Light Rail Preemption of Traffic Signals: A Question of Balance

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As Maryland expands its network of light rail transit facilities, an increasing number of situations arise where light rail and traffic-signalized intersections must operate in conjunction with each other. These include at-grade crossings close to signalized intersections and light rail facilities that closely parallel arterial roadways where there are closely spaced traffic signals on the arterial. These locations present the traffic engineer with unique problems that must be resolved to facilitate movement of the light rail vehicle and other vehicular traffic through the area. In most cases, the periodic preemption of a traffic signal at an isolated intersection will cause only momentary disruption to vehicular traffic. It is when more frequent preemption occurs, or when the signal operates as part of a coordinated traffic signal system, that problems arise. These include disruption of traffic signal coordination on the arterial, excessive clearance intervals needed to ensure that right-of-way has been cleared for the light rail, and excessive delay to vehicles waiting at the preempted traffic signal. In addition no two locations have the same characteristics or solutions. The traffic engineer must consider these and other factors when developing a traffic control scheme for each individual location. Maryland is evaluating several traffic control strategies for these types of locations. They include allowing the signal to cycle through other nonconflicting phases while the light rail vehicle passes through an intersection; allowing the signal controller to select, on the basis of traffic demand, which phase should be serviced first after preemption; and reducing the disruption to the signal system caused by frequent light rail preemption. The field testing and design of these strategies are addressed.

The subject of this paper is balance in terms of traffic numbers, that is, vehicles and people in quantity and travel time, and in terms of mindset, that is, perception of needs and advantages.

On the one hand, there is a continually increasing number of vehicles on local roadways; on the other, there is a move to get people out of their cars and on to buses and light rail service. The emphasis on mass transit is particularly important in the era of the Clean Air Act Amendments (CAAA) and penalties for not reducing vehicle emissions in nonattainment areas.

Our customers tell us that, assuming there is not a vast disparity in the cost of car versus transit, people make their decisions on which mode of transportation to use on the basis of time and convenience. The more their travel time can be reduced, the more likely it is that travelers will be enticed to use buses and light rail, leading to less congestion and pollution. However, there will still be people in their personal vehicles for local transportation and for getting to destinations not served by mass transit.

The result of greater transit usage is more and more situations in which transit facilities come into conflict with roadway facilities. Simply put, how do traffic engineers fairly balance the needs of car and transit users when they both must approach and traverse a heavily congested intersection?

Whatever the resolution in a particular situation, there must be a balance between the legitimate needs of drivers and transit passengers. In achieving that balance, a measure of priority must be provided to the transit operation if mass transit is to be made appealing enough to get drivers out of their cars and onto mass transit.

Most often, that priority has been provided by traffic signal preemption. Such preemption in the cases of light rail and freight train service halted some or all traffic flow at the intersection until the transit vehicle or freight train could move into and through the intersection. In some cases the complete halting of all traffic flow at the intersection could not be avoided owing to the way the intersection had been laid out. In others, where the geometrics are conducive, a balance has been achieved by taking advantage of state-of-the-art technology.

The Problem

Maryland is currently constructing extensions to its light rail system in the Baltimore downtown and metropolitan areas. For right-of-way concerns and the accessibility of most of its customers, the light rail lines are located on or immediately parallel to major arterial roadways. In the more urbanized areas, they also cross closely spaced, signalized intersecting streets. Most are at-grade crossings.

When traffic signals on these arterials and intersecting streets are very close together, they are coordinated for efficient vehicle movement. When traffic engineers preempt a signal within a traffic signal system, a measure of coordination is lost on the arterial roadway, as well as on the cross roads. Preemption sequences for transit vehicles are extremely disruptive to vehicular traffic because the priority is given without considering the impacts on the arterial or the entire system. As one might expect, the result was worst at closely spaced traffic signals and at high-volume intersections. Vehicles get stacked up between the signals and cannot move. Excessive clearance intervals are needed to ensure that the right-of-way has been cleared for the transit vehicle. Long queues develop at the intersecting roadways. Finally, there are excessive delays to vehicles waiting at the preempted traffic signals until the signals get back in step with one another.

We realized, as our traffic engineers were asked to help our transit sister agency with signal coordination, that these circumstances were unacceptable to our customers, both transit users and motor vehicle drivers. To compound the problems for our traffic engineers, no two situations are identical. Each presents new problems and requires new solutions for configuration of the roadways and the coordination necessary for the signals.

