A Sophisticated Transit Signal Priority System – How it Works

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ABSTRACT:

In recent years, transit signal priority (TSP) systems have been implemented in order to increase transit schedule reliability and decrease transit travel time, thereby improving the transit system operations, and making transit an attractive alternative mode of transportation.

Active transit priority causes regular operation of traffic signals to be altered temporarily in response to the presence of a transit vehicle. Traffic signal control system strategies for active transit priority include: green extension, early phase activation (red truncation), lift strategy, special transit phase, TSP in the non-coordinated phase, and free mode TSP operation.

The application of active transit priority on a regular basis can be disruptive to competing traffic movements. For this reason, active priority for transit vehicles has been divided into two categories, namely unconditional or conditional. Generally, signal priority is unconditional if it is granted every time a transit vehicle is detected approaching a signalized intersection. Signal priority is conditional if only granted when additional conditions are met, such as schedule adherence, passenger load, etc.

Conditional active transit priority requires increased system sophistication in order to determine whether the additional conditions have been met prior to granting priority. A sophisticated TSP system includes three main components:

1. Transit Management System (TMS), which includes the Vehicle Logic Unit (VLU) on board the transit vehicle, and CAD/AVL and schedule and runcutting software;

2. Traffic Signal Control System, including central software and local controller; and

3. Transit vehicle detection system.

This paper will describe the development the state-of-the-art in terms of TSP systems, and present lessons-learned through the implementation of TSP in the Region of York, City of Mississauga, Halifax Regional Municipality and Region of Waterloo.

1 INTRODUCTION

The purpose of this paper is to describe the development of the state-of-the-art in terms of TSP systems, and present lessons-learned through the implementation of TSP in the Region of York, City of Mississauga, Halifax Regional Municipality, and Region of Waterloo.

2 TRANSIT SIGNAL PRIORITY

A TSP system may include three main components:

1. Transit Management System (TMS), which includes the Vehicle Logic Unit (VLU);

2. Traffic Signal Control System (TSCS), including central software and local controller, and;

3. Transit vehicle detection system.

Exhibit 1 provides an overview of a TSP system, which uses a centralized traffic signal control system. In a central traffic signal control system, the TSP routine is implemented by the central software, which also monitors TSP activities, archives TSP event logs, and stores TSP parameters. In contrast, in a distributed traffic signal control system, as presented in Exhibit 2, all TSP functionality resides in the local controller, with the central software acting as a database for TSP parameters, event logging, and monitoring purposes. The traffic signal control system architecture does not dictate the performance of the TSP. Rather the TSP performance is dictated by the TSP functionality offered by a particular vendor.

With respect to transit vehicle detection, two strategies may be employed, a local approach and a centralized approach. A distributed traffic signal approach cannot use a centralized approach to transit vehicle detection. This is a moot point since centralized transit vehicle detection is not common in the industry.

Exhibit 1: Overview of a TSP System (Centralized Traffic Signal Control)

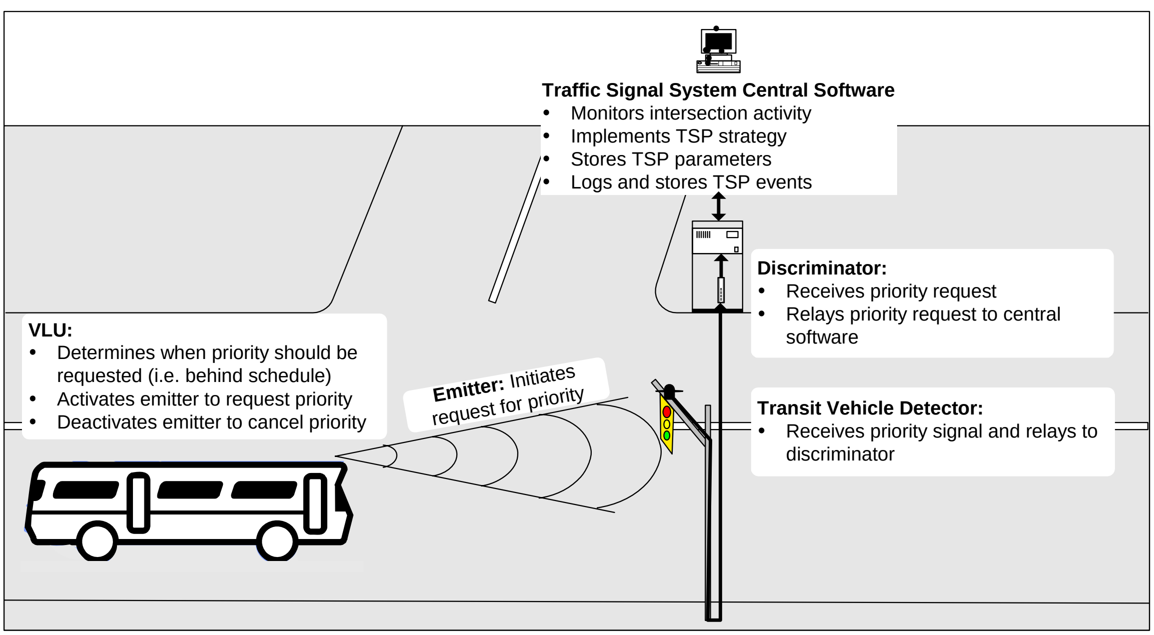
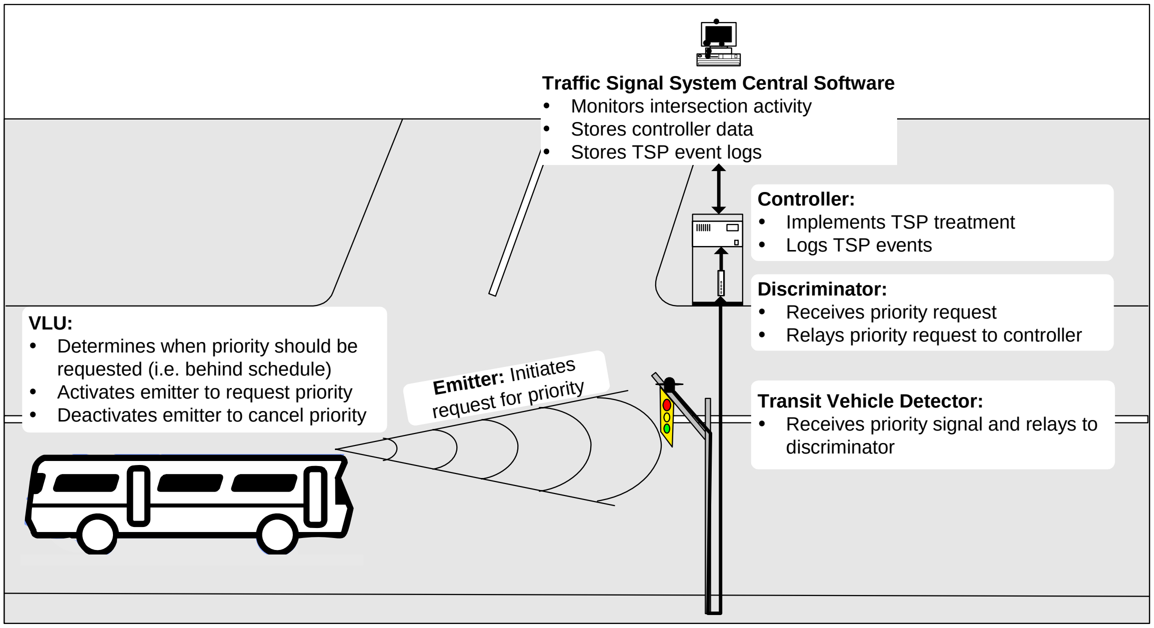


Exhibit 2: Overview of a TSP System (Distributed Traffic Signal Control)



TSP involves permanent (passive) or temporary (active) modifications to the operation of a traffic control signal in order to provide priority to transit vehicles at an intersection. These two techniques are described below.

