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16. Abstract
In this project, researchers developed and field-tested an intelligent traffic control system for identifying and progressing platoons at isolated traffic signals on signalized arterials. The main focus of research are signals located downstream of other traffic signal. However, the system can also be installed at sites where an upstream signal does not exist but where platoons naturally form. This system uses advance detection to obtain real-time information about the presence and speeds of individual vehicles. Then, it uses an algorithm developed by researchers to identify if a platoon — of a user-specified size and density — is approaching the signal and estimates platoon arrival time at the stopbar. When the system identifies a platoon, it issues a low-priority preemption signal to progress the detected platoon. The duration of the initial preemption signal is based on estimated arrival and departure times for the smallest acceptable platoon. Then, the system switches to an extension mode and provides progression to any additional vehicles determined to be in the platoon. It accomplishes this by increasing preemption time until such time as no more vehicles are determined to be in the platoon or the max-timer expires. The system also ensures that the last progressed vehicle does not get trapped in its dilemma zone. This document describes research and development work conducted in this project.

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PLATOON IDENTIFICATION AND ACCOMMODATION SYSTEM FOR ISOLATED TRAFFIC SIGNALS ON ARTERIALS

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1. INTRODUCTION

BACKGROUND

Texas motorists often encounter urban/suburban signal-controlled intersections operating in isolated (semi- or fully-actuated) mode. Often, these intersections are located not too far from other signalized intersections. With properly programmed controllers, such intersections operate efficiently during the off-peak periods when light traffic arrives from upstream intersections, or when there is balanced demand at all approaches. However, many such intersections operate poorly during peak periods when detectable platoons begin to arrive from the upstream signal(s). Figures 1, 2, and 3 illustrate these inefficiencies and underscore their causes and effects. In these figures, the upstream signal is shown at the left, and the isolated signal in question is located east of that intersection. Furthermore, the main-street (eastbound direction) demand is assumed to be significantly higher than the cross-street demand at the isolated signal.

Figure 1 illustrates the case when the through phase at the isolated signal gaps out in the presence of a single vehicle at the northbound approach to the isolated signal and begins to terminate (signal indication changes to yellow) as the platoon from the upstream signal is about to arrive. Figure 2 further illustrates that, as the signal serves this one vehicle, the platoon is forced to stop, incurring significant delay to these vehicles. Figure 3 illustrates the case when a portion of the main-street platoon still remains to be served when the signal phase reaches its programmed maximum (Max) time.
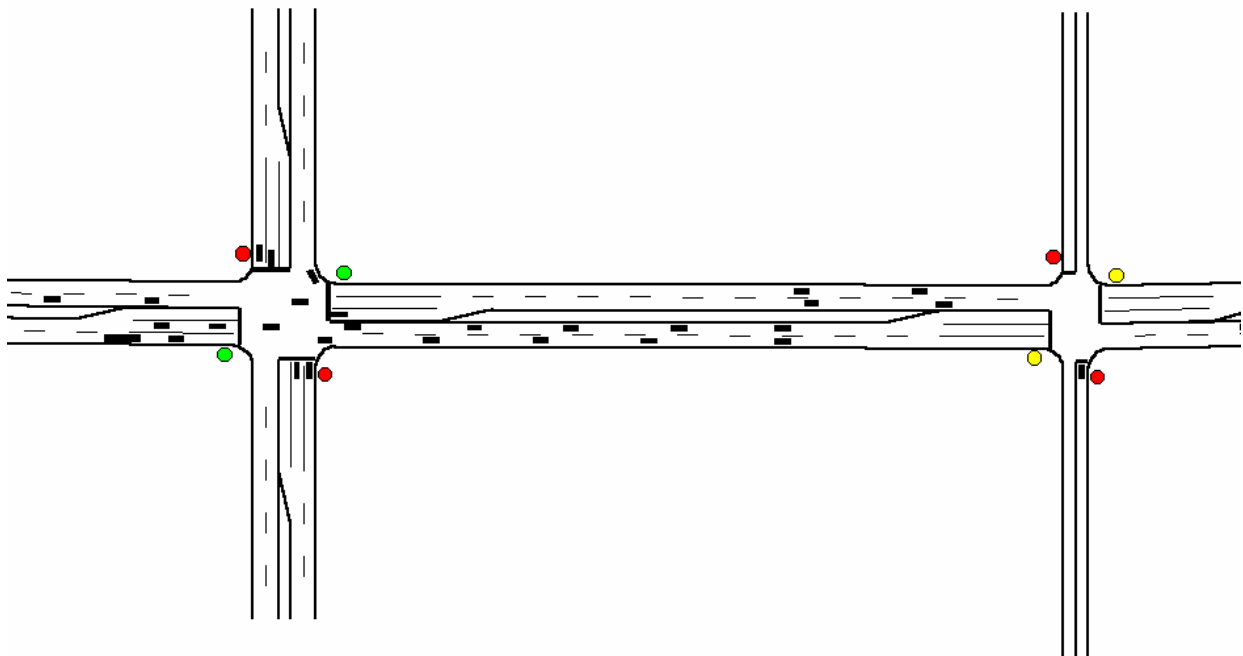
Figure 1. Green Phase Gaps Out as Platoon Approaches the Isolated Signals.
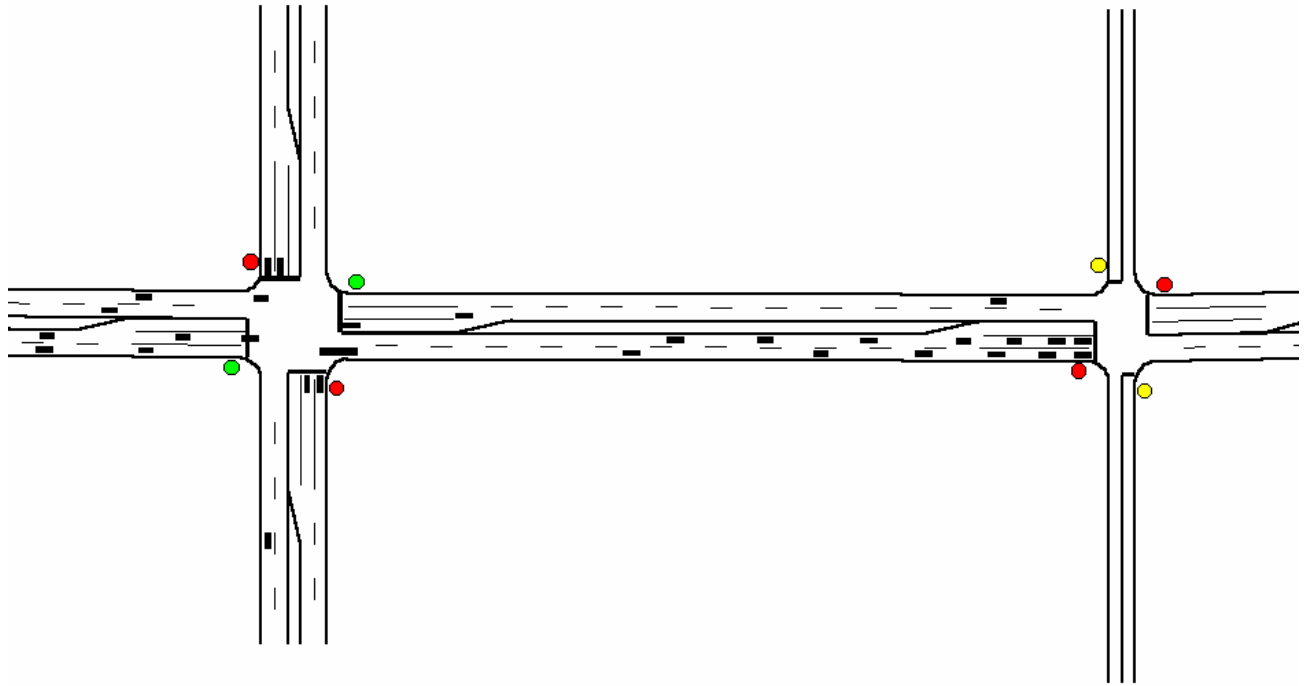
Figure 2. Platoon Forced to Stop.
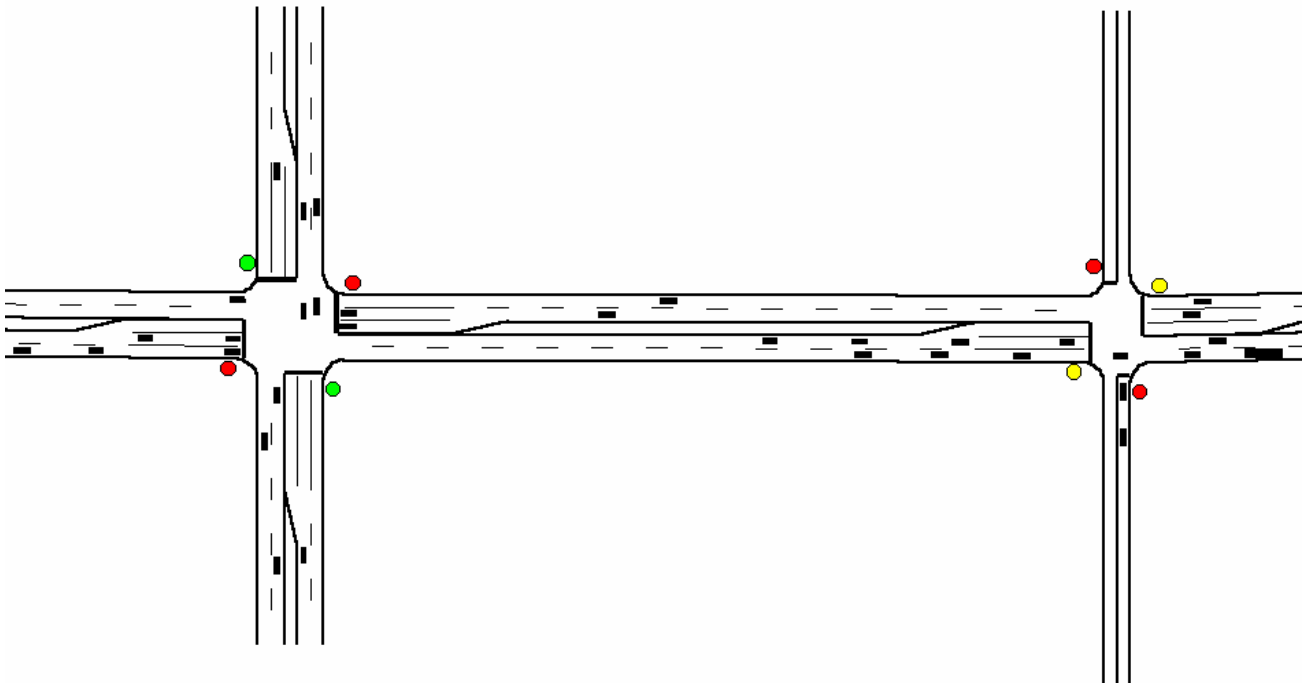
Figure 3. Phase Maxes-Out before Serving All Vehicles in the Queue.

