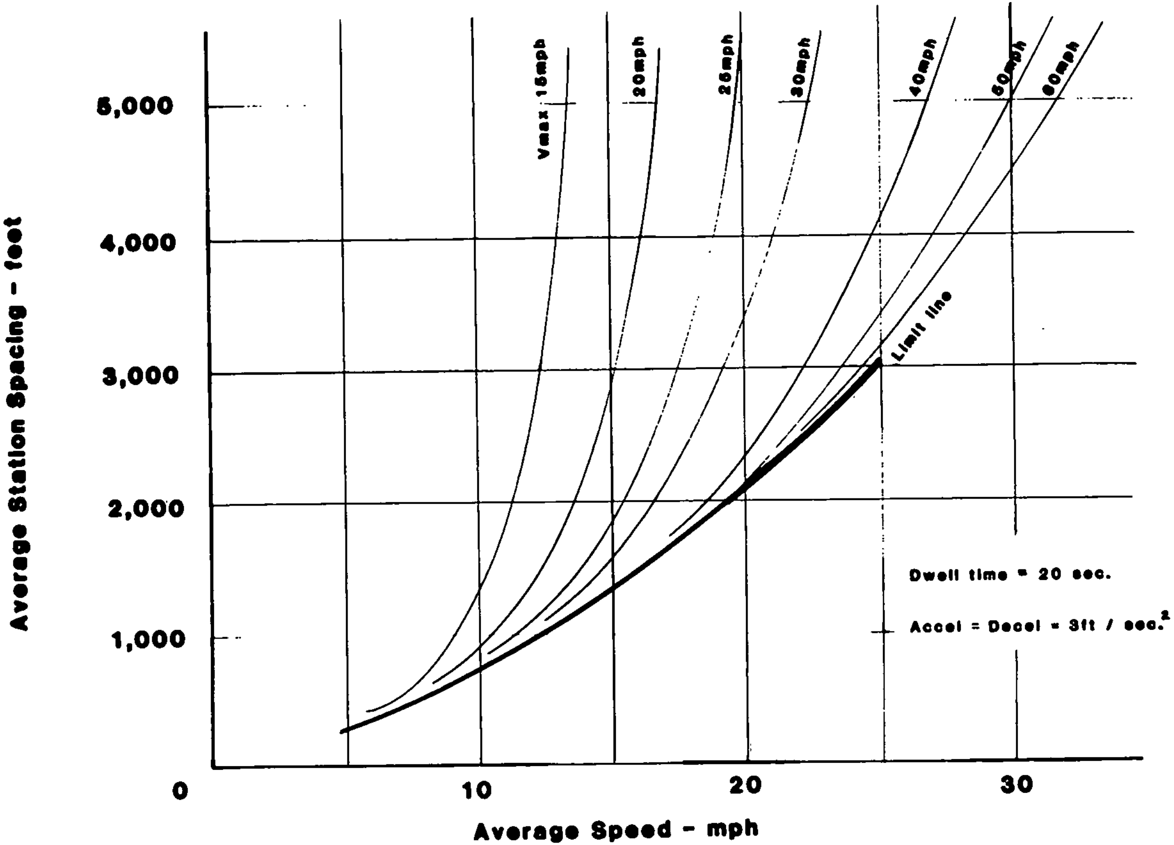

FIGURE 3 Station spacing versus average speed.

situations, and has shown promise. Because these lights are supplementary to the traffic signals, and are powered off the preempt circuit, no major circuitry or detection is required for their use.

A major advantage of traffic signals is the flexibility of the new controllers, particularly the 170 controller, to accept custom programs designed for LRT, and the ease with which control timing may be changed in the field. Moreover, use of standard traffic control hardware makes maintenance both inexpensive and fast with existing personnel and skills.

Gated Crossings

In certain situations, railroad gates may be preferred. Railroad gates actuated by track circuits are considered extremely reliable and are designed to fail in a safe condition (down). Developed for use on railroads, where trains cannot stop for crossings, they are often used where LRT speeds exceed about 35 mph. For instance, gates are used at arterial crossings not located in intersections, where traffic signals are often ineffective, or where unusual intersection configuration makes traffic signal control unreliable.

On Calgary's North East Line, part of which operates at up to 50 mph on an expressway median, gates are used to control left turns across the tracks in conjunction with traffic signal control of other conflicting movements.

At low-speed crossings where gates are used, less costly loop or overhead detectors can be used for actuation, provided provision is made for the train to stop in the event of nonactuation and provided the regulatory agency will permit such actuation.