Passive Transit Priority – is a low-tech transit signal priority solution that does not adjust the signal settings in response to the presence of a transit vehicle. Signal settings (i.e. offset and green split) are developed to favour transit vehicles by considering the operating characteristics of the transit vehicle. Geometric treatments such as bus stop relocation, taper length modifications, parking/stoppage restrictions, queue jump lanes, etc can also provide “passive’ priority to buses.

Passive transit priority strategies do not require monitoring and/or detection of transit vehicles, and can therefore be implemented anywhere – when warranted. This approach to transit priority produces consistent signal operation for vehicle traffic while increasing the efficiency of transit operations for the given traffic constraints. However, changes in regular signal timing plans can be of limited value because transit vehicles can still arrive during the red interval due to variations in travel time, while the priority based green phases can delay the cross-street vehicles regardless of the presence of a transit vehicle.

Active Transit Priority –Active transit priority causes regular operation of traffic signals to be altered temporarily in response to the presence of transit vehicle. A transit vehicle detection system is used to identify the transit vehicle in mixed traffic.

The application of active transit priority on a regular basis can be disruptive to competing traffic movements. For this reason, active priority for transit vehicles has been divided into two categories, namely unconditional or conditional. Generally,

- Signal priority is unconditional if it is granted every time a transit vehicle is detected approaching a signalized intersection;

- Signal priority is conditional if only granted when additional conditions are met, such as schedule adherence, passenger load, etc.

Conditional active transit priority requires increased system sophistication in order to determine whether the additional conditions have been met prior to granting priority.

3 TRANSIT SIGNAL PRIORITY CYCLE

In general, the TSP cycle includes the following three functions that use the transit vehicle detection system, in concert with the traffic signal control system (either local controller and/or central traffic signal control system), to progress the transit vehicle through the signalized intersection:

1. Check-In – The transit vehicle detector detects the transit vehicle and issues a request for priority to the traffic signal control system (i.e. central software or local controller).

2. TSP Sequence – A TSP timing sequence is implemented that may use a host of TSP strategies depending on the capabilities of the traffic signal control system and local controller. TSP strategies used may include: Green Extension, Early Phase Activation, Phase Rotation, Lift Strategy and Special Transit Phase, etc to progress the transit vehicle through the signalized intersection.

3. Check-Out - The transit vehicle detector issues a request to the traffic signal control system to cancel the TSP Sequence.

The following subsections describe the above functions in more detail.

3.1 Check-In/Check-Out

The use of the check-in and check-out function is predicated on the ability of the transit vehicle detection systems capability to perform this function. Approaches to transit detection vary, and are outlined is Section 4. The capability of the transit vehicle detection system can be enhanced through the use of the on-board Vehicle Logic Unit (VLU). The following provides a description of the VLU functionality used to enhance transit vehicle detection, and more specifically, the check-in/check-out functions.

The VLU monitors the progress of the transit vehicle along the routes, typically using a combination of GPS and dead reckoning (vehicle odometer). The VLU checks its progress against the route schedule. If off schedule (behind), by a determined threshold, the VLU automatically relays a TSP message to the transit vehicle emitter. The detector captures the signal and relays it via hard-wire to a processor. The processor then interprets the message for the traffic signal control system and requests the appropriate priority treatment (i.e. eastbound TSP on phase 2). The traffic signal control system is responsible for implementing the priority treatment. Once the transit vehicle clears the signalized intersection, the priority treatment is cancelled (e.g. check-out).

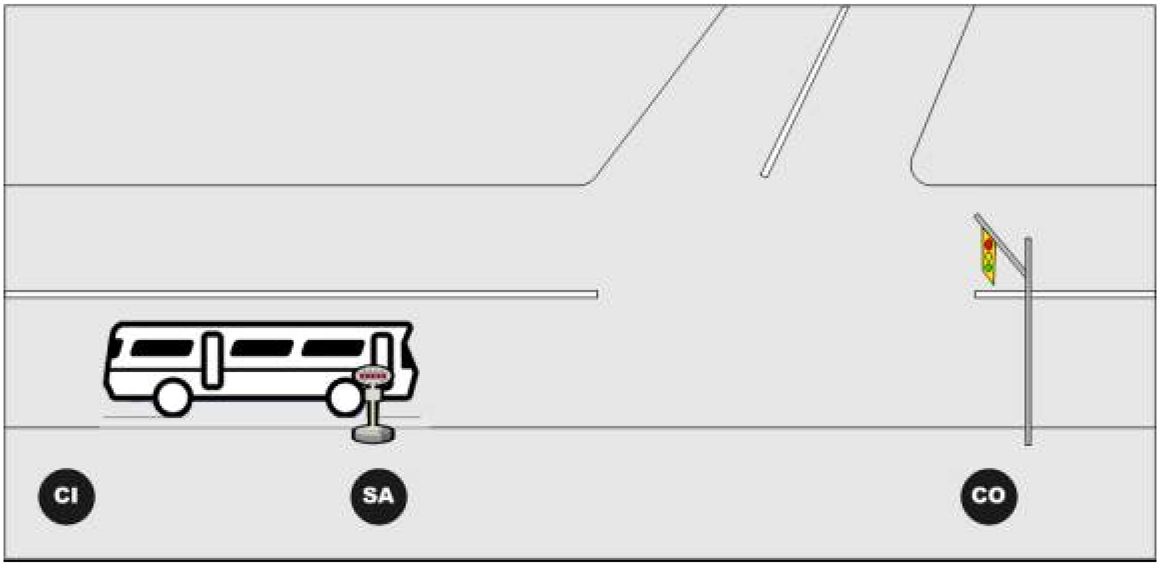
Within the VLU there are three TSP assignment points that can be coded per approach. These assignment points are presented in Exhibit 3 and includes:

- CI – Check-in is used to initiate the priority request, at intersections without transit stops on far side transit stops.

- SA – Stop assignment point may be used when the stop is a short distance to the signalized intersection (e.g. nearside stop). The VLU will activate the emitter to inform the traffic signal control unit that the transit vehicle is ready to depart when the doors are closed. The use of the stop assignment point is optional and is a function of the bus stop usage, dwell time characteristics, and the TSP logic in the traffic signal control system.