There are two reasons for the inefficiencies illustrated in the figures. The first is the inability of local detectors, installed within 500-600 feet of the stopbar for providing actuated control and dilemma-zone protection, to recognize an approaching platoon and the inability of these detectors to assign priority to approaches with significantly different demands. The second is non-optimum maximum phase times programmed by the user. These inefficiencies can be removed by using detectors installed at a significant distance upstream of such approaches and by using real-time data from these detectors to identify platoons of vehicles and manipulate the controller parameters to progress or accommodate these platoons. Such an intelligent real-time control has the potential to minimize driver aggravation and reduce stops, delay, fuel consumption, and excessive pavement wear and tear.

The Texas Department of Transportation (TxDOT) operates many such intersections located on state routes and farm roads going through small towns. TxDOT desires to improve signal operations at these intersections to minimize the above-mentioned inefficiencies and resulting adverse effects of standard isolated control. At many of these intersections, interconnecting traffic signals to provide coordination for through traffic is not a feasible approach because of unpredictable fluctuations in traffic demand. A better approach is to keep isolated control at these signals, but to provide for dynamic coordination when a need arises.

RESEARCH OBJECTIVES

TxDOT initiated this two-year project to develop an intelligent traffic control system that is capable of:

- platoon detection on a specified priority approach,
- demand detection on conflicting phases, and
- controller manipulation to accommodate the detected platoon without unduly taxing vehicles on the conflicting phases.

Additional objectives of this research project were to use an architecture that provides for implementation by retrofitting existing controllers/cabinets and to install and test the developed system at two selected sites in Texas.

SYSTEM APPLICATIONS

This report describes work conducted by Texas Transportation Institute (TTI) researchers in this project to develop and install a platoon identification and accommodation (PIA) system. The PIA system is useful for signals that face the following traffic conditions during significant parts of a normal day:

- A significant number of platoons of vehicles arrive at one of the main approaches.
- There is light demand for movements being serviced by phases conflicting with the main-street phase.
- The traffic signal faces varying and unpredictable demand levels during a normal day.

A candidate approach for providing priority treatment to platoons of through vehicles may belong to one of the following two categories:

- The signal approach receives traffic from an upstream signal, but it is not interconnected to the upstream signal to provide coordinated operation.
- There is no signal upstream of the signal approach, but platoons form naturally due to vehicles slowing down as they approach the intersection.

HOW PIA WORKS

The PIA system consists of hardware and software that perform the following functions using a detector trap installed a certain distance upstream (in advance) of the stopbar:

- detect the presence of a platoon of vehicles;
- measure speed of each vehicle and calculate estimated platoon arrival time at the stopbar;
- when appropriate, override normal controller operation to progress the platoon; and
- provide dilemma-zone protection to vehicles at the back end of the platoon.

ORGANIZATION OF THIS REPORT

This report is organized as described below:

- Chapter 2 analyzes project requirements and provides a summary of literature reviewed.
- Chapter 3 describes the development of PIA algorithm and software and in-lab testing of the software.
- Chapter 4 describes the complete PIA system and comprehensive testing of this system.
- Chapter 5 describes field implementation and testing at two sites.
- Chapter 6 provides guidelines for installing and operating the system and offers future recommendations.
- Appendix A provides detailed descriptions of various screens in the PIA software.
- Appendix B provides information for wiring a digital input/output card to the back panel.

2. REQUIREMENT ANALYSIS AND TECHNOLOGY REVIEW

RESEARCH NEEDS

This project required the development of a platoon-detection algorithm. Furthermore, it required identification and comparison of various methods of manipulating modern controllers and field-testing of the most promising implementation method. The need for near-term implementation of project results implied that emphasis be placed on algorithms/methods that are flexible and that can be implemented by retrofitting existing controllers.

The request for proposal (RFP) from TxDOT recognized that the platoon identification and accommodation system will require data from detectors installed at a sufficient distance upstream of the intersection to provide sufficient time to process the data and for controller manipulation in advance of platoon arrival at the stopbar. The RFP also suggested that one detector per lane may be sufficient for this purpose. In this chapter, we discuss these issues and provide a review of existing technology in related areas.

ANALYSIS OF PLATOON DETECTION PROCESS

From the onset of this project, researchers held the view that advance detection should utilize a speed trap consisting of a pair of detectors per lane because a trap produces better estimates of vehicular speeds than a single detector. The most important issue, however, is the optimal location of such detectors. We will address this issue next. Figure 4 illustrates various variables and constraints that need to be incorporated to determine the optimal placement of upstream or advance detector(s). The lower part of this figure illustrates a moving platoon in time and space. The list of constraints and requirements include, but are not limited to, the following:

- For all practical purposes, distance of upstream detector from controller/computer cabinet has an upper limit of about 1500 ft for hard-wired connections. Radio-based (wireless) communications may be needed for longer distances.

- The detector must be far upstream to ensure that its operation is not affected by any queue at the downstream approach. This consideration will also ensure that the number of vehicles counted by the detector is an accurate estimate of demand.

- A certain number of vehicles must pass over the detector within a specified time window before the detection algorithm can classify these vehicles as a platoon. By this time, the front end of the platoon may have dispersed and moved closer to the downstream intersection (rather, closer to the back of any queue at the downstream signal), and there may not be sufficient time available to manipulate the controller to serve this platoon without stopping it. Thus, the detector must be a significant distance upstream of the signal to provide sufficient time for detecting a platoon, the time needed to take action (that is, to manipulate controller operation at the downstream signal), and the time needed to clear a queue from the previous cycle. How much time is sufficient depends on the following factors:

Advance Detector

Location of Lead
Vehicle when Platoon
Detected

Platoon Dispersion

Lead Vehicle's
Distance to Signal

Limit for Hard-wired Communication

Upstream Signal

Isolated Signal

Cabinet

Time

Trajectory of
Last Vehicle in
Platoon

Lead Vehicle's
Trajectory

Time Platoon
Detected

Location of Lead
Vehicles when
Platoon Detected

Time to
Manipulate
Controller

Time Lead
Vehicle Passes
over Detector

Distance

Figure 4. Constraints and Requirements on the Placement of Upstream Loop Detector.

- minimum number of vehicles that constitute a platoon,
- platoon speed,
- platoon dispersion,
- locations of lead and trail vehicles in a platoon,
- the state of the controller when platoon detected, and
- the method used to manipulate the controller.

An ideal platoon detection algorithm developed in this project should take into account all of these variables. In addition, the platoon detection algorithm must minimize the probability of Type I and Type II errors. In this context, a Type I error would be failing to detect a platoon, and a Type II error would be detecting a platoon when one does not exist.