The problem—and the challenge—came down to finding a way of freezing only the movement at a particular intersection that would conflict with the transit vehicle without immobilizing the entire intersection and signal system. The trick was to keep nonconflicting vehicles moving by efficiently using the available green time in phases that did not affect the transit vehicle. Indeed, this is a delicate balance.

Meeting the Challenge

The answer to this challenge lies in newly available technology and a commitment by policy makers to customer-driven quality in transportation and to compliance with new federal requirements under the CAAA and the Intermodal Surface Transportation Efficiency Act.

Maryland has been exploring several strategies to address the problem. These include

- Allowing the signal to cycle through other nonconflicting phases while the light rail vehicle is passing through the intersection;
- Allowing the signal controller to select, on the basis of traffic demand, which phase should be serviced first after the preemption;
- Using different track clearance sequences—the signal sequences used to clear motorists from the tracks;
- Finding ways to reduce disruption to the coordinated signal system that is caused by frequent light rail preemption; and
- Holding the transit vehicle until the best possible moment within the traffic signal cycle to allow the most efficient movement through the intersection.

These different strategies are now possible through the use of state-of-the-art traffic signal controllers. The emphasis in Maryland has been on the use of signal systems to provide smooth traffic flow along arterial roadways. By definition, signal preemption runs contrary to this approach. But the new controllers allow minimal disruption, thereby adhering more closely to our original approach than was possible with earlier controllers. The previous technology was limited in its ability to balance the needs of motorists and transit users because of limitations in the "thinking" ability of the software. In this case, the policy emphasis drove the development of more advanced and specific-results-oriented software.

Learning Ground

In August 1993 Maryland successfully implemented its first experimental bus preemption system. It was installed along MD 2 (Ritchie Highway) between Baltimore and Annapolis, an arterial that carries average daily traffic (ADT) of 32,000 to 35,000.

What We Did

The preemption system consisted of bus priority control of 13 signalized intersections that operated as a coordinated signal system. The system allowed express buses to use any of three types of priority controls, depending on whether the bus stop was located on the near side or the far side of the intersection (in the Ritchie Highway case, we did not relocate any of the bus stops). The three types of priority controls are queue jumping, extending the green time, and phase reservicing.

The queue jump maneuver (Figure 1) was used at locations where the bus stopped on the near side of the intersection. This maneuver gave the bus an exclusive phase within the traffic signal sequence that would allow the bus to proceed through the intersection without any conflict from other vehicles.

Extending the green time (Figure 2) was used at locations where the bus stopped on the far side of the intersection. This would allow a bus approaching an intersection on a green indication to extend that green indication, thus ensuring that the bus got though the intersection without having to stop for a red signal. This would prevent a bus from having to stop twice at the same intersection, once for the red signal and again on the far side of the intersection to pick up and discharge passengers.

This phase extension was provided by giving the transit vehicle an additional extendable green interval to proceed through the intersection. The additional green time would be borrowed from the minor movements and then returned to the next signal cycle. The additional green interval was up to 15 to 20 sec.

The phase reservice (Figure 3) was used at a location where the bus made a left turn off the arterial to service a major park-and-ride lot. This maneuver had the effect of serving the left-turn phase twice (if necessary) within the same signal cycle. The left turn would be serviced as a normal lead left turn for all vehicles and again as a lag left turn only if a bus were present. Any other vehicles that were present during the lag portion would be serviced as well, but the lag option would be called only by the presence of a bus in the queue of left-turn vehicles.

The decision of which option to choose was made by the traffic signal controller. The system was completely automated and required absolutely no action by the bus driver. The system used a NEMA-TS2-type controller and the 3M OPTICOM Priority Control System. The control system transmitted the signal from the bus