- CO – Clearing point, which is used to inform the traffic signal controller that the transit vehicle has successfully cleared the signalized intersection.

Exhibit 3: TSP Assignment Points



3.2 TSP Sequence

As a transit vehicle approaches a signalized intersection, Check-In occurs, which begins the TSP Sequence. There are many TSP Sequences that may be used, and are implemented on a site-specific application. The TSP Sequence functionality required for a specific application is driven by several factors including:

- Traffic signal control system architecture (distributed versus centralized);
- The TSP functionality offered by the traffic signal control system;
- The transit vehicle detection functionality;
- The VLU functionality;
- The position of the transit stop, nearside, farside, or upstream of the signalized intersection;
- The use of passive priority techniques such as queue-by-pass lanes.

In most applications the TSP sequence operates on a first-come, first-serve basis. TSP Sequences include: coordinated (maintain the main-street start of green offset and cycle length, or start main-street green early, but maintain the cycle length), free-mode operations (no offset or cycle length) and real-time control strategies. TSP Sequences include:

- Green Extension;
- Early Phase Activation;
- Lift Strategy;

- Special Transit Phase;
- Phase Rotation;
- TSP in the non-coordinated phase (phases 4 and 8); and
- Free Mode TSP operation.

The Real-Time Priority Strategies are not presented within this paper. Typically real-time control strategies may make use of the above TSP Sequence functions, which are implemented within the real-time traffic control environment.

The following provides a more detailed description of the above TSP sequences. It is important to note that the following provides a general description of the functionality. Specific vendors may use a slightly different approach to perform the functionality, offer enhancements to the functionality, or not perform the functionality at all. Exhibit 4 presents a coordinated TSP sequence where the basic pattern (i.e. cycle length, offset and phase splits) is not interrupted, since the transit vehicle Check-In and Check-Out occurs within the coordinated main street green phase (i.e. phase 2 and 6) and transit vehicle phase.

Exhibit 4 also presents the minimum duration, extensible portion and clearance duration for phases 1 through 8 for a typical NEMA 8-phase dual ring configuration. This basic exhibit will be used to depict the remaining coordinated active priority TSP Sequences.

Exhibit 4: No Modifications to Green Splits

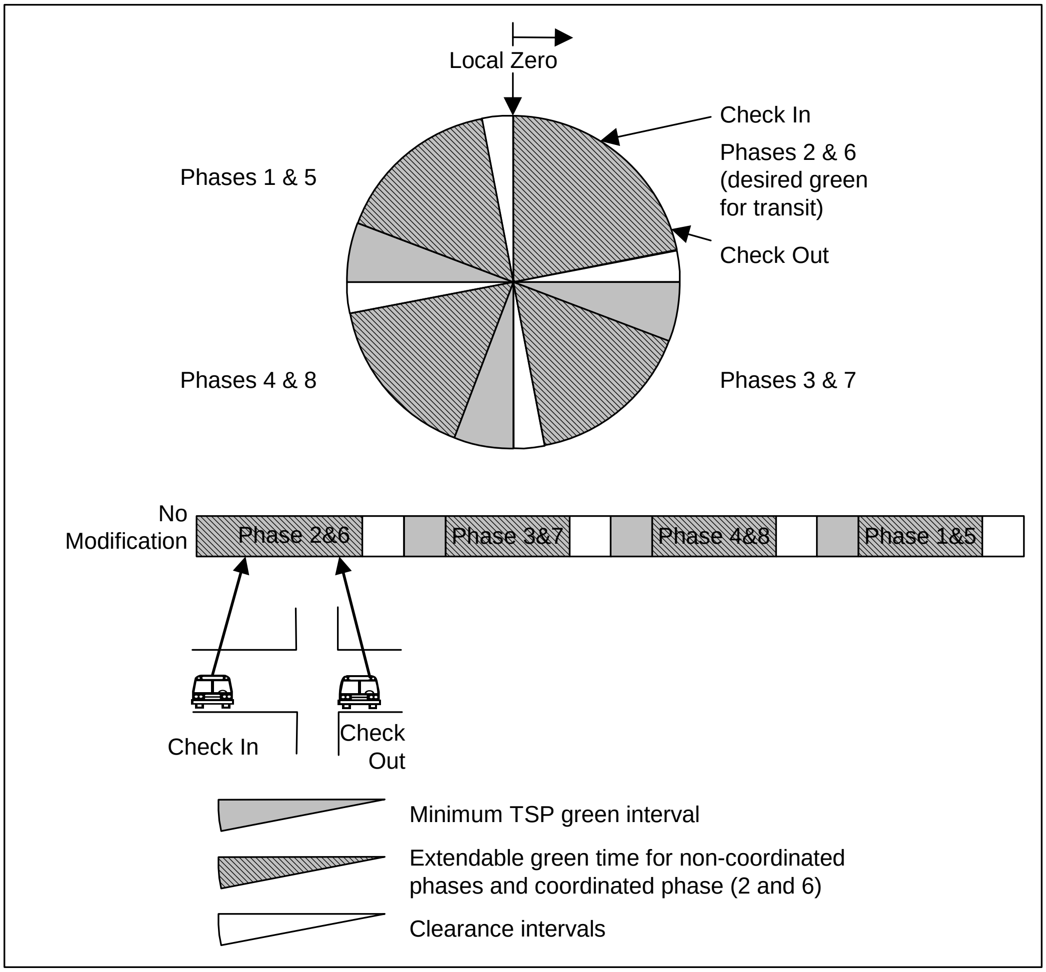
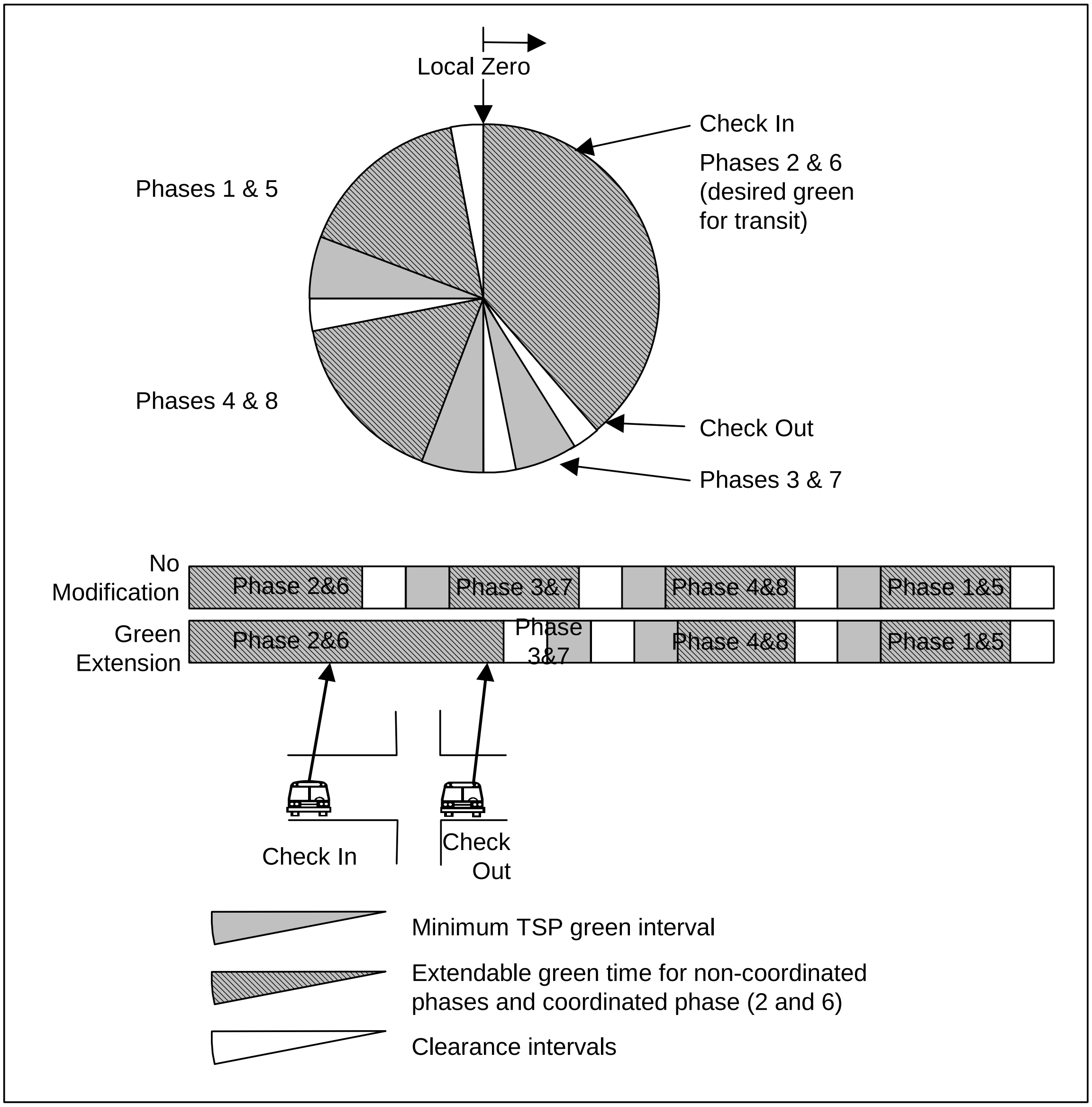