Before proceeding, researchers conducted detailed reviews of literature and controllers used in Texas to identify any useful technology already available for use in this project. The next two sections provide the results of this review and a discussion of methods of controller manipulation.

LITERATURE REVIEW

The following is a chronological summary of the literature review conducted by researchers:

- In 1969, Robertson developed a platoon dispersion model for the TRANSYT program (1). Over the years, this model gained wide popularity due the adaptation of TRANSYT by FHWA and its subsequent popularity in the U.S. Robertson's platoon dispersion model assumes that dispersion is dependent on external friction and can be calibrated to represent various conditions.
- In a 1977 paper, Lin et al. described how to model platoon characteristics (2). Topics discussed included platoon width, platoon splitting, and platoon movement at an intersection with two-way flow and left-turn lanes.
- In 1978, El-Reedy and Ashworth proposed a modification to the Robertson model (3).
- In 1979, Baras et al. proposed a statistical model of urban traffic headway statistics (4). This model uses detector data to predict platoon size and passage time.
- In 1980, Michalopoulos and Pisharody developed equations for studying the dynamics of platoons at signalized links (5). Their key contribution of this research was to mathematically model platoon dispersion as well as platoon compression.
- In 1980, Baras et al. developed and tested several algorithms for estimating platoon size and passage time based on detector data (6).
- In 1983, Smelt conducted field studies to investigate platoon dispersion on a divided signalized link (7).
- In 1983, Tan conducted field studies in Australia to investigate the dispersion of platoons released from an upstream signal (8).
- In 1985, Castle et al. studied the behavior of platoons on high-standard arterials (9). They concluded that platoons remained together for distances up to 2000 meters. Their research also showed that optimal timing of downstream signals to accommodate such platoons results in up to 10 percent reduction in delay.

- In 1988, Baass et al. hypothesized that platoon dispersion depends not only on external friction but also on internal friction between vehicles in a platoon (10).
- In 1989, Denny published a review of platoon dispersion models and suggested the use of analytical and empirical data to predict platoon dispersion (11).
- In 1991, Saito examined the possibility of developing a refined model for use in TRANSYT (12). This work was based on field studies conducted by the author.
- A 1995 paper by Dell'Olmo and Mirchandani describes a real-time program that first identifies a platoon and then predicts its movement in the signalized network (13).
- In 1996, Manar and Baass demonstrated that platoon dispersion depends on both external and internal friction (14). Their work shows that the platoons disperse with an increase in volume and density until dispersion reaches its maximum value. Platoons start compressing when volumes increase beyond that point. The authors also developed mathematical models to capture these characteristics.
- In a 1996 paper, Yokota et al. demonstrated the use of a single detector to estimate vehicle type and speed (15). Their algorithm uses pulse data from a phase-locked loop.
- In 1999, Yu demonstrated that platoon dispersion depends on link travel time and proposed a methodology to calibrate the dispersion model in TRANSYT (16). This work was a follow-up of research reported by Yu and Benekohal in 1997 (17).

CONTROLLER MANIPULATION

As mentioned previously, the ability to effectively manipulate the controller is essential in accommodating a detected platoon. The signal controller can be in either one of two primary states at the estimated time of platoon arrival. The first state is when the primary phase, one that serves vehicles (platoon) arriving from the upstream signal, is green. If so, the primary phase can be made to stay green by placing a hold on the phase for a specified time period. The specified time would be dependent on the estimated platoon size. The second state exists when either the primary phase has begun terminating (that is, has a yellow indication) or is already red and a conflicting movement is being (or about to be) served. In this case, the current/next conflicting phase can be forced off after providing a minimum green time. Furthermore, any additional conflicting phases with existing demand could be either skipped or served for the lengths of their respective minimum times. Conceptually, skipping a selected set of conflicting phases would require removing any calls on associated detectors and placing a call on the priority phase. In this scheme, once activated, the main-street phase needs to be held green until the platoon has been serviced. This may require holding the green beyond the expiration of the associated Max timer. This conceptual method can be easily implemented in a simulated environment, but may be difficult in the field. The reason is that most modern traffic controllers do not permit direct manipulation of the Max timer value. Rather, these controller have features to dynamically change the max timer setting within a pre-specified range (defined by Max1 and Max2 settings) when the controller is operating under volume/density control. However, this change occurs in specified steps and over several cycles. One method of implementing this strategy would be to download a revised Max2 parameter through the serial port followed by the activation of Max2 through an external device. Using such a device, this result may be achieved through the back panel or by grounding a pin on the ABC connector.

A simpler method, however, is to externally (through the back panel) apply a hold on the main-street phase for as long as needed. TTI researchers have used this feature in several recent projects dealing with dilemma-zone protection on high-speed approaches (18, 19, 20, 21). However, the use of phase-hold limits the system to work only when the priority phase is green. Thus, there was a need for a flexible method. Use of low-priority preemption for this purpose is one such method.

The literature review revealed two instances of the use of low-priority signal preemption for accommodating platoons of vehicles arriving from an upstream signalized intersection to an intersection under isolated signal control. The first reference is a recent report prepared by researchers at Purdue University (22) for Indiana Department of Transportation. This report describes the development and field verification of platoon and demand detection algorithms. Furthermore, the report describes test results showing the performance of these algorithms together with low-priority signal preemption to provide priority to a platoon of vehicles approaching an intersection under isolated signal control. These tests were conducted in a laboratory setting using a hardware-in-loop simulation setup consisting of a simulation program and an Econolite TS-1 controller. Based on the success of laboratory tests, the authors had recommended field implementation and testing. According to this reference, this method of accommodating platoons has several advantages including flexibility to handle multiple approaches and low cost of implementation. The second reference describes a system that is already in place in Farmington, New Mexico (23). This system, however, does not detect platoons. Rather, it detects the onset of green at the upstream signal and uses an external device to transmit a delayed, low-priority signal to the downstream signal. The delay is based on predetermined travel time. This system works well when there is low demand on conflicting phases, especially the left-turn phase opposing the priority phase. In concept, this system is similar to the Dynamic Arterial-Responsive Traffic System (DARTS) deployed by TxDOT several decades ago (24).

Based on this analysis, researchers selected low-priority preemption for use in this project. Modern NEMA controllers used in Texas provide several low-priority preempts. In these controllers, a low priority preempt can be activated by using an external device that generates and transmits a pulsating signal of specified frequency to the controller.

3. PLATOON IDENTIFICATION AND ACCOMMODATION

BACKGROUND

Providing platoon progression at a selected signal approach requires the ability to detect each approaching platoon and manipulating the controller to ensure that the signal is green when the first vehicle in the platoon arrives at the stopbar. This requirement translates into the need to install an advance detector trap. Furthermore, the signal may be serving a conflicting phase at the estimated platoon arrival time. Any such phase must be quickly, but safely, terminated to provide a green signal to progress the detected platoon. As stated earlier, we decided to use low-priority signal preemption to achieve this objective. An additional objective was to ensure that the system is able to operate under a wide variety of traffic conditions without adversely affecting vehicles at conflicting phases. Achieving this objective required the ability to monitor phase and detector status in real-time and take appropriate action.

SYSTEM ARCHITECTURE

The requirement that the system developed in this project should be able to work with existing controller cabinets required that it consist of additional hardware and software for providing an interface with the existing cabinet. Figure 5 illustrates the architecture and components of the PIA system developed in this project.
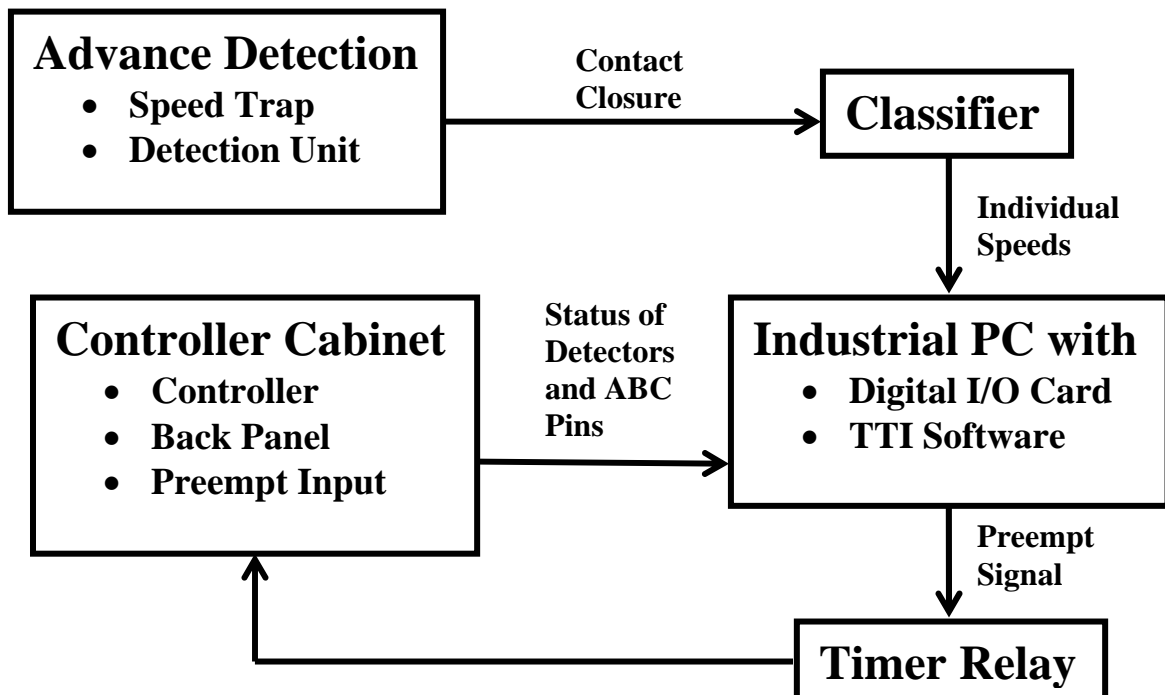
Figure 5. Architecture of PIA System.