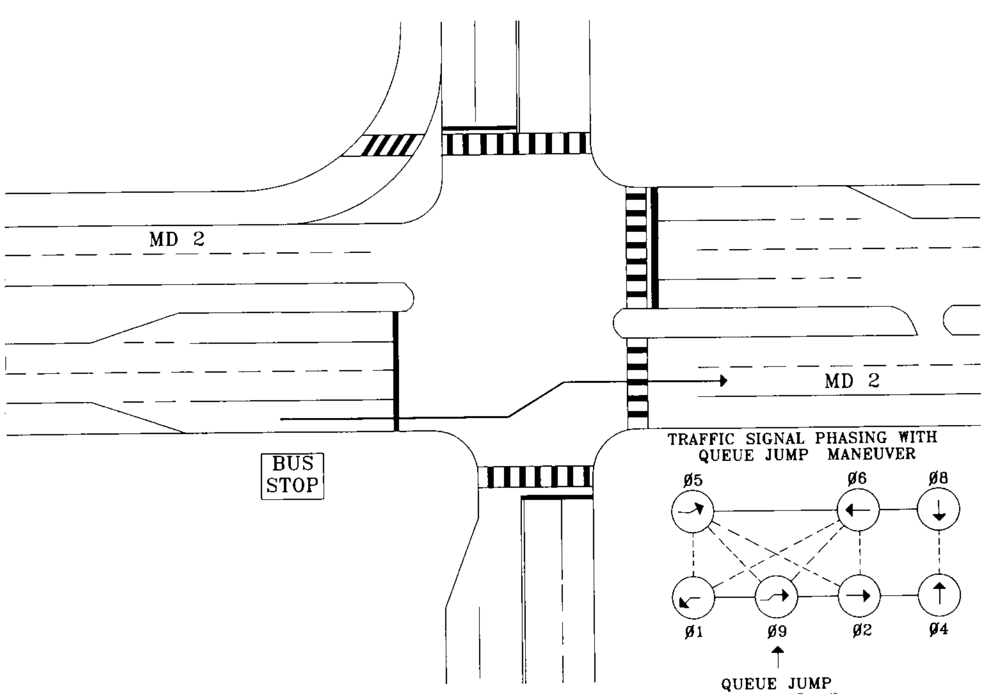

FIGURE 1 Queue jump maneuver.

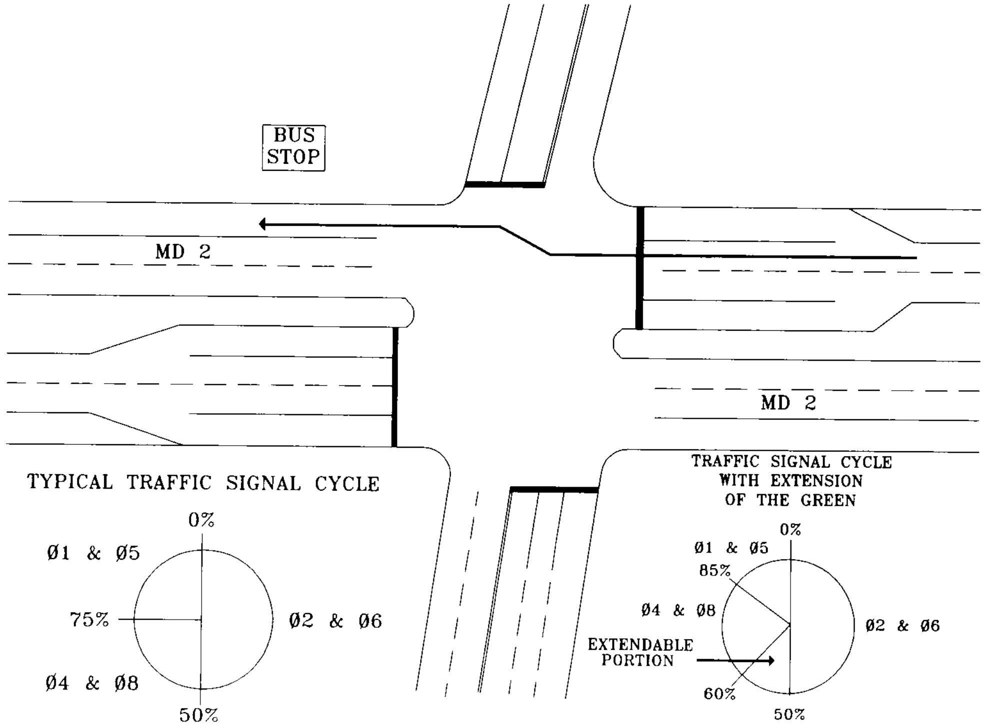

FIGURE 2 Extending the green time.

