U.S. Department
of Transportation
Federal Highway
Administration

Memorandum

Subject: Traffic Signal Priority
Transit Operations

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Reply to Attn. of: HRC-WE

To: TSP Working Group

In discussing what part of TSP to standardize I would propose the included figures and comments for discussion. This is not meant to be an all-inclusive document and as such some items are discussed in more detail than others. As this work and discussion progresses and more details are available they could be added, changed or clarified.

Taking a broad brush or the 500,000-foot overview as some suggest I see the following system blocks and the communications between the blocks. Each of which I will discuss individually. Also within each block there would be additional blocks and sub systems.

The goal of the standardization effort will be to define the following:

- What parts of the system should be standardized?
- Develop a standardized message set.
- Identify potential algorithms that define how it would operate.
- Discuss the hardware required for implementation.
- Communications systems requirements.
- Cost implications

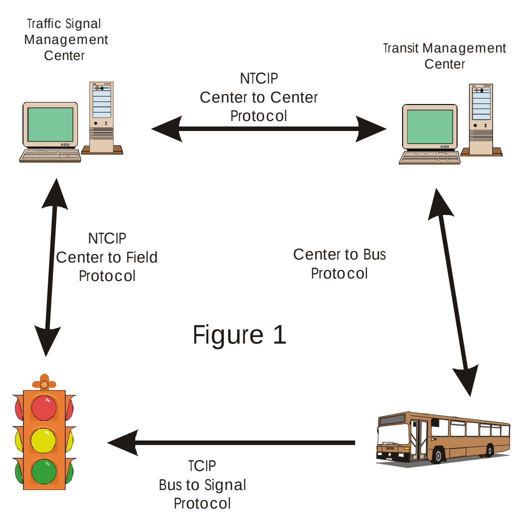


Figure 1

With the communications links there could be some spirited discussion on if and how the transit vehicle would communicate with the traffic signal. Some of this discussion would revolve around three potential detection schemes Zone Detection, Point Detection and Continuous Detection.

I will save the discussion of potential costs for a later time.

Transit Vehicle

The transit vehicle would collect store, process and transmit information. Depending on the scheme used all or some of this information would be transmitted to the traffic signal. Some of this information may only be transmitted once to each traffic signal, other messages would be constantly updated and some only when there is a change in status.

This information could include the following:

- Vehicle location (latitude, longitude)
- Passenger count
- Schedule Adherence (in time units)
- Vehicle routing (will the vehicle be turning?)
- Door and lift status (for near side stops)
- Predicted time when the door might close based upon lift cycle time. (Could be a user selected constant)
- Stop Location (near side/far side)
- Speed (moving average over the last X seconds)
- Vehicle turn signal or flasher status

Transit Management Center

The transit management center would provide information to the transit vehicles and the traffic management center.

To the vehicle

- vehicle routing
- schedule information/adherence

To the Traffic Management Center

- Vehicle Routing
- Priority Request Weighting Factors (i.e. to help judge if coordination or priority is more important for a system, arterial or intersection)

Traffic Signal

The traffic signal would receive information from the transit vehicle, which might include the following:

From the transit vehicle

- Bus Location (Latitude, longitude)
- Satellite ID's used in determining the GPS location (needed in Differential GPS solution)
- Passenger Count? (or maybe a priority importance)

- Schedule Adherence information (might include how far ahead or behind schedule)
- Route information (route number, express/local?)
- Run Number
- Speed (moving average)
- Vehicle ID (could include AVI tag ID)
- Door and lift status (for near side stops)
- Predicted time when the door might close based upon lift cycle time. (Could be a user selected constant)
- Stop Location (near side/far side)
- Speed (moving average over the last X seconds)
- Vehicle turn signal or flasher status
- Time point information (important for crossing or transfer routes)
- Vehicle Length (for use with Light Rail Transit Vehicles)

From/To adjacent signals
- Signal timing information
- Vehicle check-outs
- Schedule adherence information (to help begin to predict priority service strategy and timings)
- Vehicle locations

This may have to be done via the traffic management center or field master controller for systems that don't have peer-to-peer communications.

To Traffic Management Center
- Signal Priority Status
  - Early Green (amount of time granted)
  - Extended Green (amount of time granted)
  - Vehicle arrive at end of green
  - No priority granted
- Vehicle location information (including check out)
- Vehicle speed information
- Predicted vehicle arrival times
- Actual vehicle arrival times
- Vehicle ID information (for statistics and vehicle tracking)

To the vehicle
- Information to correct vehicle location
- Confirmation of receipt of a priority request
- Confirmation of a granted priority request
- Confirmation of a "Queue Jump" service. (this information may or may not be shown to the driver)

From Traffic Management Center
- Signal Timing/Operational information

- Priority or coordination more important?
- Current allowable early green or green extension time based upon coordination information. This could be calculated locally or on a system wide basis for a given arterial.