The components of this system include:

- advance detection provided using one speed trap per lane on the priority approach,
- a hardware classifier,
- an external personal computer (PC),
- a timer relay,
- back panel in the cabinet for providing an interface between the cabinet and external hardware, and
- a connection panel.

The detection system includes advance detectors, a communication infrastructure, and a detection unit. Advance detectors can use inductive loops or video cameras. Communication can be provided through a hard-wired connection or wireless system. The detection unit consists of loop amplifiers for inductive loops or a video detection unit for video detection. The PC provides additional computational needs including platoon detection and interface with the cabinet. A digital input/output (I/O) card installed in the PC provides this interface. The PC should be field-hardened to withstand extreme temperatures inside a controller cabinet. The time relay provides a fail-safe operation. The function of this relay is to terminate preemption if its duration exceeds a user-specified setting. The connector panel provides for clean and standardized wiring between the PC and the back panel. For TS-2 cabinets, a breakout panel must be installed for providing access to controller status information through bus interface units (BIUs) in the cabinet.

PLATOON IDENTIFICATION PROCESS

Algorithm Development

The first step was to develop a flexible algorithm with configurable parameters for use under a wide variety of traffic conditions, intersections geometry/characteristics, and control. The platoon identification and progression algorithm developed by researchers in this project is based on these considerations. Figure 6 provides a flowchart of this algorithm. As shown in this flowchart, the algorithm uses real-time data from the classifier (connect to advance detectors) and the controller cabinet. These data are:

- Real-time data from the classifier includes detection times and speeds of individual vehicles as they go over the speed trap, and
- Data from the controller cabinet includes the status of stopbar detectors and the status of A, B, and C (ABC) pins for each ring in the controller. The algorithm uses the latter data for assessing the status of phases.

The algorithm uses the first set of data for platoon identification and for scheduling low-priority preemption. It uses the detector and phase status data combined with user selections to constrain the algorithm from issuing a preemption signal under a specified set of circumstances. The algorithm operates in several different modes. The following subsections provide descriptions of these modes.

```
                    ┌─────────┐
                    │  Start  │
                    └─────────┘
                         │
                         ▼
                    ┌─────────┐
                    │Initialize│
                    └─────────┘
                         │                                    ┌──────────────┐
                         │              Detection Time +     │  Real-Time   │
                         ▼              Individual Speed      │  Data from   │
              ┌─────────────────┐◄──────────────────────────│  Classifier  │
              │ Initial Platoon │                            └──────────────┘
              │ Identification  │
              │     Stage       │            ┌──────────────┐
              ├─────────────────┤            │  Preemption  │              ┌──────────────┐
              │    Platoon?     │            │  Scheduler   │              │              │
              └─────────────────┘            ├──────────────┤              │              │
          No         │    Yes    ───────────►│   Initial    │────────────► │  Controller  │
                     │           Yes         │   Schedule   │              │   Cabinet    │
                     │ Yes                   ├──────────────┤              │              │
                     ▼                  ┌───►│    Extend     │              │              │
              ┌─────────────────┐       │    │  Preemption   │              └──────────────┘
              │     Platoon     │       │    ├──────────────┤
              │    Extension    │   Yes │    │     End      │
              │     Stage       │       │    │  Preemption  │
              ├─────────────────┤       │    └──────────────┘
              │    Extension    │───────┘           │
         Yes  │  Criteria Met?  │                   ▼
              └─────────────────┘         ┌──────────────────┐     Real-Time Phase +
                                          │  User-Specified  │     Detector Status
                                          │    Conflicting   │◄──────────────────────
                                          │  Phases Served?  │
                                          └──────────────────┘
                                                            No
```
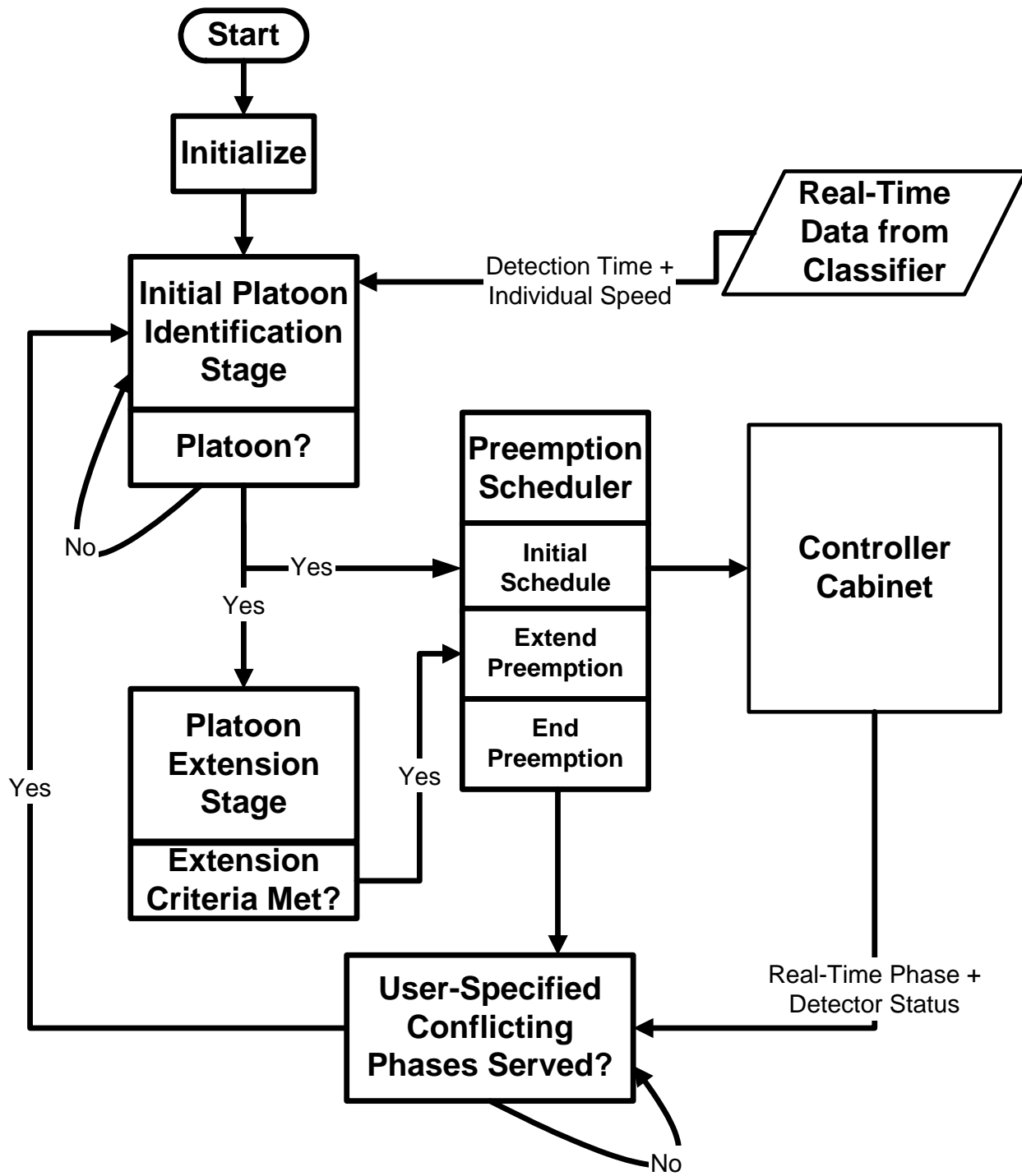
Figure 6. Logic of Platoon Detection Algorithm.