Although safer than traffic signals, crossing gates have drawbacks. Their operation cycle is slower, so that they increase traffic interference significantly. The installation cost is significantly higher. They require more maintenance and are prone to minor collision and vandalism damage.

TRAFFIC NETWORK RESILIENCY

A frequent design goal is to try to preserve the traffic status quo, or even to provide for future additional traffic capacity as part of LRT design. The introduction of LRT into a transportation network will lead to trip diversion from bus and automobile to LRT. It can change the function of the streets it runs on to greater pedestrian orientation, and above all, the period of street disruption or closure necessary for construction will force new traffic patterns to develop.

Thus instead of preserving the traffic status quo, the LRT designers should evaluate the actual traffic needs on the basis of access requirements and the availability of alternatives for through traffic before arriving at a proposed street design and traffic mix.

When LRT was built on Holladay Street, an arterial street in Portland, the three existing traffic lanes were replaced by two lanes plus LRT. However, following over a year of street closure for construction, traffic never returned to its former levels. Two years later the Oregon Convention Center was located on this street, largely because of the LRT, and Holladay Street was reduced to a one-lane local access street serving the new convention center and its direction reversed. More people than ever before are traveling the street (by LRT) and the traffic network has adjusted itself.

SPEED PROFILES

A speed profile is a graphical representation of line speed related to time or location. It can be a valuable tool in developing alignment design. For instance it enables measurement of the schedule consequences of alternative designs at a specific location. Figure 4 shows alternative speed profiles for a sharp curve on the Portland LRT at 97th Avenue. Increasing curve radius or superelevation to achieve 15 mph rather than 10 mph produces a 17-sec time saving.

Similarly comparisons can be made of time savings from specifying cars with higher top speeds or greater acceleration, or from reducing station or traffic delays.

Consideration of speed profile will often guide designers to group speed impacts, for instance by placing a station near a low-speed curve, or by preferring to invest in grade separation where increased speed can result (i.e., where there is no station stop).

Figure 5 shows conceptually three speed/time profiles for a section of line, including an intersection and a farside station. Profile A is grade separated, but must stop for the station anyway. Profile B is at-grade with preempt. Profile C is at-grade without preempt. The train stops for a traffic signal and then for the station. The respective travel times for the segment are as follows:

A. Grade separated, 50 mph max: 65 sec,
B. At-grade, preempt, 35 mph max: 74 sec, and
C. At-grade, no preempt, 35 mph max: 105 sec.

For this situation, grade separation saved 9 sec, but preempt saved 31 sec.

On the proposed LRT extension to Portland Airport, the LRT must exit the median of a freeway. The original proposal required a 1,000-ft elevated