Traffic Signal Management Center

The traffic signal management center would act as an information broker between the transit management center and the traffic signal controller. It would also collect data from the signal controller regarding how many priority requests were serviced and how that service was provided.

The traffic signal management center might provide the following reports or data on system operation for system operators. This information would also be available at the Transit Management Centers.

- Number of priority requests received and granted
- How the requests were serviced
- The amount of time the traffic signal was adjusted (early green time or green time extension)
- Bus location when priority was serviced. In other words was the vehicle in the right place at the right time.
- Predicted bus arrival times as calculated by the traffic signal system
- Bus speeds and travel times
- Actual vehicle arrival time to monitor the accuracy of the predicted arrival time
- Percentage of vehicles meeting schedule

To the Transit Management Center

- Reports based upon the above information
- Traffic signal systems condition information such as a flow indicator, failure to clear standing queues with a transit vehicle, the number of cycles needed to clear the transit vehicle, etc.
- Transit Priority Requests status system wide or per intersection
- Transit Priority Request information per vehicle and route.
- Vehicle ID information. (Would be used by the Transit Management system to verify vehicle locations. This might be limited to indicating that the specific vehicle has just passed/approached a particular intersection)

To all of the above messages there should be messages for system management that would include messages for error logging and management.

Existing Standards

To go along with this we need to discuss the messages that will be used to transmit the above information. If at all possible we want to use messages that have already been identified in other standards work such as the NTCIP Standards, ATMS Data Dictionary, Location Referencing, etc.

However, for the link between the transit vehicle and the traffic signal we will have to develop a completely new set of messages. The messages will be dependent upon the type of detection system employed. For example if a point detection is used it may not send latitude and longitude information only information that a vehicle has passed the specified point.

The location information employed could take a number of different forms. It could be the full latitude and longitude or a truncated form of latitude and longitude since we don’t necessarily need to know exactly where on the globe it is just where within a limited area, so maybe the degrees part of this notation wouldn’t be needed. This would shorten the message required.

There are also some systems that operate using a sign post/odometer system. With these systems there wouldn’t be latitude and longitude information only that the vehicle is some distance from a given point. The messages for vehicle location will have to be capable of using either of these types of location information. These existing systems are set to notify the next signal and there may be some problems associated with notifying several signals in advance.

However, the system used needs to retain a sufficient degree of accuracy. For example knowing that the vehicle is within a certain block may not be sufficient. Additional accuracy will also be needed where signals are closely spaced and it is desired to notify more than one signal in advance.

Traffic Signal Priority for Transit Vehicle Operations.

The strategies used for detection of the transit vehicle and general algorithms used provide priority service will greatly impact the standard protocols and messages that are developed and maybe even the hardware implementations. In development of the standard message sets and protocols we need to attempt to define how these systems might be operated to ensure that we have defined all the messages and protocols that may be needed. Some of these messages will be mandatory, some optional and some will most likely be developed as proprietary by system vendors.

Here are some of the issues that I am currently aware of. There will most likely be many others before the work is complete.

- We will need to develop strategies to the level of algorithms to define things like permissible message latency and refresh times/rates. Different messages and pieces of information will have different refresh rates.

- Consider that the messages for a continuous detection system would need to pass an exact location in terms of longitude and latitude where a point detection system would only have to say that a vehicle is present. These are two completely different messages.

- Error handling and any messages that might be associated with that will be an important part of the standard. Take for example an intersection where the equipment installed in the controller cabinet isn’t working correctly. You would want the system to know that, not just the traffic signal management systems but the transit management systems and maybe even the transit vehicles.

- Where will the bulk of the information processing take place? In the transit vehicle, in the traffic signal controller, in external black boxes in each location? This will also have a bearing on the messages needed.

Once we have completed that work we will need to provide the system designers and operators some guidance on what messages will be needed for their proposed system operation. We have found in the NTCIP efforts for traffic signals that this can be quite a daunting effort.

I will continue this discussion with a description of the methods of detecting a request for traffic signal priority.

Transit Vehicle Detection Systems

I can identify three distinct types of detection systems that might be employed, Zone Detection Point Detection and Continuous Detection. Zone detection would be a system that a vehicle is within a fixed area advance of the intersection. Point detection would be a system based upon sensing the location of the transit vehicle at a fixed point. Continuous detection would provide the traffic signal with vehicle location information at closely spaced time intervals.

The biggest and most important difference between the systems is that point and zone detection systems are reactive and continuous detection can be predictive or proactive.

Zone Detection

This type of detection stems from its use in vehicle preemption systems. The system notifies the traffic signal that the vehicle is within a certain zone. The zone is typically defined by the strength of the signal from the vehicle as received at the traffic signal. *The zone detection system simply says that the vehicle is within this zone but not exactly where.*

These preemption systems were originally developed for use with railroad and emergency vehicles, which must take complete control of signal operations for safety reasons. A key part of this operation is to hold the traffic signal phase green, or flash red for railroads, to service the leg of the intersection on which the vehicle is approaching.