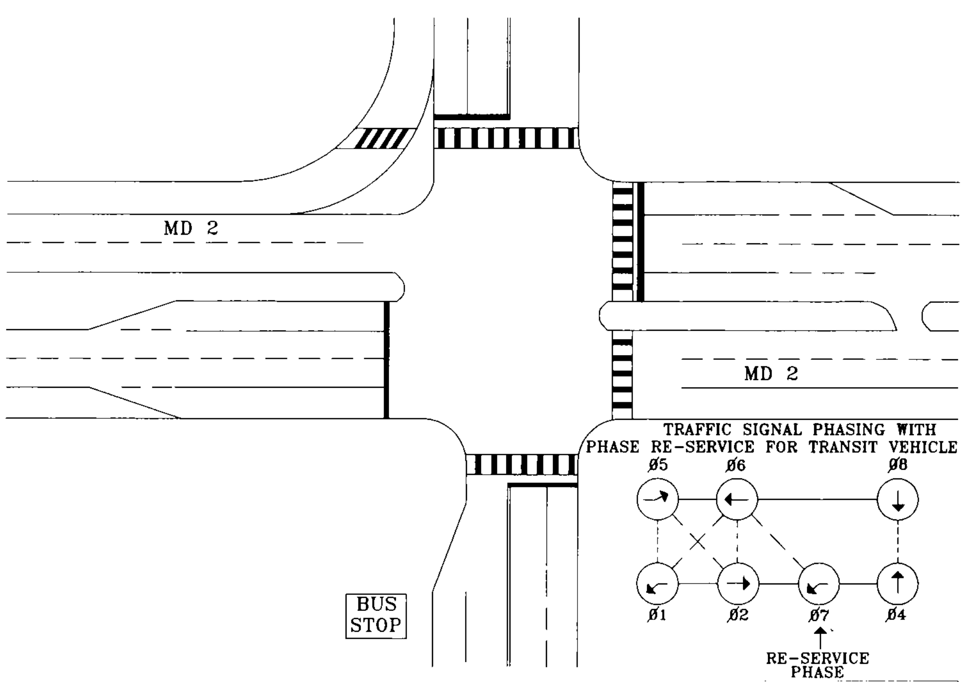

FIGURE 3 Phase reservice.

to the local intersection controller. The controller, in turn, depending upon the status of the intersection at that time, would determine what type of priority control to provide.

Results

The system reduced bus travel times by 14 to 18 percent on the affected section of roadway. This was achieved because all three types of priority controls were provided without affecting coordination on the arterial. At no time do any of the signals lose their coordination relationship with one another.

In some cases, motorists also realized a decrease in their travel time because they were able to use the extended green time provided for the buses. Very few complaints were received from motorists on the minor street approaches due to any additional delay encountered by them.

At the time the Ritchie Highway bus priority system was fully operational, we were satisfied that we had achieved great results. In reality, this was a critical evolutionary step that has led to much greater expectations in their application to the "new kid on the transit block," light rail.

Human Factors

Aside from the technical and policy implications of priority control for transit vehicles, there is an aspect that is critical to modern traffic engineering: the human factors element. A significant concern in this priority control preemption concept is whether drivers will understand and accept the different and varying traffic movements and the new signal displays. These displays are unique to transit vehicles and alert drivers to their assigned right-of-way through the intersection (Figure 4). However, for the intersection to operate safely and efficiently, motorists must also understand what the new displays indicate.

These signal displays are not covered in the *Manual on Uniform Traffic Control Devices* (MUTCD) because the situations in which they are used are new. As a result, they have received an "experimental" designation from the Federal Highway Administration. Maryland will be reviewing driver acceptance and comprehension with an eye to modifying them to make them more clearly and universally understood. The results will be reported to the National Committee on Uniform Traffic Control Devices, as with all experimental designations.

Lessons

We learned from the Ritchie Highway experience that we can balance the needs of motorists and bus riders without drastically affecting traffic flow on an arterial highway. We now believe we can transfer successfully the preemption lessons and approaches to light rail transit.

One of the more important factors in considering how to adapt the preemption phasing is whether the light rail line is a major line or a spur line. There are two levels of light rail service, and each must be treated a bit differently. Main line service requires a much tighter, set schedule, and it cannot vary if service is to remain consistent with the schedule throughout the system. As a result, main line service trains must always receive a higher priority. There is more flexibility with the spur, or feeder-type, lines because the schedules are more flexible and allow more opportunities to balance the needs of both types of vehicles at a particular intersection. The light rail train can leave the stop a few seconds later than scheduled to accommodate other vehicular movements within the intersection.

New Applications and Implications for Light Rail

MD 170 (Aviation Boulevard) at Elm Road–Baltimore Washington International Airport Spur

A grade separation is the preferred treatment for a roadway or rail crossing. However, monetary constraints precluded the option from consideration at this location.

This intersection serves as the main entrance to the Baltimore Washington International Airport (BWI), with an average of 40,000 vehicles traveling through it daily (Figure 5). Aviation Boulevard for the most part encircles the airport. At its intersection with Elm Road, it runs in an east-west direction. Elm Road runs north-south.

This light rail line is a hybrid between the main line and spur configuration. It is to function as a spur line but is designed so that at some future time it can convert to main line service.