Exhibit 5 presents a green extension coordinated TSP sequence where the cycle length and offset are maintained, but the transit phase (phases 2 and 6) is extended to progress the transit vehicle through the signalized intersection. This is one of the more commonly used TSP sequences. Under the green extension coordinated TSP sequence, all non-transit phases must be serviced based on their minimum TSP green duration. The minimum TSP green duration is independent of the minimum green duration entered in the controller, but must be equal to or greater than the minimum green duration. As a result, the maximum permissible transit phase extension is the sum of the extensible portion of the non-transit phase minimum TSP green duration and clearance duration. Typically a maximum TSP sequence duration is programmed that will timeout the TSP sequence in order to service the non-transit phases within their programmed minimum TSP green durations. When the transit phase is extended less than its maximum permissible duration, time is removed from the following non-transit phases. Typically each successive phase operates at its minimum TSP green duration until the regular sequence is established.

Exhibit 5: Green Extension



An important consideration with the green extension sequence is the recovery from the TSP to reach the local zero. As presented in Exhibit 5, the maximum extensible time is removed from each phase following the transit phase until the extension time is made up. A more elegant recovery approach distributes a portion of the extensible time from all the remaining phases.

Exhibit 6 presents an early phase activation coordinated TSP sequence where the cycle length is maintained, but the transit phase for the current cycle starts early. This is one of the more commonly used TSP sequences. Under this scenario the non-transit green phases may be truncated to their minimum TSP green duration in order to return to the transit green phase as early as possible (not unlike a cycle with early termination of actuated phases). Once the transit vehicle is serviced, the transit green phase will terminate at its normal point in the cycle, and the following non-transit phases will be serviced according to there programmed split durations, returning into coordination in the following cycle.