Initial Platoon Identification

This portion of the algorithm uses several parameters for initial platoon identification. These parameters are:

- number of vehicles in the platoon (n),
- advance detector distance from the stopbar (D),
- difference between the estimated arrival times of the first and the last vehicles in the group of last n vehicles (d) passing over the advance detector,
- cumulative headway threshold (T_c) specified by the user, and
- preemption advance (P_a).

Number of vehicles in a platoon (n) is a user-specified parameter that defines the smallest group of vehicles that can be classified as a platoon if it meets the T_c condition. The algorithm uses the detected speed of a vehicle and its travel distance (D) to calculate its estimated arrival time at the stopbar. If a vehicle's estimated arrival time does not meet the minimum headway requirement between it and the immediately preceding vehicle in the same lane, the algorithm adjusts its arrival time to account for the fact that a vehicle following another vehicle must maintain a safe headway (i.e., 2.5 seconds). With this information available, the algorithm proceeds as described below.

In real-time, the algorithm keeps track of the last group of n consecutive vehicles. If d is less than or equal to T_c, then a platoon of user-specified size and density exists. At this point, the algorithm schedules a low-priority preemption. Each preemption schedule consists of preemption activation and termination times. A preemption scheduler activates the preemption signal using this schedule. Preemption advance (P_a) specifies the time a preemption is to be initiated in advance of platoon arrival. Then, the algorithm switches to its extension mode.

Platoon Extension Mode

In its extension mode, the algorithm evaluates each additional vehicle to determine if it is a part of the previously detected platoon or if it is going to be in its dilemma zone during the scheduled preemption end time. If any of these conditions is true, the algorithm extends the preemption termination by an appropriate amount of time. This mode of algorithm uses the following three parameters:

- average headway threshold (T_h),
- extension to last vehicle in the platoon (T_e), and
- preemption clearance (P_c).

The first two thresholds assess if a vehicle is part of the previously detected platoon. Average headway calculation starts with the assumption that the subject vehicle is a part of the previously detected platoon. Thus, this calculation uses data for all vehicles in the platoon including the subject vehicle. If the calculated headway is less than or equal to the user-specified threshold (T_h), the algorithm concludes that its assumption is true. The algorithm also calculates the headway between the last vehicle in the platoon and the subject vehicle. If the calculated value is less than or equal to T_e, this condition is true. It should be noted that these calculations use the

14

estimated arrival times of vehicles at the stopbar. Preemption clearance is the difference between the predicted arrival time of the last vehicle and the preemption termination time. Setting this value equal to -2.5 seconds is equivalent to terminating the preemption as the last vehicle exits its dilemma zone.

Constraints on Platoon Accommodation

A user can place constraints on the platoon accommodation process of the algorithm. For this purpose, the algorithm has the following configurable parameters:

- A timer has been provided to restrict the preemption duration in the presence of demand at any conflicting phase. This feature is similar to the Max timer in traffic controllers.
- A timer has been provided to lock the algorithm from issuing another preempt for a specified duration after termination of a preempt. This feature is similar to the "Red Revert" feature in traffic controllers.
- A capability has been provided for the user to specify which conflicting phases should not be skipped to provide progression to the next identified platoon, if these phases received demand during the current preemption. This feature is similar to the "Phase Skip" feature in modern controllers. However, the algorithm feature is more flexible in that it allows the user to select a subset of phases that cannot be skipped. In contrast, controllers only permit all or nothing choices.

Platoon Identification Software Development and Initial Testing

Soon after completing the development of the algorithm described above, we transformed this logic into a computer program using Microsoft Visual Basic, and we tested the program using a controller-in-loop simulation using the Corridor Simulation (CORSIM) program (Figure 7) (25). During this stage, we used a wide range of traffic conditions to further refine the algorithm/software and determined optimal values for a number of user-configurable algorithm parameters (number of vehicles in the platoon and various thresholds). For all simulation studies, we assumed a high-speed approach and placed simulated advance detection 1000 ft in advance of the stopbar. For implementation ease, we decided to classify signal approaches into two categories based on approach speed. According to this classification, an approach with a posted speed of 45 mph or higher was to be characterized as a high-speed approach. All other approaches would be considered low-speed.

Researchers conducted these simulations over a period of several months and discovered that the platoon detection algorithm/software worked very well. At this point, the researchers decided to move to the next level of research and development and added software routines to provide an interface to the controller cabinet. This interface uses a digital input/output card installed in the computer to obtain the phase and stopbar-detector status from the controller in real time and send a low-priority preemption signal to the controller. It also provides a real-time graphic display of the status information. The next chapter provides more detailed information about this stage of development. However, before proceeding to that chapter, it would be appropriate to provide a full description of the PIA software. The next section is devoted to this issue.

Figure 7. Software Using Controller-in-loop Simulation.

PIA SOFTWARE

As described earlier, the PIA algorithm uses several parameters specified by the user. The PIA software, developed by researchers, provides dialogue boxes and windows for entering and displaying these parameters. In addition, its users have the ability to define constraints on the system. In this section, we describe the PIA software. Figure 8 illustrates the main program window for the PIA system.

Clicking the "Stop" button stops program operation. When done so, the button label changes to "Start." In this state, clicking the button starts or resumes program operation. This program can be configured to automatically start when the PC boots/re-boots.

Key sections on this main screen are those with the following headers:

- Platoon Information,
- Activation Window,
- Preemption Information,
- Algorithm Parameters, and
- System Stability Information.

The following subsections provide detailed information about these sections.
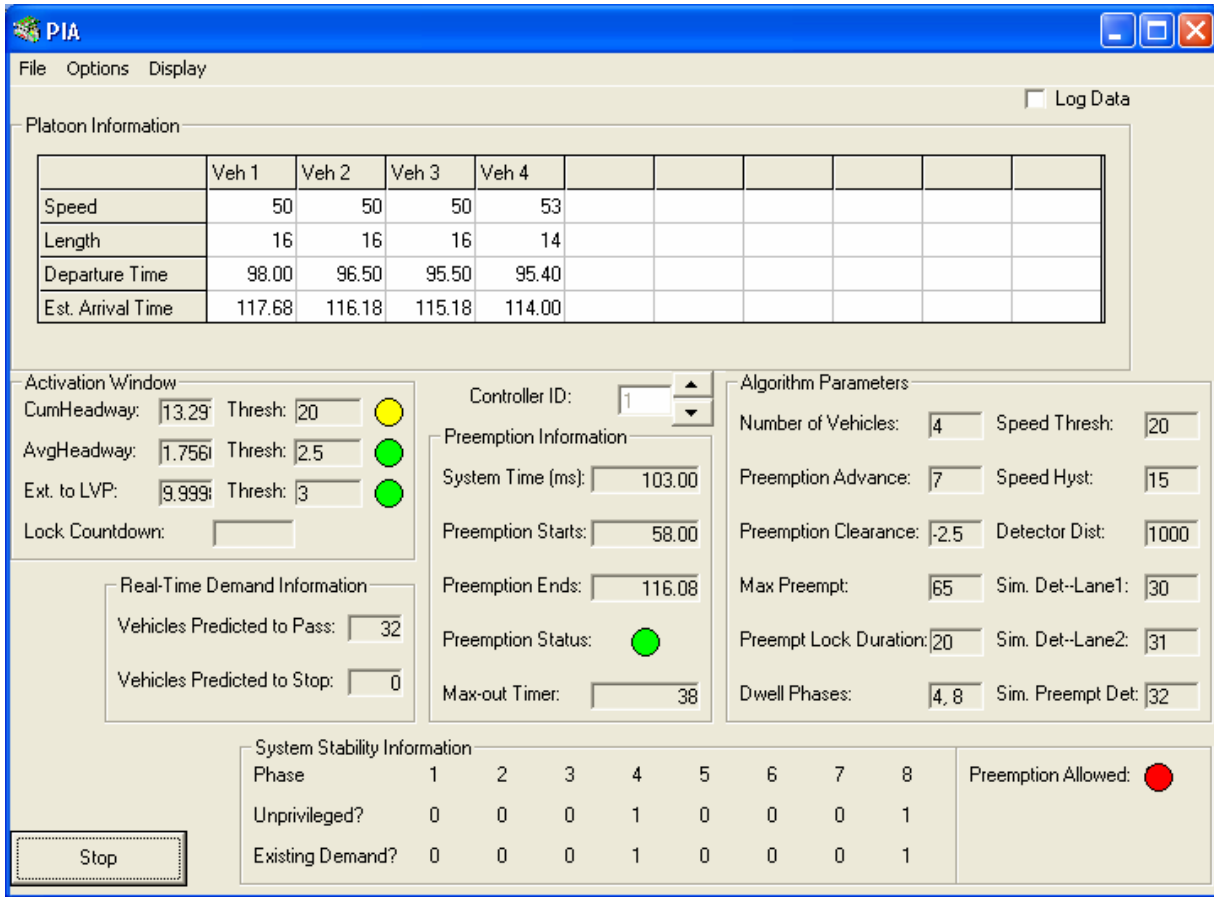
Figure 8. PIA Main Screen.