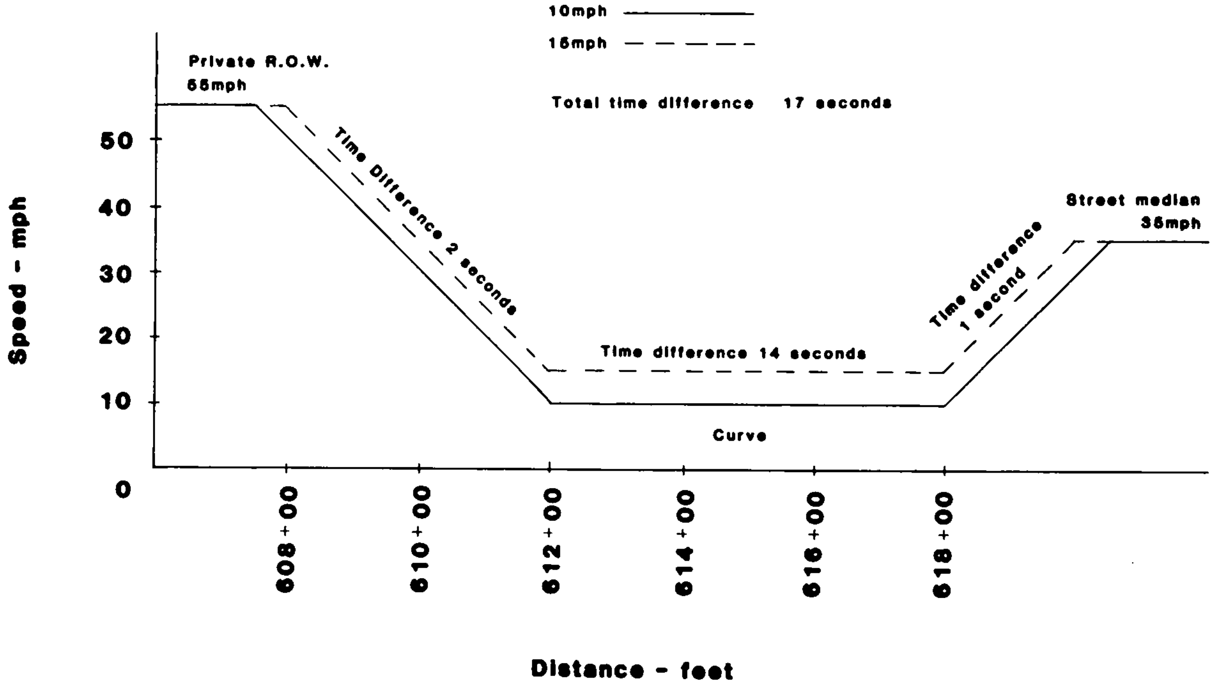

FIGURE 4 Speed profiles for 97th Avenue curve: 10 mph versus 15 mph.

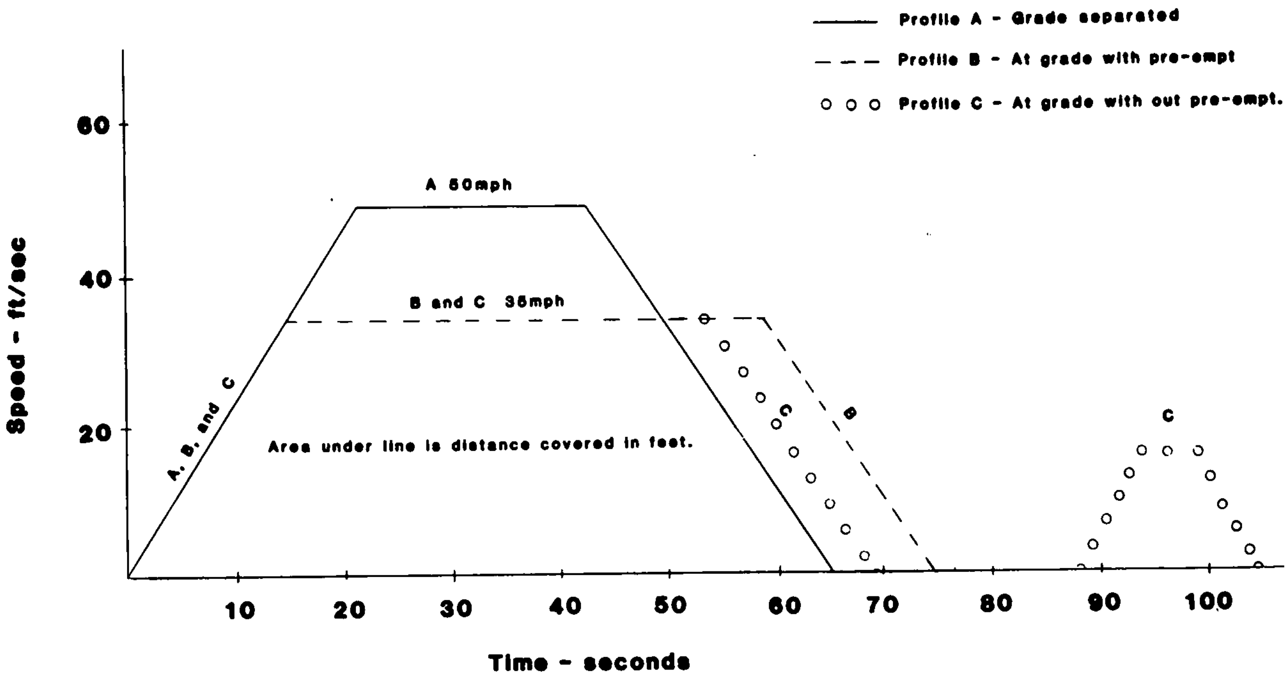

FIGURE 5 Speed profile for a line segment with intersection and farside station.

structure to lift out of the median, over the freeway lanes, and descend to grade. However, by reducing LRT speed to about 15 mph it becomes possible to curve down into a nearby existing underpass to exit the freeway median instead of building the elevated structure. And by placing a station at the end of this curve, the curve delay is shared with the station delay, resulting in a large cost savings and little operating time loss.

CONCLUSION

In setting out these guidelines for at-grade design an attempt has been made to set up a thought process that the designer can use to weigh alternatives and avoid being stampeded into costly design solutions where such may not be warranted. If these guidelines help the designer to keep it simple, to avoid the "might-as-wells," and head off the PEPS, then it has been well worthwhile.