The stop at BWI is the southern terminus of the light rail spur to BWI. This would be the beginning of the northbound trip. There is also a stop located just north of the MD 170 grade crossing. For the light rail line to serve BWI, it must cross Aviation Boulevard at Elm Road. It crosses Aviation Boulevard approximately 30.5 m (100 ft) east of the centerline of the intersection (Figure 6). This intersection is located at the west end of the system.

The crossing will be double-tracked to allow inbound and outbound trips to cross simultaneously. It will be controlled by gates and overhead cantilevered signals. The crossing will meet all federal standards for a railway grade crossing. We estimate that the crossing sequence will require 55 sec. This includes track clearance, time for the gates and warning lights to activate, and rail crossing time and rail clearance time before the gates open. All times are computed on the basis of federal requirements.

The light rail crossing will require that main street traffic be stopped. To lessen the delays at this intersection caused by preemption, it is highly desirable to serve the minor nonconflicting movements at the same time the preemption is occurring. This would allow the preemption to be exited back to the main street movements.

The minor street movements at this location will consist of a northbound leading left-turn movement and the northbound and southbound through movements. The southbound left-turn movement is prohibited at this intersection and will be accommodated at another location. The northbound right-turn movement will be controlled by gates to prevent conflict with the transit vehicles. The preemption will occur about every 15 min.

Three preemption options (Figure 7) are under study for this location. The first is a simple preemption sequence that would allow the minor movements to be served during the preemption. This preemption sequence would be used on demand by the transit vehicle; that is, no delay would be encountered by the transit vehicle. The preemption would be exited to the main street. This preemption sequence would be the most beneficial to the transit vehicle, but it would create the most disruption to traffic on the arterial roadway.

The second option is to allow the preemption to occur during a "window" within the normal traffic signal cycle. Normally when a preemption occurs, whatever phase is currently being timed is immediately exited in order to serve the preemption phase. In some cases, this could mean a phase would be exited as soon as it was given its initial green time. But the idea here is to provide a window within the traffic signal cycle during which the preemption could not occur. In the case of this location, the preemption would not be allowed when the main street phases were timing or about to begin timing. The preemption would be allowed to occur during the final 10 to 15 sec of the main street