Platoon Information Window

This window provides a real-time display of vehicles as they pass over the advance detector. The amount of information displayed (that is, the number of columns with information) depends on the number-of-vehicles value specified by the user. This parameter is described later. At this time, it is sufficient to note that in the illustration of Figure 8 this value is 4. Therefore, the program is displaying the following rolling horizon information about the last four vehicles:

- Speeds: speeds of vehicles as they passed over the advance detector,
- Lengths: lengths of vehicles as they passed over the advance detector,
- Departure Time: time at which the vehicle passed over the advance detector, and
- Est. Arrival Time: time at which the vehicle is estimated to arrive at the stopbar. If a vehicle's estimated arrival time is less than the estimated arrival time of the previous vehicle in the same lane plus a minimum headway, the estimated arrival time of the subject vehicle is modified to reflect a minimum headway between the two vehicles.

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Activation Window

The activation window shows the real-time algorithm parameters and their corresponding thresholds. If a parameter is less than its corresponding threshold, the light located in its row is lit. Light status is based on the decision made for the last vehicle, not the current time step. That is, if the vehicle that passed over the advance detector 10 seconds ago satisfied a condition, the light will be lit even though there is no vehicle over the advance detector at this moment. The light will remain lit until the condition is re-evaluated. Re-evaluation takes place when the next vehicle passes over the detector. The following is a description of each parameter in the activation window.

Cumulative Headway (CumHeadway)
This is the difference between the estimated arrival time of the first and the last vehicles in a platoon, respectively. This parameter is only relevant in the platoon identification step. Once the system recognizes a platoon, it evaluates successive vehicles using the platoon extension criteria.

Average Headway (AvgHeadway)
This value is the average headway of vehicles in the platoon calculated from the first vehicle in the platoon to the subject vehicle. This value is compared to its corresponding threshold to decide whether a vehicle should be considered as a part of a previous platoon based on the average headway with the vehicle included. This parameter is important when a secondary platoon follows a primary platoon.

Extension to Last Vehicle in Platoon (Ext. to LVP)
This value is the difference between the estimated arrival of the subject vehicle and the last vehicle in an identified platoon. Note that if a vehicle is not deemed to extend the platoon, then it is not considered in the Ext. to LVP calculations for the next vehicle.

Lock Countdown
When a preemption terminates, the program enforces a preempt lock period during which it cannot identify platoons. This period is intended to serve the minor movement phases. The Lock-Countdown box shows the time left in the lock countdown period before the algorithm resumes platoon detection mode.

Real-Time Demand Window

This window shows real-time estimates of vehicles predicted to pass and vehicles predicted to stop. The information is used in conjunction with the platoon information to set up the preemption schedule as described below.

Vehicles Predicted to Pass
This estimate appears at the end of each preemption cycle.

Vehicles Predicted to Stop
Vehicles that arrive during red or do not meet the platoon identification/extension criteria form queues at the signal. The algorithm uses this estimate to expedite a preemption schedule in order to accommodate the waiting queues.

Preemption Information

This window shows the preemption schedule information while the program is running. Information in this category is described below.

System Time
In a system installed in the field, this box displays computer clock time. In a lab setting, this box displays time-step for the current simulation run.

Preemption Starts
This field displays the time the preemption is scheduled to start.

Preemption Ends
This field displays the time the preemption is scheduled to end.

Preemption Status
This circle is lit when the counter falls between the scheduled start and the end of preemption times. It indicates that the algorithm has issued a preemption signal.

Max-out Timer
This counter keeps tracks of the preemption duration, similar to the max-out timer in actual controllers. The program increments the counter only when there is demand at a conflicting phase.

Algorithm Parameters Window

This window contains the current setup of algorithm parameters. These user-configurable parameters are described below.

Number of Vehicles
This parameter identifies the smallest number of vehicles that can be classified as a platoon. The recommended value for this parameter is 4. This number, together with cumulative headway, is used for initial platoon identification.

Preemption Advance
This field displays the time between signal preemption activation and the predicted arrival of the start of the platoon at the downstream signal. Note that preemption is activated prior to the platoon arrival.

Preemption Clearance
This field displays the time between predicted arrival of the last vehicle in the platoon at the downstream signal and signal preemption termination. Setting this time equal to –2.5 seconds is equivalent to terminating the preemption as the last vehicle in the platoon exits its dilemma zone.

Max Preempt
This is the maximum time preemption will be allowed to continue when there is continuous conflicting demand.

Preempt Lock Duration
This is the time no platoon identification is allowed once preemption is terminated.

Speed Threshold
This field displays the speed value below which the program recognizes a gridlock condition and activates a flush mode. The flush mode applies a continuous preempt while this condition remains true.

Speed Hysteresis
The summation of speed threshold and speed hysteresis determines the speed above which the program recognizes a return-to-normal condition after a gridlock occurs.

Simulation Detector—Lane 1
This entry is for simulation only. The entry is the detector number acting as the classifier in the first lane.

Simulation Detector—Lane 2
This entry is for simulation only. The entry is the detector number acting as the classifier in the second lane.

Detector Distance
This field displays the distance between the advance detector used by the classifier and the downstream signal.

Preempt Detector (preemptDet)
This entry is for simulation only. The entry is the detector number acting as the preempt detector.

System Stability Window

The system stability window displays additional parameters and indicators of the current status of the algorithm. Descriptions of key elements are provided below.

Unprivileged Phases
An unprivileged phase is a phase that does not get served when the signal is preempted (such as opposing left-turn or side-street phases) and, therefore, needs special attention from the platoon detection and progression (PDP) subsystem. A "1" under a phase in the system stability window means that this phase is designated by the user as an unprivileged phase. The PDP subsystem monitors the demand on all unprivileged phases while a preemption call is active and ensures that each unprivileged phase is serviced before allowing a subsequent preemption. This treatment is important to ensure that excessive queues do not build on unprivileged phases.

Existing Demand

If a call is placed on an unprivileged phase during preemption, the PDP subsystem raises a flag for that phase (a "1" is shown in the existing demand row). If an existing demand flag is raised for any of the unprivileged phases, the PDP will disable preemption (preemption allowed light will be lit red). The existing demand flags are cleared only under two conditions: 1) the detector call is cleared during phases other than the phase the call is registered for; and 2) the phase that has the call displays green and ends with a "gap-out" condition. The first condition accounts for cases when a demand is cleared by a permitted operation such as right-turn-on-red or permitted left turn. The second case makes sure that the phase that has the demand was served sufficiently and no queues were left unserved (i.e., the phase did not end with a "max-out"). The program provides the platoon identification and progression function only when there are no existing demand flags (i.e., when preemption allowed is lit green). This mechanism ensures that all vehicles arriving at specified unprivileged phases during preemption get serviced before providing priority treatment to the platoon. This feature is similar to the "Skip Phases" feature provided by modern controllers used in Texas. This feature in a controller provides for either skipping of all conflicting phases or no skipping at all. In contrast, the feature provided in the PIA software is more flexible in that the user can select a subset of phases to be in either category. The main objective of this PIA feature is to ensure system stability before intervention with a platoon preemption request.

When the main-street priority phase turns green to serve a waiting queue, the system issues a short (5-second) preemption to evaluate the presence of an approaching platoon. This is known as "Green Grab."

Different System States

Figures 9, 10, and 11 illustrate the three common scenarios of program operation. Figure 9 illustrates the case when a platoon was identified and was being progressed, and the last vehicle passing over the classifier meets extension conditions for both average headway and dilemma zone. Figure 10 illustrates the scenario when a platoon was identified and progressed, while an additional vehicle meets only the average headway condition. Figure 11 identifies the scenario when the algorithm is locked (prevented) from detecting and progressing platoons. Appendix A provides illustrations of additional program screens.