Some more modern traffic signal controller software packages have made minor modifications to this by creating a lower priority for use by transit. This priority scheme is such that priority requests from rail or emergency vehicles are serviced at a predetermined priority level, i.e. higher priority requests will be serviced first and will override a lower priority. Other modifications have been such that the transit vehicle places a preemption request only under certain conditions such as more than X number of passengers or Y seconds/minutes behind schedule. The impact is still that the signal is dropped out of coordination to service the request. Following the service of the request the signal remains out of coordination for several cycles while it regains synchronization.

A key feature of these systems is the limited ability for many existing traffic signal control systems to respond to a request for priority. Traditionally this response has been based upon either a simple switch or an external device that takes complete control of the intersection to advance the signal phase to that which is requested by the vehicle.

Optical Signaling: In the optical signaling type implementation, the signal remains on until the optical signal is lost which is typically just as it passes the intersection. Some of these systems can transit a limited amount of additional information such as a vehicle ID number. The distance that the vehicle can be detected will vary from vehicle to vehicle and intersection to intersection due to a number of things such as dirt on the lenses, the age of the optical source, and weather. With some of the optical systems that actual point of detection can be manually set and changed. However, it can not be done "on-the-fly" and once set is fixed until it is changed.

Radio Frequency Signaling: This system operates using a radio transmitter and receiver pair. The receiver sensitivity is adjusted to define the zone of detection. The system also provides information on what leg or direction it is approaching the intersection.

Point Detection

This common type of detection is currently being used for Traffic Signal Priority for both transit and emergency vehicles. The implementations include use of AVI tags and readers or a device that transmits vehicle data using the traffic signal detector loops.

With point detection the traffic signal must make some assumptions on the travel time from the detection point to when the vehicle would arrive at the signal. To know when the vehicle has cleared the intersection an additional detection point is added downstream of the signal.

In the point detection we would only know that the vehicle was at a certain fixed point at a certain time. There would be no additional knowledge of its location.

AVI Tag Systems: These systems are based upon using an Automatic Vehicle Identification tag similar to those used in tolling operations. The system reads the tag number then must consult a stored database to determine the route and schedule information for that particular vehicle. If a "read/write" type of tag is used then the tag could provide a limited amount of information to the traffic signal system. In systems as currently implemented a proprietary tag system is used.

Loop Detector Based Systems: These systems are based upon a transponder that transmits information to an inductive detector loop installed in the pavement. The typical installation uses loops already installed to operate the traffic signal. These systems have all of the characteristics described above.

Vehicle Odometer Based Systems: These systems are based upon use of an odometer or sign post Automatic Vehicle Location System. In this type of system a single message would be sent by the vehicle at a pre-selected point. These messages are typically sent via a radio channel directly to the traffic signal controller and therefore can contain significant additional information. With these systems if the vehicle were off route due to construction it would have to be reprogrammed for a new route. If the vehicle were off route due to driver error the signal wouldn't be able to correctly respond. This could also lead to situations where a vehicle is granted priority when it shouldn't have, resulting in impact to the overall traffic flow.

The major limitation of these systems is that once the vehicle has passed the detection point no other information can be provided to the traffic signal controller. From this point of detection the signal controller can only assume that the vehicle will take a fixed amount of time to arrive at the intersection. The time that is actually needed for the vehicle to travel from the detection point to arrival at the intersection can vary greatly. This may result in the signal controller granting and servicing a priority request that the vehicle isn't able to use.

Continuous Detection

Continuous detection systems provide a direct two way communications link between the transit vehicle and the traffic signal controller. Over this link a great volume of information can be passed. In particular the system would provide the traffic signal controller with an update of its location at very short intervals. The selection of this time interval would be based upon the traffic signal timing parameters and could be in the order of every five seconds. *In effect continuous detection is a special form of point detection only with many points.*

Using this information the traffic signal controller can then make a prediction of when the vehicle would arrive at the intersection. This type of implementation would provide a greater chance that the traffic signal controller would provide the correct timing to service the vehicle.

This type of system would work best if the vehicle location is determined using Global Position System (GPS) information. The traffic signal controller could also help by providing information back to the vehicle so it can be more accurately located (Differential GPS).

This type of system would also provide additional information that could be used in normal (non-priority) traffic signal operations. If the updates of the vehicle location are provided at fine enough intervals the location of the back of the queue could be identified. This type of system could also provide a "Probe Vehicle" service to the traffic signal management system. This information could then be used to judge when to end that signal phase.

There is a possibility that this information could be provided to the traffic signal management system by the transit management system. However, many of the transit management systems update the transit vehicle location every 30 seconds to one minute, which is too coarse for use in traffic signal timing. If this method is used with a finer time resolution the communications channel between the transit vehicle and the transit management center could easily be overloaded. This method also adds a considerable amount of latency for the information to be passed from the vehicle to the transit management center to the traffic signal management center and finally out to the traffic signal system.