Exhibit 6: Early Phase Activation

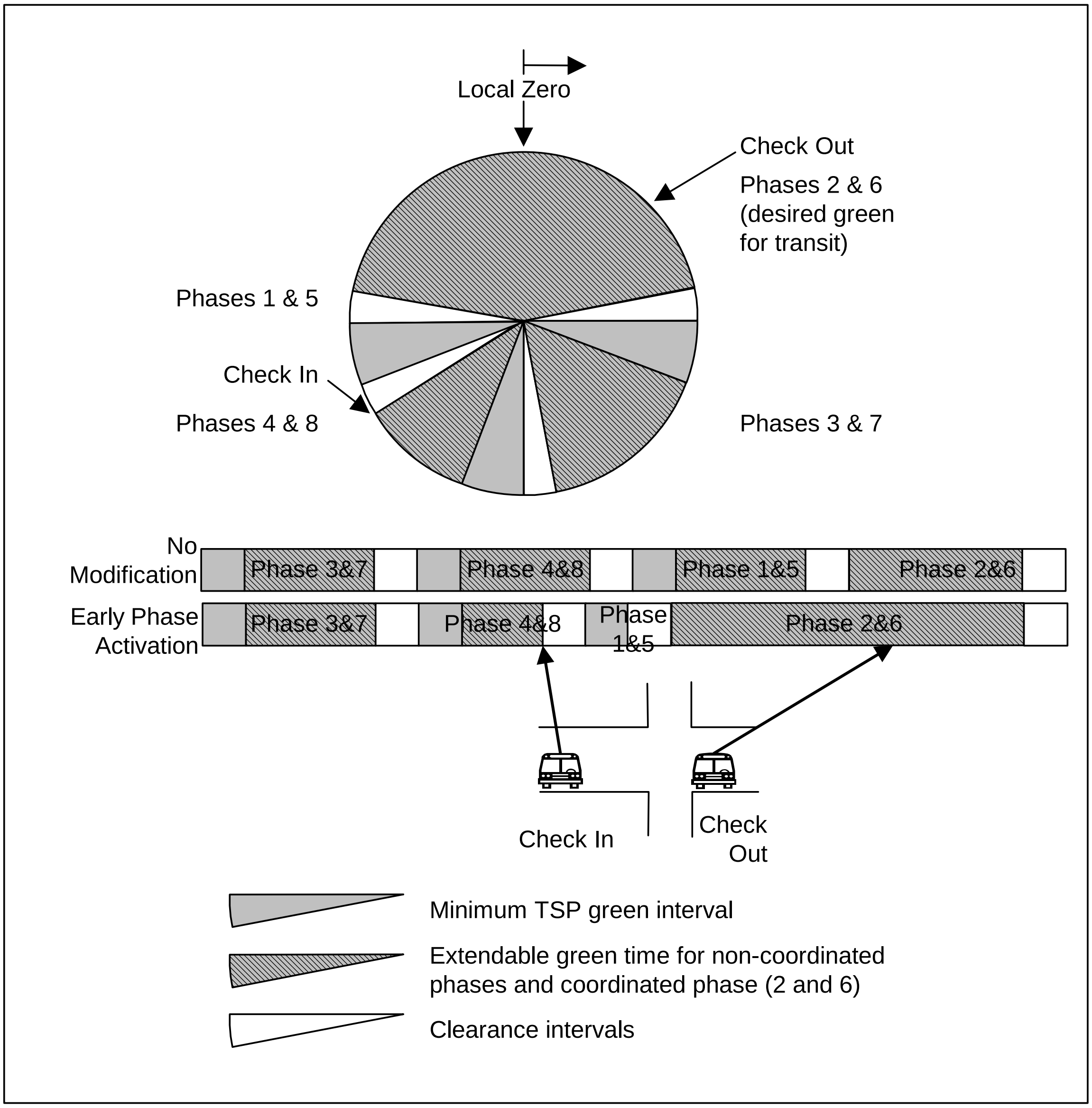
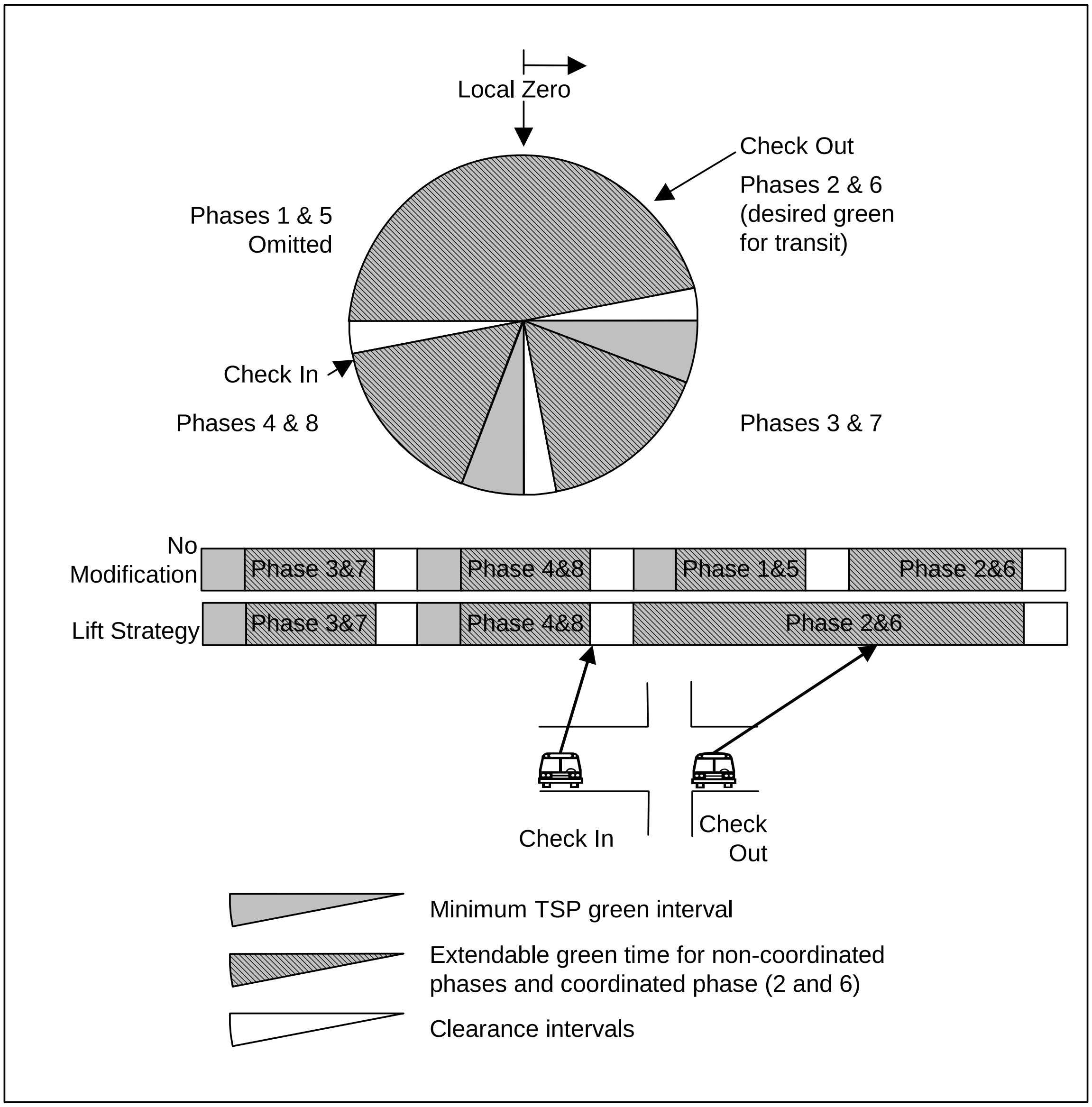