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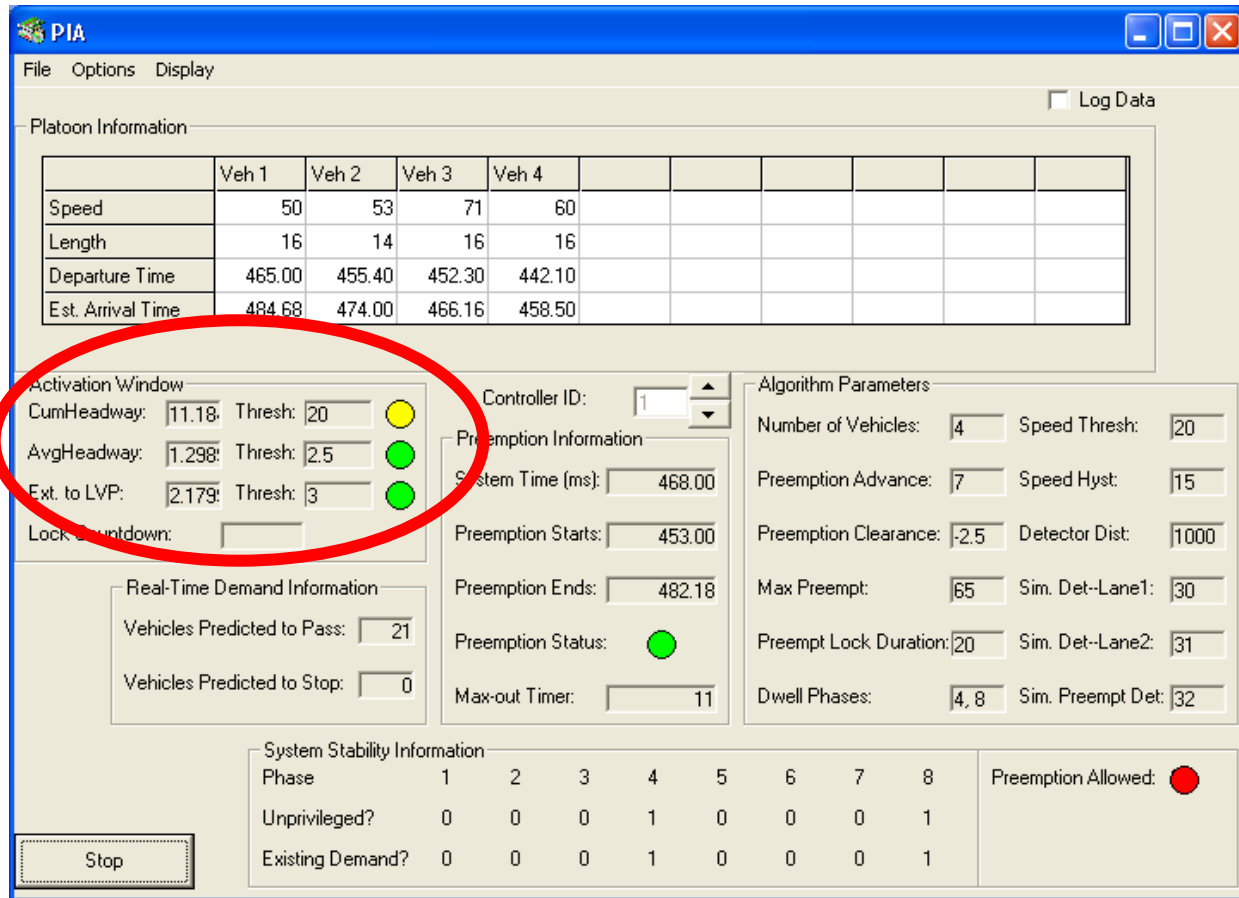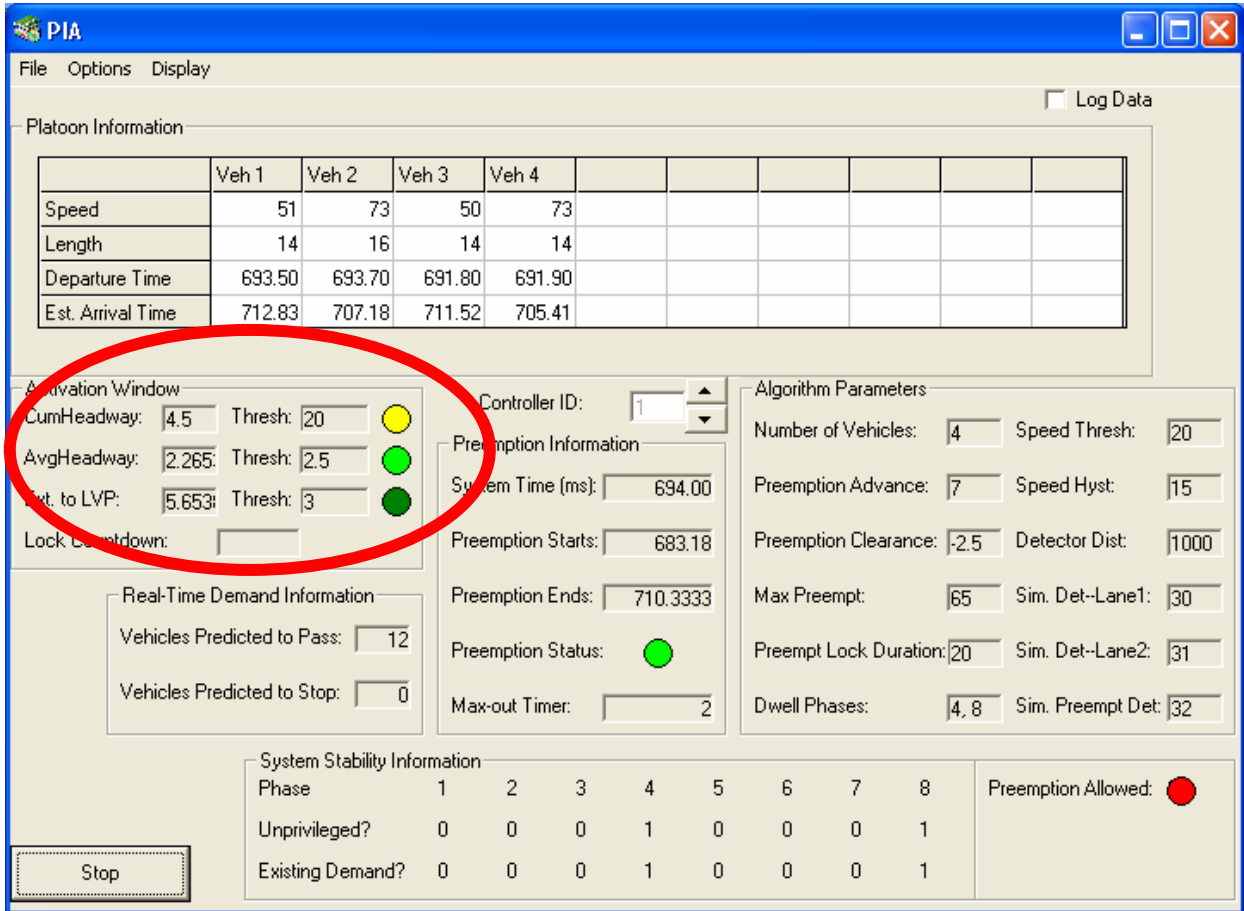**Figure 9. Platoon Identified, Last Vehicle Meets Both Extension Conditions.**

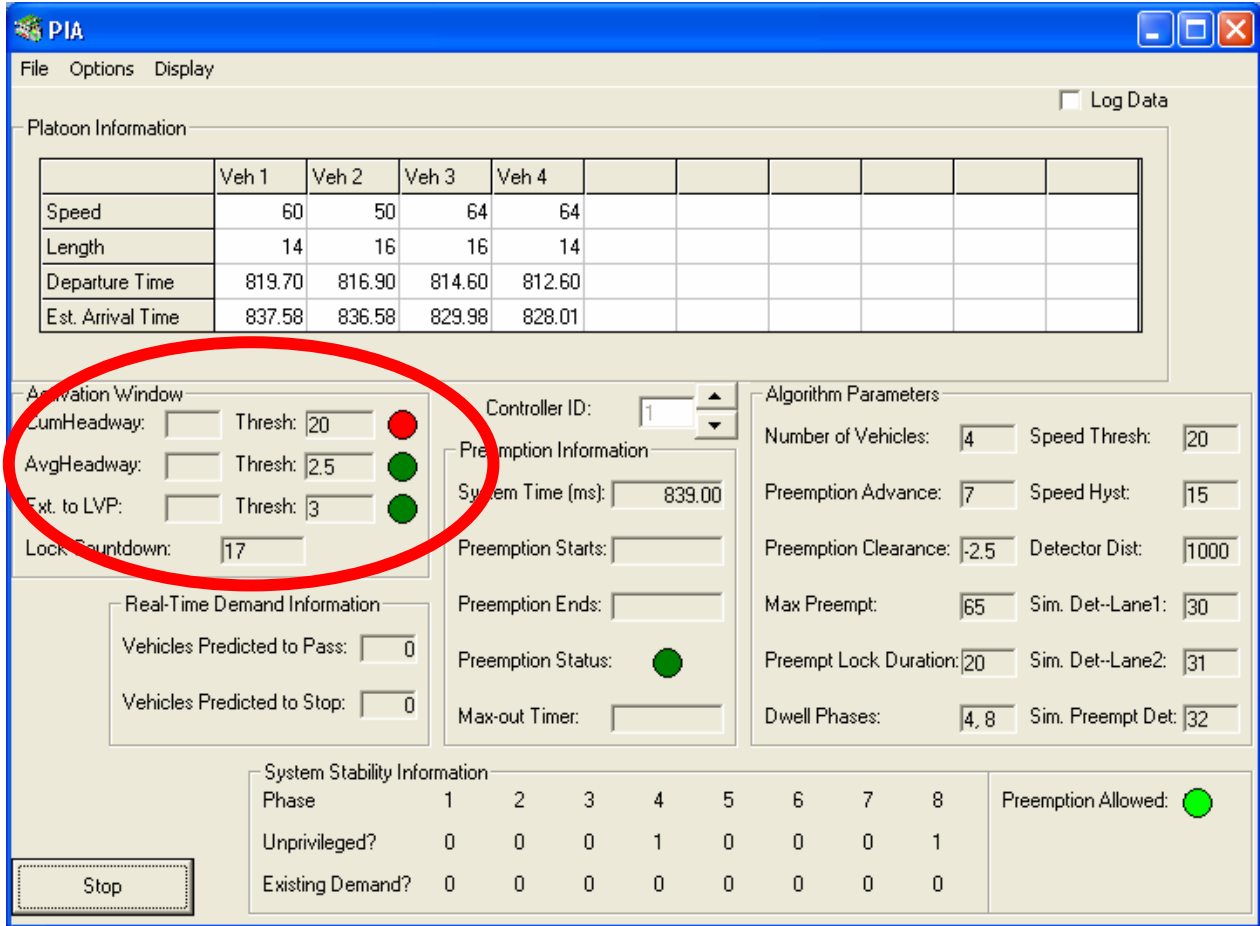**Figure 10. Platoon Identified, Last Vehicle Meets Average Headway Extension Condition Only.**