Continuous detection also has the possibility to be implemented using generic multi source hardware once the message set and communications protocols are standardized. The only new equipment that would have to be added to the transit vehicle and the traffic signal system would be the radios. The radios could be of the spread spectrum variety operating in the 5.9 GHz range specified for DSCR.

Continuous detection will be most effective during periods of congested traffic flow. This is just when the transit vehicles most need this type of service. Consider a congested intersection with standing vehicle queues. With point detection the travel time from the detection point will be very inaccurate. The vehicle would proceed to the end of the standing queue and wait an unknown number of signal cycles and completely miss the priority service. In the worst case the signal would be held green for an unreasonable amount of time resulting in the signal being dropped from coordination. With continuous detection the vehicle could be tracked as it waits in the queue and priority granted just at the right time to be most effective for all vehicles.

Continuous detection can also be operated in either a point or zone detection mode without changing any hardware or messages.

Existing AVL Systems

Many of the existing systems for AVL on transit vehicles use an odometer-based system. There are also quite a number of systems that have been imported from other parts of the world. Whatever standard is developed should take this into consideration. However, the standards must be based upon the standard North American traffic signal controller operational parameters and logic.

The existing installed base of odometer based AVL systems will most likely not be replaced with GPS based systems for some time.

Potential Methods for Operation of Traffic Signal Priority for Transit Vehicles

The methods of operation are largely a function of the type of detection system employed and the traffic signal operational parameters. The TCHRP A16 study has an excellent discussion of these issues.

System Hardware Issues

An important goal in a standardization effort is to make sure that the standard is implementable on an open source hardware platform. The majority of the system functions at the traffic signal controller would operate within the traffic signal software program. The output from the communications channel between the bus and the traffic signal controller should be a data stream.

There should be no need for external processing devices. A simple block diagram of the system is as follows:

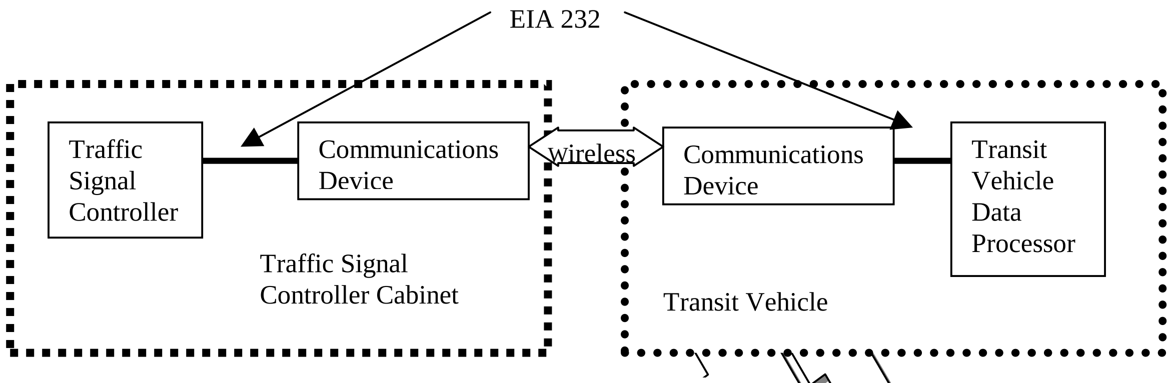


Figure 2

A system configured like this could use the most generic commodity type components. This is critical for cost reduction and widespread universal implementation. More importantly it would allow interoperability over many more transit systems. If only the messages and protocols are standardized interoperability will not be realized. Neighboring transit systems would have to agree on installation of a particular hardware based system. This also would make the system proprietary with the typically higher system costs.

In times of emergency, vehicles could be brought from any place in the country and operate in the system. Otherwise additional hardware would have to be purchased and installed.

The agency operating the traffic signal wants to keep the processing loads as low as possible. Therefore we should not require the traffic signal controller to keep a database on transit vehicles, ID's, routings etc.

Existing hardware implementations of Traffic Signal Priority require additional proprietary hardware boxes between the communications channel and at least the traffic signal.