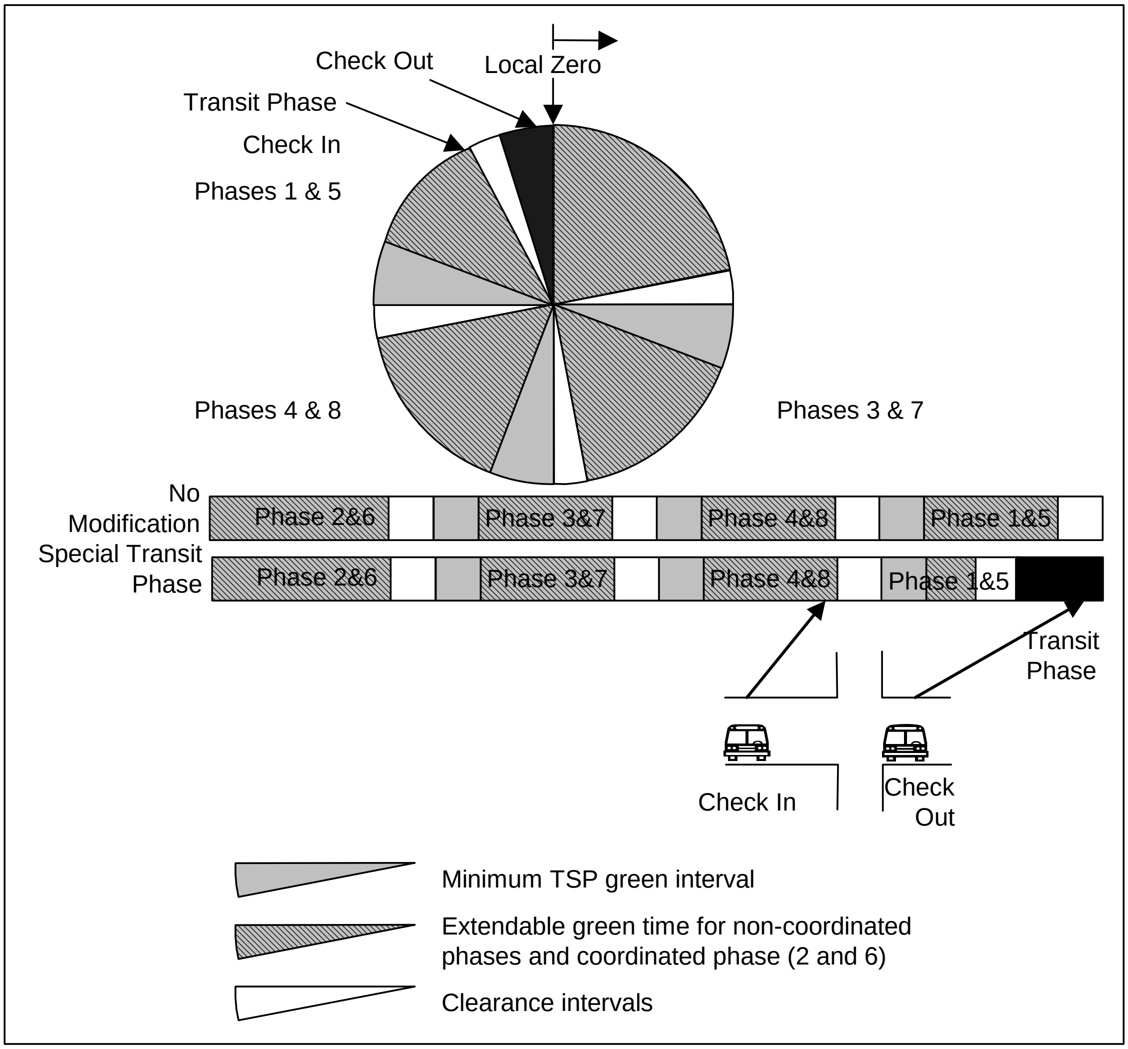
Exhibit 7 presents a lift strategy coordinated TSP sequence where the cycle length is maintained, but the transit phase for the current cycle starts early. Many practitioners do not consider a lift strategy to be a TSP Sequence, since it skips phases. In particular, the skipping of pedestrian phases should be avoided. As a result, vendors do not typically offer this feature as part of their TSP enhancements. Under this scenario selected non-critical phases are skipped in order to return to the transit green phase as early as possible. Once the transit vehicle is serviced, the transit green phase will terminate at its normal point in the cycle, and the following non-transit phases will be serviced according to their programmed split durations, returning into coordination in the following cycle.

Exhibit 7: Lift Strategy



The phase sequence presented in Exhibit 8 has a special transit phase inserted prior to the start of main street green to service the transit vehicle. This scenario may be used at locations with near-side transit stops, where it is advantageous to start the transit vehicle prior to the start of main-street green to avoid transit vehicle and general purpose vehicle merging conflicts.

Exhibit 8: Special Transit Phase



The phase sequence presented in Exhibit 9 has been altered to provide an earlier opportunity to progress the transit vehicle. In this scenario, the transit vehicle is processed through a protected advanced left turn movement that is typically a protected lagging phase (phase 1 & 5). These left turn phases are inserted into the lead position at the arrival of the transit vehicle to process the transit vehicle earlier.

Exhibit 9: Phase Rotation

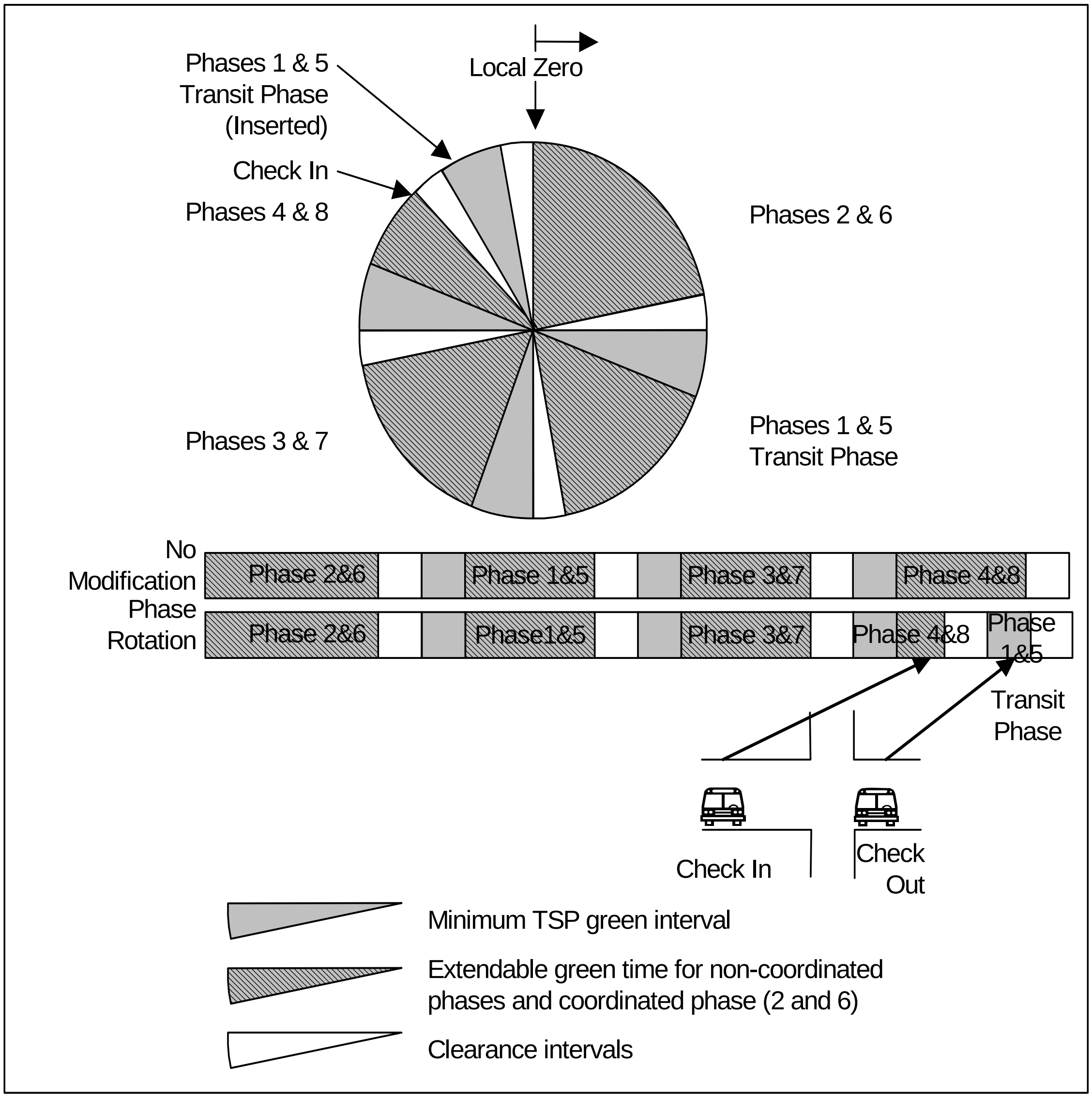
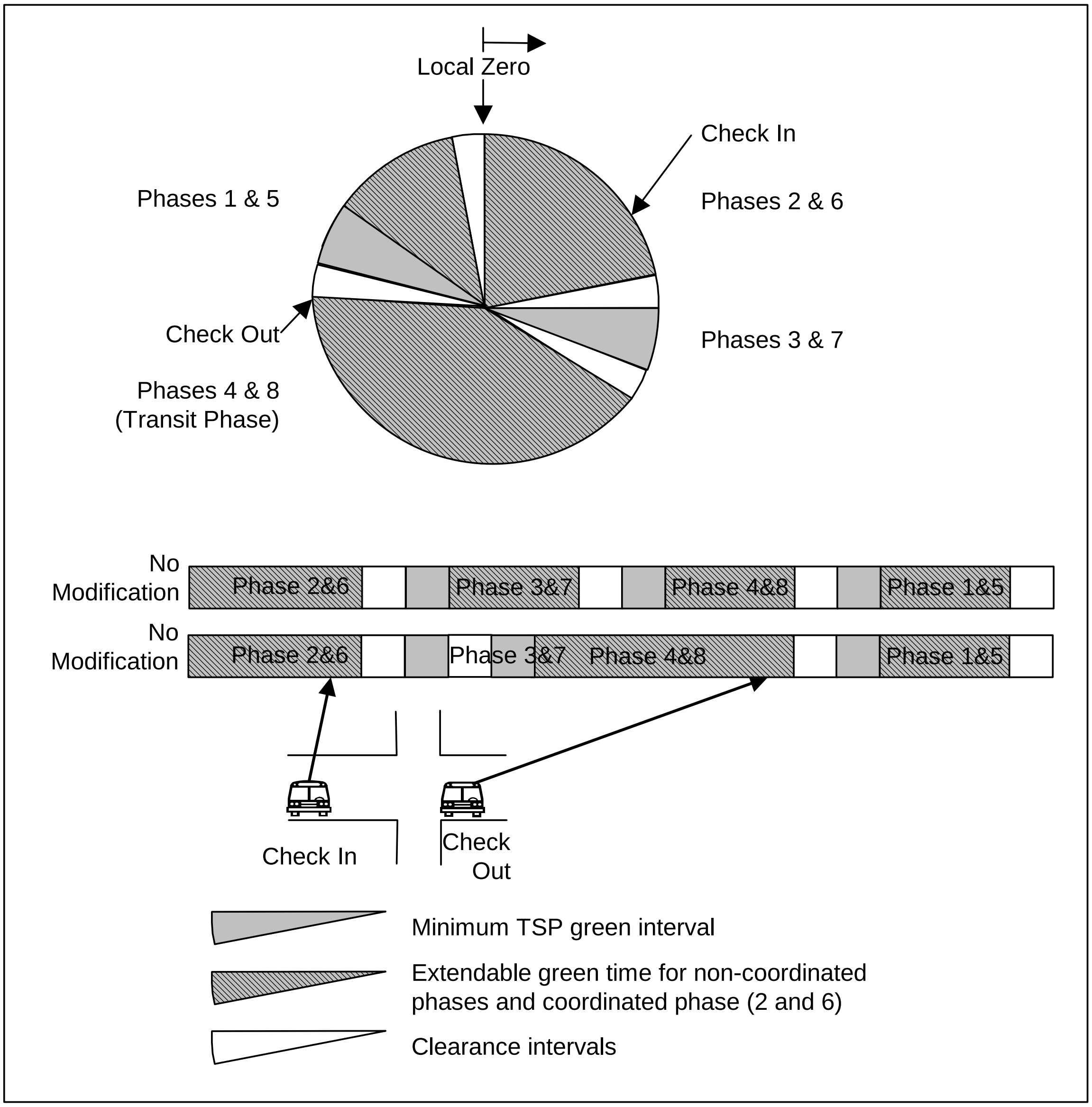