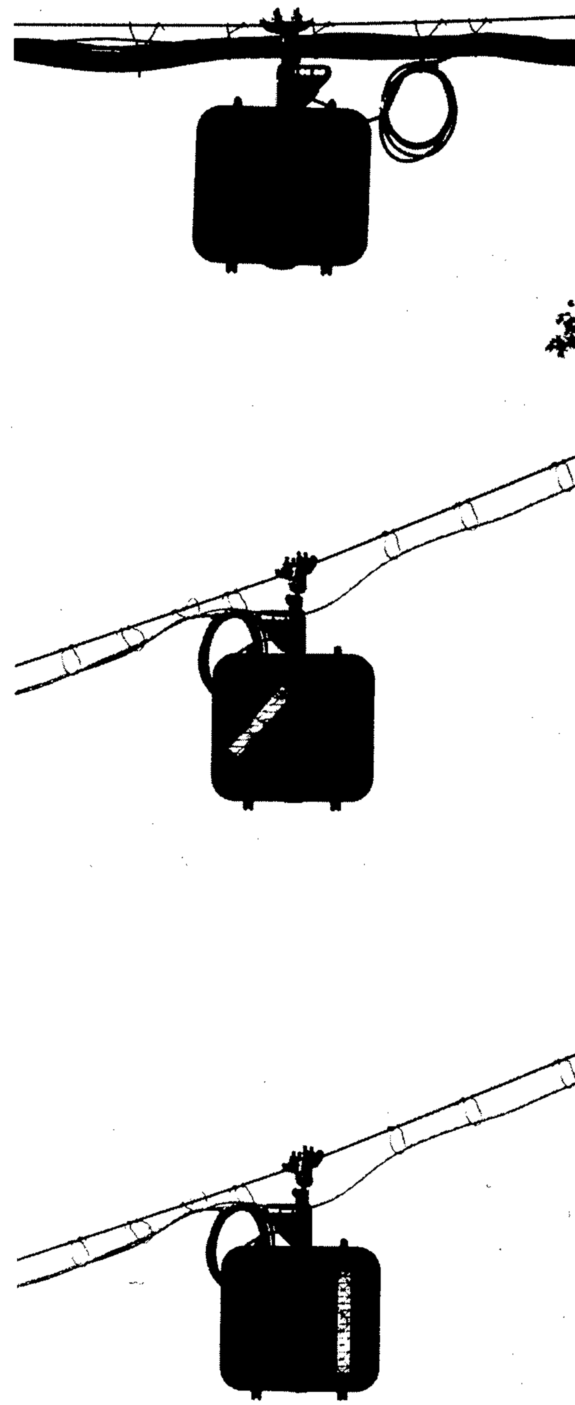

FIGURE 4 Transit vehicle display. *Top*: The transit vehicle display remains dark at all times except for the queue jump maneuver. *Middle*: The transit vehicle display shows a 45-degree white bar when the signal controller has received the call for the queue jump maneuver. This is not an assignment of right-of-way to the transit vehicle. During this display the adjacent main street through movements receive a red indication. *Bottom*: The transit vehicle signal display shows a vertical white bar when the transit vehicle has the right-of-way. During this time all conflicting movements at the intersection receive red indications.

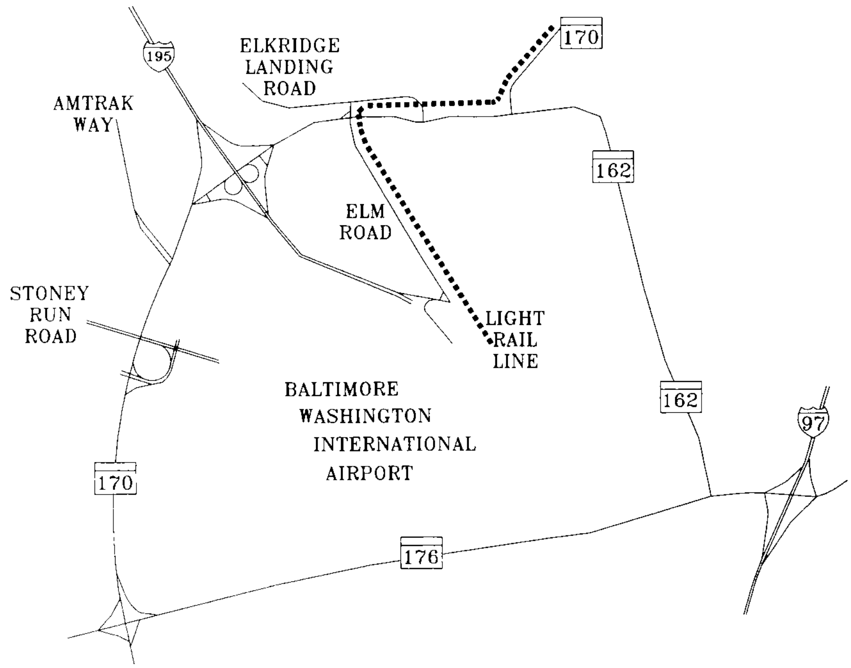

FIGURE 5 BWI light rail spur.