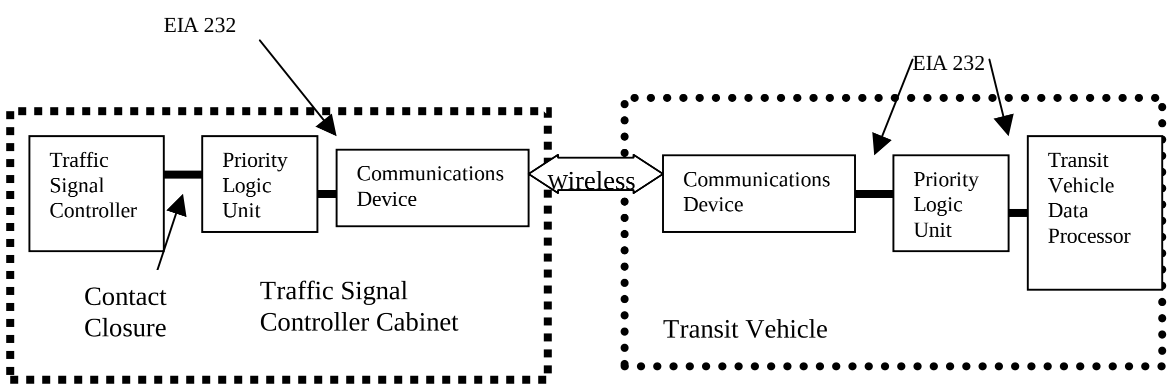


Figure 3

These extra boxes may lead to issues of ownership and who maintains what. Also consider that neighboring transit properties must agree in advance on systems and equipment which may be a problem. This will also be a problem for vehicles that are brought in from transit properties outside the region to respond to emergencies.

The cost of proprietary boxes is often an issue when systems are expanded and new equipment is added. Many times these additional boxes are provided at costs much higher than the original systems. We have found this to be true in the world of traffic signal control equipment.

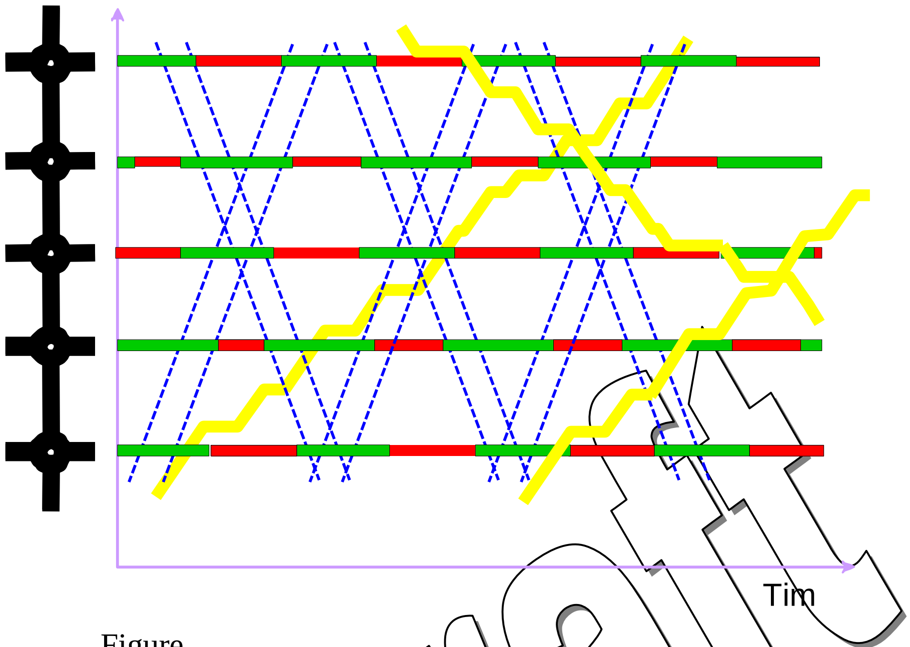
Furthermore, there may not be sufficient space in many existing traffic signal controller cabinets for additional equipment. Over the last several years there has been an explosion of new equipment added to existing traffic signal controllers such as communications equipment, video detection units, and video control and transmission equipment.

Many locations would be in Central Business Districts that already have a very small traffic signal controller cabinet and no additional space has been provided for many of these new devices. In some of these situations a second cabinet has been added, but only as a last resort and over the strong objections of maintenance staff. Real estate is not available for any additional cabinets at many locations.

Traffic Signal Timing Issues

The ultimate goal of this whole exercise is to adjust the traffic signal operation to better regulate the travel time for transit vehicles. The intent of regulating in this application is to ensure that transit vehicles arrive at the appointed locations at the correct times. This may mean not only providing additional green time, it may also mean providing additional red time to the transit vehicle if it gets ahead of schedule. This all must be done in a manner that does not adversely impact the other vehicles on the roadway.

In the realm of traffic engineering the basic method for representing traffic flow through a series of intersections is through the use of a “Time Space Diagram”. An example of this is shown in Figure 4. On this figure the vertical axis is distance and the horizontal axis is time. The left margin shows a representation of the roadway and each intersection. The sloped dashed lines indicate the “green band” of free flowing traffic. The jagged lines are the transit vehicle movements. The horizontal portions of the jagged lines represent a stopped transit vehicle. Note that the flow characteristics of the transit vehicle are quite different than those represented by the “green bands”.



Figure

To help minimize the travel time for a transit vehicle through a series of traffic signals, we would like to minimize the "horizontal" portions of this figure or at least to limit them to when the transit vehicle is stopped to load/unload passengers. The other part is to make the travel time as consistent and predictable as possible for any given base traffic flow.
This task of making the travel time predictable is complicated because there is a great amount on uncertainty on the times that the transit vehicle might enter the system and the time required to load/unload passengers once in the system. The delays caused by these uncertainties are completely random and can not be easily anticipated.