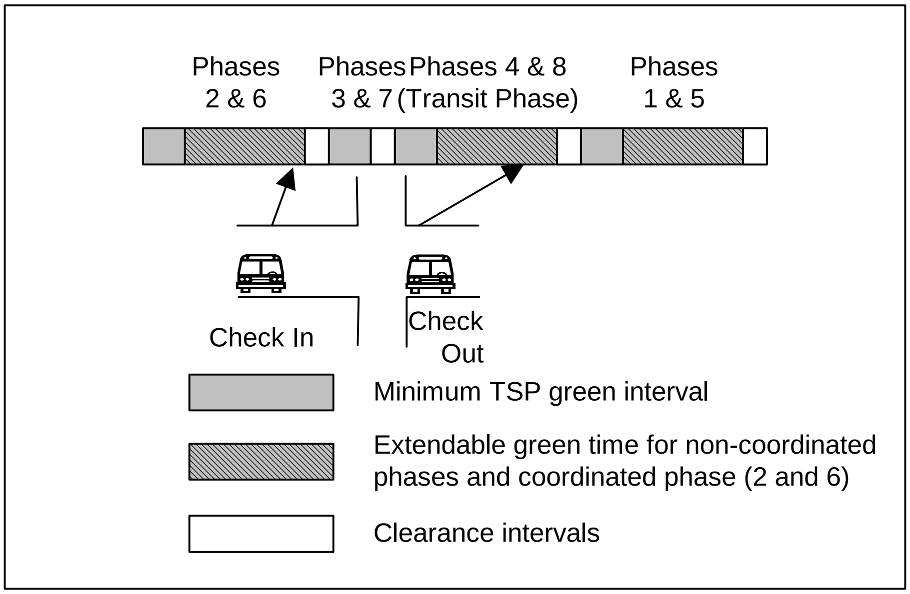
Exhibit 10 presents coordinated operations with TSP provided in the non-coordinated phases (phases 4 and 8). In this scenario, the non-transit phases are truncated to their minimum TSP green duration to provide an early activation of phase 4 and 8, when the transit vehicle arrives prior to the start of phases 4 and 8. Also, phase 4 and 8 may be extended to service the transit vehicle, but terminate with sufficient time to service a transit vehicle minimum green duration for phases 1 and 5, and return to main street green (2 and 6) at the desired offset.

Exhibit 10: Non-Coordinated Transit Phase



In Free Mode (uncoordinated operation) there is no set cycle length or offset. Exhibit 11 presents TSP operation during Free Mode, with a Check-In occurring in phase 2 and 6. In response to a TSP Check-In, the controller terminates phases 2 and 6 (after the TSP minimum green is serviced) and displays phase 3 and 7 for there TSP minimum green duration to quickly arrive at the transit phase, 4 and 8. Alternatively, non-critical phases may be omitted to progress to the transit phase more quickly, similar to the Lift Strategy approach presented in Exhibit 7. Also, the transit phase (4 and 8) may be extended to a pre-programmed maximum phase duration to ensure that the transit vehicle clears the signalized intersection, similar to the Green Extension strategy presented in Exhibit 5.