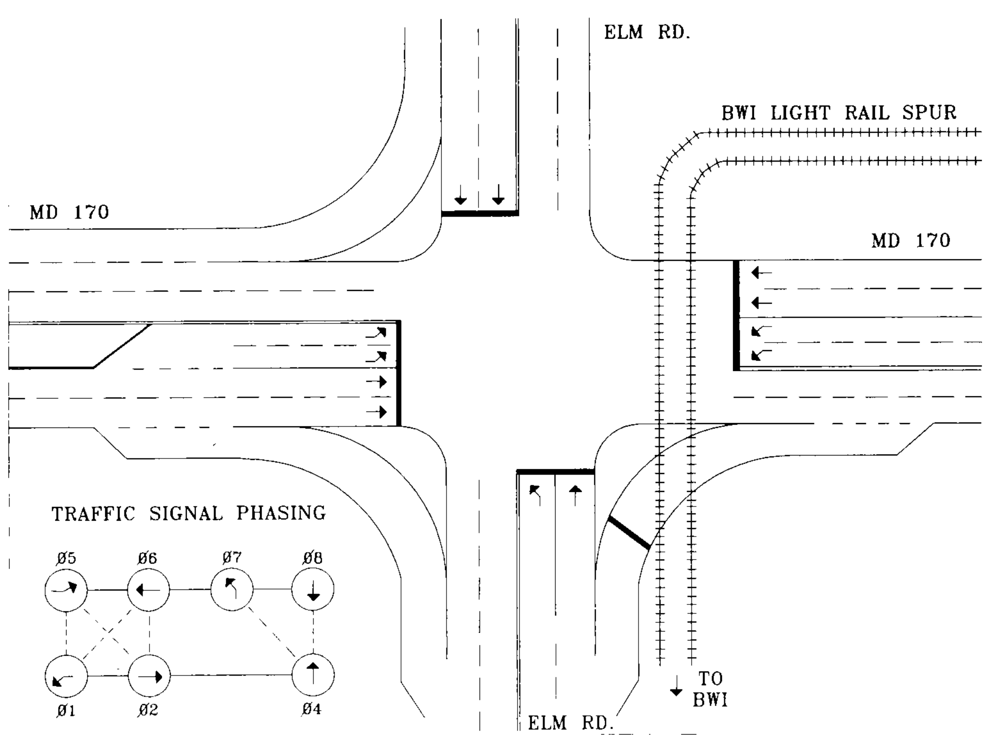

FIGURE 6 MD 170 at Elm Road/BWI spur.

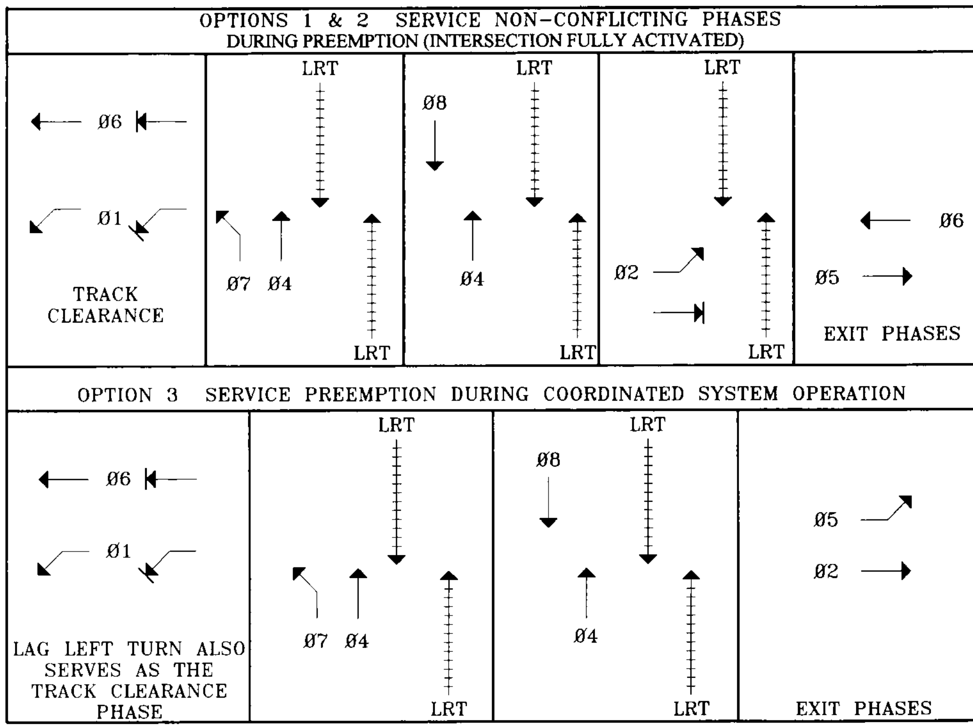

FIGURE 7 MD 170 at Elm Road/BWI spur: preemption options.

phases, or during the side street movements. The side street movements would then be served during the preemption sequence.

The third—and more desirable option from a highway standpoint—is to control when the transit vehicle is allowed to use the crossing. This would be accomplished in the same manner as the queue jump on MD 2 for the bus priority system.

The desired preemption sequence would allow the transit vehicle to use the crossing during the same point in the traffic signal cycle that the minor street phases would be active. This would be the same as the first type of preemption except that the transit vehicle would be told when to proceed toward the crossing. All track clearance intervals and other safety devices would be used accordingly.

The stops on both sides of the crossing would be used as a holding area for the transit vehicle. The train at each holding location would receive a signal from the local intersection that would tell it when it could proceed towards the crossing. The transit vehicle would receive a signal from the intersection controller to begin moving toward the intersection at the appropriate time that would allow all safety sequences to occur as the transit vehicle approaches the intersection, and would have the train reach the crossing at the desired point in the traffic signal phasing sequence. It is estimated this would cause a delay of at most 1 to 2 min to the transit vehicle. Since the trains would be sitting in a station waiting to move, the delay would probably go unnoticed by the rider. This preemption sequence would leave the coordination between the intersections intact and is the most desirable from a highway standpoint.