The other great uncertainty is the travel time from when the vehicle is detected or requests priority treatment. The figure below illustrates the number of factors that are a part of this variability.

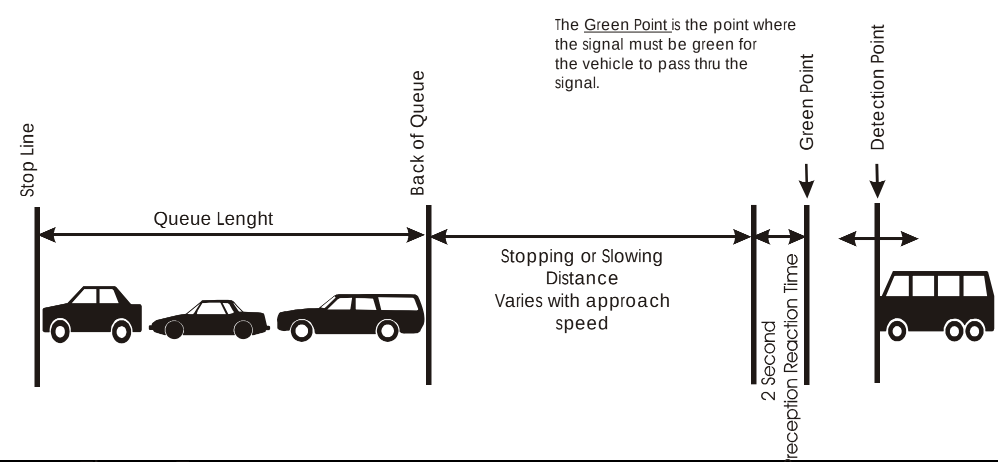


Figure 5

The key to this figure is that the traffic signal must be green at a point where the driver judges that the vehicle will be able to safely pass through the intersection. This is called the green point. In response to a call for priority treatment the traffic signal must adjust its timings such that the green light is on at this point. Or in the case of a near side stop or a vehicle ahead of schedule it may be better to show a yellow or red signal at this point so that the vehicle will stop and possibly be the first vehicle in the queue.

Given the variables shown in this figure the time/distance optimum for detecting the vehicle or requesting priority treatment is variable. The length of the queue at the traffic signal will vary with volume and signal timing. The distance needed to stop or slow the transit vehicle will vary with speed and roadway surface conditions. Therefore it would follow that the point where the vehicle must be detected or make a request for priority is also variable.

The other variable not shown in Figure 5 is the indication being displayed by the traffic signal when this request for service is made. The typical representation of the traffic signal cycle is shown in Figure 6. Think of this figure as an analog clock indicating the duration of signal indications for only one direction of traffic flow.

On Figure 6 several points when the transit vehicle might arrive at the traffic signal are shown. The transit vehicle could arrive at the signal at any point in time. Consider what happens as the vehicle arrives at the points shown.

With any of the points shown the vehicle is not guaranteed to clear the intersection. When the intersection flows exceed the maximum flow rate for the intersection it may take several cycles to clear the intersection.

Point A. If the vehicle arrives at point A there is a good chance that it will be serviced under most conditions. However, if there is significant queuing at the intersection it may not reach the Green Point while the signal is green.

Point B. The result would be similar to point A. This point would represent the latest possible Green Point.

Point C. If the vehicle arrives at this point it must wait until the next green phase. Depending upon the signal cycle length, the total time interval represented by the circle, the wait could be significant. Assume that the circle represents a 120-second cycle. Based upon Figure 6 the wait could be as long as 50 seconds plus the time required to clear any vehicles queued ahead of the transit vehicle. In this case there would be a minimum number of vehicles queued ahead of the transit vehicle.

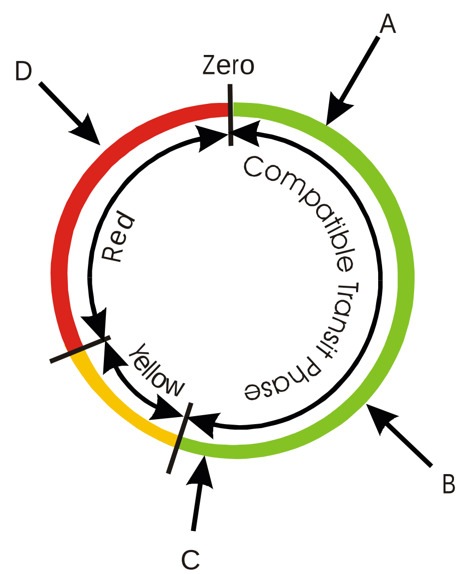


Figure 6

For locations with a near side transit stop or a queue jump operation maybe this is the correct point when the transit vehicle should arrive at the signal. This would allow the transit vehicle to load/unload the vehicle during the signal red time. This way there would also be the greatest chance that the transit vehicle would be the first vehicle in the queue.