Exhibit 11: Free-Mode TSP



4 TRANSIT VEHICLE DETECTION

4.1 Transit Vehicle Detection Techniques

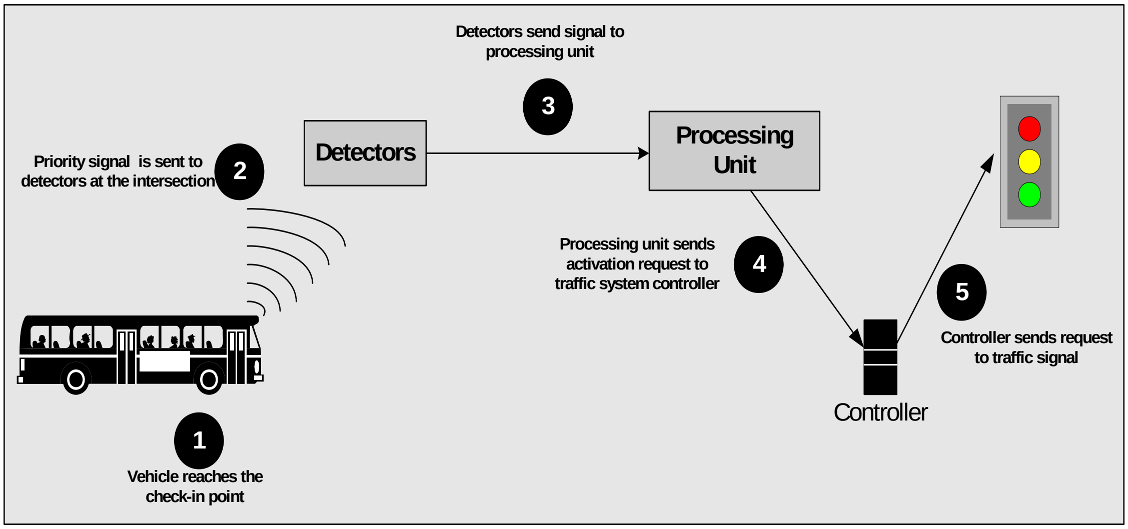
Two forms of transit detection options are available. The more common detection type is Local detection, which takes place entirely in the field. The other is the Central option, which utilizes the traffic management system to relay the request for priority to the traffic signal system.

4.1.1 LOCAL DETECTION SYSTEM

The local system approach uses on vehicle equipment (i.e. emitter, transponder, etc.) that interface with the Vehicle Logic Unit (VLU). In this approach, the VLU controls activation of the transit vehicle based on a predefined condition (i.e. schedule adherence). When these conditions are met, the on vehicle transit vehicle detection equipment communicates the request for priority to the roadside equipment. The request is then evaluated by the roadside equipment and the TSP request is sent to the signal system.

Exhibit 12 presents a high level description of the local detection option.

Exhibit 12: Local Detection Option

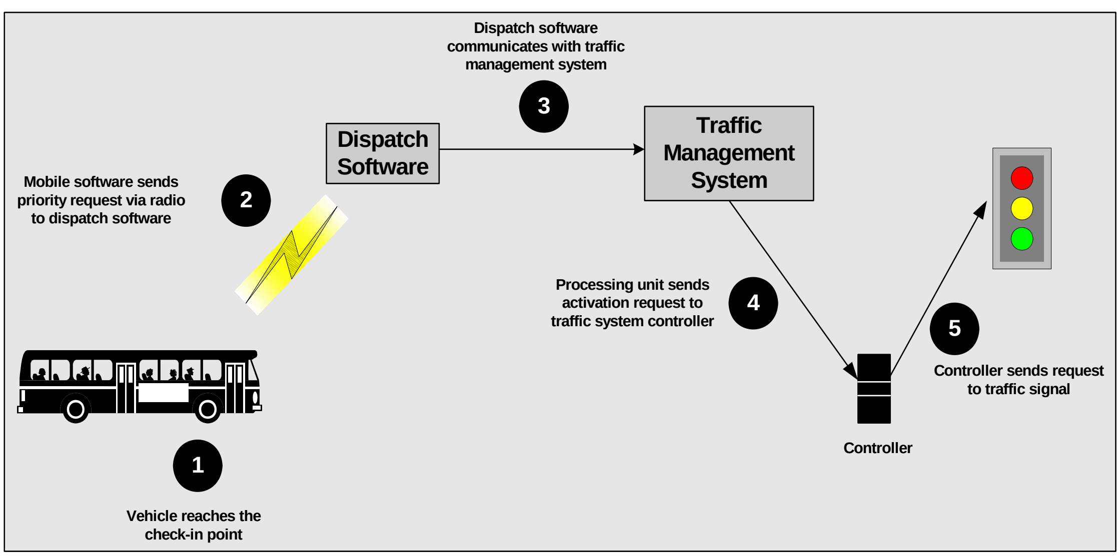


4.1.2 CENTRAL DETECTION SYSTEM

In the central detection system, the transit management system's CAD tracks the transit vehicle using GPS. The VLU sends the priority request to the dispatch center via wireless communication (i.e. RF radio, GPRS). The CAD converts the message into a protocol that can then be directly communicated with a traffic signal control system. The TSP request is then evaluated by the traffic signal system for approval, and an appropriate TSP strategy implemented.

Exhibit 13 presents a central detection system. One manufacturer capable of performing central transit vehicle detection is ILG Systems (Siemens). This approach requires the use of their CAD software and the SCOOT traffic adaptive signal control system.

Exhibit 13: Central Detection Option



5 LESSONS LEARNED

TSP systems can be used to achieve several objectives, such as maintaining a schedule, or reducing travel time. However, what is often misunderstood is that depending on how a sophisticated TSP system is used, the objective of maintaining a schedule can be in conflict with reducing travel time, and vice-versa. Conditional priority based on schedule adherence will not reduce overall travel time, if the schedule has sufficient slack time built-in to accommodate current operating delays. In a conditional TSP system based on schedule adherence, an assessment of TSP activity versus schedule must be made.

The cooperation between the transit agency and the traffic agency is required for successful TSP implementation. Each agency controls half of the system; the transit agencies system determines when to request priority, while the traffic agency determines when priority will be granted. Both agencies are required to fine-tune and maintain the system, since both agencies operate system components, and store TSP event logs.

The accuracy of the transit vehicle detection system is a function of the VLU and the specific detector technology used. In some instances the VLU can enhance the detection accuracy of the specific detection technology used.

The TSP recovery logic used in the traffic signal controller is the most important element of the TSP routine. The ability to distribute the impact of TSP over multiple phases can be of benefit.

The red truncation strategy and green truncation strategy are the most commonly implemented strategies. The green extension strategy can save the transit vehicle half of the signal cycle or more, depending on the cycle composition and green splits. The red truncation saves the transit vehicle only the duration of the truncated time, yet the red truncation and green extension strategy can cause the same disbenefit to mixed traffic.

The queue jump passive priority technique can provide significant travel time saving, but requires operator knowledge of when to use the queue jump (e.g. peak periods) and when to remain in mixed traffic (e.g. off-peak periods).

Provinces that do not have the “yield to bus” law may require the use of transit only signal displays in queue jump lanes.

The transit riders’ perception of TSP can be just as important as the true travel time saving.