The second option was the one selected for initial usage at this location. This option will provide the best balance in the needs of transit and nontransit vehicles. The BWI light rail system is currently under design. It is scheduled to be fully operational in mid-1996.

MD 648, MD 176 to Eastern Avenue

MD 648/Eastern Avenue is an excellent example of the point we are trying to make. This main line light rail system runs parallel to a moderately to heavily traveled arterial roadway, and it crosses all of the side streets. Care must be taken to clear the side street traffic so it is not backed onto the tracks as a result of the arterial traffic signals and the light rail priority.

This section of MD 648 contains four traffic signals within a 503-m (1,650-ft) section of roadway, an average signal spacing of 168 m (550 ft). These four signals operate as a coordinated system. Three of the four are preempted by light rail, all in quick succession.

The light rail line runs parallel to MD 648 and is located approximately 15 m (50 ft) west of MD 648. MD 648 itself has an ADT of 14,000 vehicles in this section. The signal phasing at all three of the preempted locations consists of main street left-turn phasing, concurrent side street movements, and overlap clearance phases on the side streets to clear the crossing and the main street phases.

These same three signals use 75- and 90-sec cycle lengths and operate on the half cycle from the fourth signal in the system (using 150- and 180-sec cycle lengths). This fourth signal is at the southern end of the system and is not affected by the preemption.

The preemption sequence first uses a track clearance interval to ensure that no vehicles are stopped on the tracks and then rests in the main street phase until the transit vehicle passes. The preemption is exited back to the side streets to reduce delays. The preemption sequence along this arterial occurs an average of once every 7 min.

The problems encountered along this arterial are due to the closely spaced traffic signals and the frequency of the preemption, which can at times cause severe disruptions to traffic on the arterial (long vehicle queues, excessive stops, etc.).

The MD 648/Eastern Avenue system is currently operational. Traffic engineers are fine-tuning the signal system operations to provide a more efficient balance between the competing transit and nontransit needs.

Several alternatives under consideration include

- Having the controller serve minor nonconflicting movements during preemption sequence,
- Developing ways of getting the controller back into step faster (it can take up to four signal cycles to get the signal back into step with the other signals in the system), and
- Having the controller rest in a particular phase until the coordination clock and the local controller clock get back into sync with one another.

This latter alternative can create additional delay to other movements. For example, if the controller exited the preemption to the side street, the controller would rest in the side street phase until the coordination time clock reached the same point in the cycle. This may be acceptable at some locations that have short cycle lengths, but it probably would not be acceptable at locations that have long cycle lengths.

Unresolved Issues

An unresolved question is whether the benefits of quickly regaining the coordination on the arterial outweigh the additional delays that may arise from having the controller dwell in a phase until the local cycle time clock and the coordination time clock get back into step. Whereas the answer may differ in different jurisdictions, the political commitment in Maryland favors the former.

With the increasing usage of light rail, we must give light rail the most efficient flow along its tracks while preventing gridlock and critical traffic backups at adjacent arterial roadways. What is an acceptable amount of delay for both transportation modes is the issue.

If there is a downside to all this, it is the need for public awareness and education. Drivers have become so used to halting at an intersection for any rail movement that it has probably become ingrained. They may need some instruction on how to approach and traverse the intersection while light rail is doing the same. They need to understand the concept of shared safety.

Conclusions

In the early days of light rail, movement priorities were identical to those for all trains. Consistent with MUTCD guidance on highway railroad crossings, the intersection froze to allow the passage of the train. Clearly, whether it be light or heavy rail, traffic in direct conflict with the train must be halted for safety reasons. However, there is one point we want to stress: we must—and now we can—move away from the old mentality of "the railroad rules" to a new framework of accommodation and balance. Safety need not be compromised.

What is new, and what allows us to use this framework of accommodation and balance, is the new technology and the commitment to use common sense. And common sense means serving all nonconflicting movements at the intersection. The technological stumbling block was how to do the preemption sequence without disrupting coordination. The breakthrough is a controller that can get the intersection back into step faster and more efficiently.

There is also the policy commitment because of genuine concerns about the environmental impact of increasing vehicle usage and the loss of highway funds if pollution in nonattainment areas is not reduced. The result is a balance in meeting the needs of drivers and transit users, and at the same time taking major steps in the direction of the CAAA and the requirements of nonattainment status.

This paper began with the concept of balance. It also ends with the concept of balance. The Maryland experience proves that traffic engineers now have what it takes, or are developing what is needed, to achieve a balance between alternative transportation facilities and approaches while being environmentally sensitive. It is indeed a perfect balance.