Point D. The result is similar to point C except that the queue ahead of the transit vehicle could be much longer.

The above discussion assumes that the location of the start and end of each interval is fixed. For transit priority the intent is to make adjustments not only to the interval lengths but also to the point on the cycle they begin. However, in order to maintain coordination with adjacent traffic signals the amount of adjustment would be minimal. In very congested situations, the amount of that adjustment might be limited to several seconds.

In congested situations arrival at the intersection at any of these points may not ensure that the vehicle would pass. Consider the transit vehicle that arrives to the end of queued traffic. Depending on the length of the queue it may take several signal cycles to clear the intersection. With current detection systems the traffic signal won't have information to judge where in the queue the transit vehicle may be located. In these conditions it would be very helpful for the traffic signal controller to track the transit vehicle to better form a strategy to reduce the amount of time spend waiting in the queue. In effect, the task of the traffic signal controller is queue management not signal priority during congested conditions.

In early implementations of priority for transit vehicles the beginning point of the compatible transit phase was manually forced to coincide with vehicle arrival. To help illustrate the potential impact of this strategy it is necessary to show the other traffic movements that would have to be either truncated or skipped.

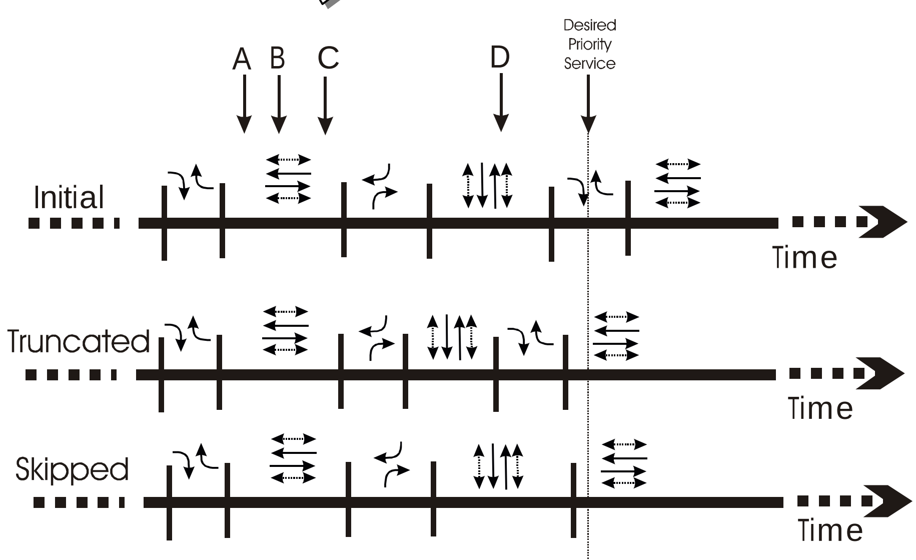


Figure 7

What has been shown in Figure 7 is that some of the vehicle phases that must be serviced prior to the priority service point have been shortened in duration. What this does is to move the beginning of the main street green earlier in the cycle. If we take this and look back at Figure 4 the effect is to slide the green portion of one of the horizontal lines left. You can therefore see that this will potentially impact traffic at the next intersection as well as traffic in the opposing direction.

For example if the green phase is brought up early to service a transit vehicle the platoon of all vehicles will arrive at the downstream intersection early. The result is that they have to stop and wait for the next signal. An argument could be made that the transit vehicle being in the platoon would send a priority request to call up the green phase at this down stream intersection early as well. However, given the uncertain movements of the transit vehicle this is not a good strategy as it assumes that the transit vehicle would continue to flow with the platoon of other vehicles. For an "express bus" or for long distances between bus stops this might be acceptable. In most cases it will not be acceptable and has the potential for significant impacts to other traffic.

Again to restate the overall goal, to minimize the impact to everyone, there must be a limit on how much adjustment of signal timing can be made to service a transit vehicle. It also must be recognized that the transit vehicle will have to stop at some signals. Therefore the goal is to reduce the impact of those stops.

It has been stated above that the transit vehicle should make a priority request a variable distance from the traffic signal. The next task would be to try and quantify what the minimum and maximum distances might be. Figure 5 identifies some of the distances that must be quantified. Some of them are fixed by physics and are a function of vehicle speed such as the stopping distance. Others such as the length of any standing queues are completely random.

It should also be noted that the distances calculated portray a worse case, which would be that the signal would be preempted. There would be no consideration of where in the signal cycle the vehicle might arrive as presented by Figure 6. In order to adjust the traffic signal timing to minimize the impact to signal coordination the request would have to be made at some distance or time in advance of the "detection point" shown in Figure 7.

The following tables presents a basic calculation that quantifies, for a worse case, the time that might be available following a request for priority for the signal to prepare to service the priority request. Note that in these tables there is now allowance for termination of phases conflicting with the priority request.

Table 1 shows the calculation with no cars queued ahead of the transit vehicle at the signal. In this case traffic is at a free flow condition and the traffic signal coordination is perfectly adjusted to facility the flow of transit vehicles. The times identified are what it would take the transit vehicle to move from a fixed detection point to the point where it would not stop at the signal.

With a detection point 500 feet from the stop line there would clearly be very little time to make adjustments to the signal timing to accommodate the transit vehicle. As the detection distance increases this time increases of course. Good starting points to identify a detection distance at least one signal cycle length in advance.

Table 1														
Time for Signal Adjustment From Point of Detection to Green Point														
Speed		2.5 Seconds	Stopping	Standee	Green	Queue	Distance Detection Point to Stop Line (feet)							
MPH	FPS	P-R Time	Distance *	Adjustment	Point	Discharge	500	1000	1500	2000	2500	3000	3500	4000
		Feet	Feet		Feet	Seconds	Seconds							
25	36.67	92	55	69	160	0	9.26	27.27	40.66	53.80	67.07	80.35	93.63	106.90
30	44.00	110	86	108	218	0	6.42	22.73	33.94	44.94	56.05	67.16	78.27	89.38
35	51.33	128	120	150	278	0	4.32	19.48	29.14	38.58	48.13	57.69	67.24	76.80
40	58.67	147	167	209	355	0	2.46	17.05	25.53	33.80	42.18	50.56	58.94	67.32
45	66.00	165	218	273	438	0	0.95	15.15	22.71	30.07	37.53	45.00	52.46	59.92
50	73.33	183	278	348	531	0	-0.42	13.64	20.46	27.09	33.81	40.54	47.27	53.99
* From 1990 AASHTO "Green Book" Page 120, Table III-1. Stopping sight distance (wet pavements)														
Standee adjustment adds to stopping distance by:					25%									
Queue Discharge rate =		2	seconds per car											
Assumed Queue =		0	passenger car equivalents											

Table 2														
Time for Signal Adjustment From Point of Detection to Green Point														
Speed		2.5 Seconds	Stopping	Standee	Green	Queue	Distance Detection Point to Stop Line (feet)							
MPH	FPS	P-R Time	Distance *	Adjustment	Point	Discharge	500	1000	1500	2000	2500	3000	3500	4000
		Feet	Feet		Feet	Seconds	Seconds							
25	36.67	92	55	69	160	20	-10.74	6.73	21.20	34.36	47.60	60.88	74.16	87.43
30	44.00	110	86	108	218	20	-13.58	2.27	14.40	25.40	36.49	47.60	58.72	69.83
35	51.33	128	120	150	278	20	-15.68	-0.91	9.53	18.98	28.52	38.07	47.63	57.18
40	58.67	147	167	209	355	20	-17.54	-3.30	5.87	14.15	22.51	30.90	39.28	47.66
45	66.00	165	218	273	438	20	-19.05	-5.15	3.02	10.38	17.83	25.30	32.76	40.22
50	73.33	183	278	348	531	20	-20.42	-6.64	0.73	7.36	14.08	20.81	27.54	34.26
* From 1990 AASHTO "Green Book" Page 120, Table III-1. Stopping sight distance (wet pavements)														
Standee adjustment adds to stopping distance by:					25%									
Queue Discharge rate =		2	seconds per car											
Assumed Queue =		10	passenger car equivalents											

In Table 2 a queue of 10 cars has been added. This queue length has a significant impact to the advance notice time for each given detection distance. For a signal operating with a 90-second cycle length on an arterial with a 35 mile per hour operating speed the detection point should be well in excess of 4000 feet.

It is also significant, though not unexpected, to note that the detection distances needed to give the traffic signal sufficient time to adjust changes significantly with speed and traffic conditions. The zero queue situation would potentially occur infrequently and only during uncongested off peak periods. The case with a 10-car queue would only during relatively uncongested periods at many intersections. At many intersections queues longer than this may not cleared on a single cycle length.

When vehicle volumes get to this point where the queues are not cleared every cycle that the traffic signal priority effort turns to one of queue management. In advance of the arrival of the transit vehicle the signal could make a best effort under the limitations of the signal timings in effect to minimize the queue. Then, assuming that a form of continuous detection is used, the traffic signal controller could track the vehicle location within the queue. Based upon the vehicles' location and speed the traffic signal would also be able to collect the additional information on the length and movement of the standing queues.

Once the transit vehicles' location within the queue the traffic signal could attempt a strategy to get the bus either to the head or tail of a platoon. For near side stops it would be best to get the vehicle to the head of the queue so that the vehicle could load/unload passengers during the red time. For a far side stop the vehicle could be at the tail of the platoon so it could load/unload during the red and merge back in to traffic before the next platoon is discharged.

Conclusion

Implementation of a system to provide priority treatment to transit vehicles is a very complex effort. Hopefully this document provides some additional thoughts and topics for discussion as the process to develop a standard proceeds.