Figure 11. Lock Period Active.

4. DETAILED SYSTEM DESCRIPTION

INTRODUCTION

This chapter provides a detailed description of the PIA system. As mentioned previously, the system consists of software and hardware components. Figure 12 provides an overview of the system architecture in terms of various subsystems. The following subsections describe these subsystems. This chapter ends with a description of in-laboratory tests performed by the researchers on a fully assembled system before field installation.
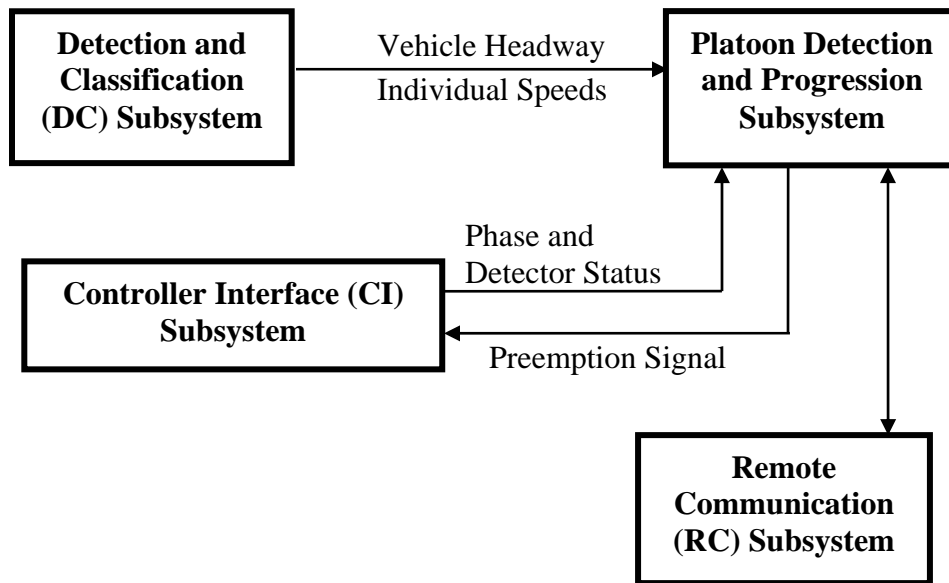
```
┌─────────────────────┐   Vehicle Headway    ┌─────────────────────┐
│    Detection and    │ ──────────────────→  │ Platoon Detection   │
│   Classification    │   Individual Speeds  │  and Progression    │
│   (DC) Subsystem    │                      │     Subsystem       │
└─────────────────────┘                      └─────────────────────┘
                                                   ↑        ↑
                          Phase and                │        │
                          Detector Status          │        │
┌─────────────────────┐ ───────────────────────────┘        │
│ Controller Interface │                                     │
│   (CI) Subsystem    │ ←──────────────────────────┐         │
└─────────────────────┘   Preemption Signal        │         │
                                                    │         ↓
                                              ┌─────────────────────┐
                                              │      Remote          │
                                              │  Communication       │
                                              │   (RC) Subsystem     │
                                              └─────────────────────┘
```

Figure 12. Subsystems in the PIA System.

Platoon Detection and Progression Subsystem

The PDP subsystem consists of a set of software subroutines — described in the previous chapter — that runs on a field-hardened personal computer. These subroutines use real-time information from the detector classification and controller interface subsystems to detect the presence of platoons and to progress the detected platoons when appropriate. This subsystem also provides dilemma-zone protection to vehicles at the back end of a platoon.

Detection and Classification Subsystem

The purpose of the DC subsystem is to provide vehicle detection and speed information for each vehicle well in advance of the stopbar. The system should consist of the following components:

- one speed trap (inductive loops or video camera-based) per lane,
- detection unit (loop amplifier or video processor) to provide contact closure information from the trap (both loops),

- communication between the trap detectors and detection unit (hard-wired or wireless), and
- a classifier that obtains contact closure information and calculates speeds and lengths of individual vehicles.

Upon each detection, the classifier sends a message over a serial connection to the PIA software. The message consists of the lane number, vehicle speed, and vehicle length. One module in the PIA software checks continuously for messages sent by the classifier. The information received is then used by the PDP subsystem to determine the schedule of preemption start and end times.

Controller Interface Subsystem

The controller interface subsystem provides the interface between the PDP algorithm and the controller cabinet. The PDP algorithm requires several inputs from the controller cabinet including phase status (green/yellow/red) of each phase in the controller and status of each stopbar detector (on/off). The PDP algorithm needs to send a signal to the controller cabinet any time it decides to activate one of the low-priority preempts.

The CI subsystem consists of a software module and a number of hardware components depending on the type of the controller cabinet. The CI software module is integrated with the PDP algorithm routines and is referred to as the PIA software. For TS-1 controller cabinets, the CI subsystem requires a digital input/output card that is installed in the field-hardened industrial PC where the PIA software resides and runs and has at least 24 inputs and eight outputs. Researchers are currently using a National Instruments Data Acquisition (NI DAQ) PCI-6527 digital I/O card with 24 inputs and 24 outputs. The digital I/O inputs connect to eight phase-on contact-closure connections on the TS-1 controller cabinet's back panel, six contact-closure connections that provide the ring-status bits A, B, and C (three per controller ring), and eight contact-closure connections that provide the status of stopbar detectors. Appendix B provides information for wiring channels from the NI DAQ card to the back panel. Based on the status of the three ring-status bits (A, B, and C) and phase-on status of each phase, the software determines if a phase is in the green, yellow, or red state.

In addition to the digital I/O card, TS-2 controller cabinets require a special TS-2 breakout panel. This panel provides contact-closure connections to the required controller cabinet inputs (i.e., phase and detector status needed by the PIA software).

The CI subsystem's software module checks the status of the controller's back panel phase-on, ring-status bits, and stopbar detector contact-closure connections once every 10 milliseconds. It determines the status of each phase (main-street or side-street) whether it is green, yellow, or red. It also determines the status of the stopbar detectors whether they are on or off based on the contact-closure connections. The CI software module updates the intersection display with the current status of the phases and stopbar detectors. The CI software module also makes available the current phase status and stopbar detector status to the PDP subsystem and activates the low-priority preemption by sending a contact-closure signal to the controller's back panel upon request from the PDP subsystem. A timer relay provides fail-safe operation for the low-priority preemption (LPP) signal sent by the PDP subsystem. This relay terminates the LPP signal any time it continues beyond a user-specified time.

Remote Communication Subsystem

The remote communication subsystem is optional. Its purpose is to provide a capability to remotely access the PC in the cabinet for maintenance and monitoring purposes. It also provides functionality to shutdown and/or to restart the PC if such a need arises or stop/re-start the PIA software. The RC subsystem contains the following components:

- a standard telephone line or a digital subscriber line (DSL) in the cabinet,
- an appropriate modem (standard or DSL) connected to the remote PC in the cabinet,
- PcAnywhere software running on the remote PC and on a computer in the office, and
- a remote power on/off switch.

The PcAnywhere program provides a dialup capability and allows a user to use a remote PC as if it were present on the desktop. The remote power on/off switch is connected to the phone line in the controller cabinet and allows a user to re-power the PC via a sequence of calls to the controller cabinet.

SYSTEM COMPONENTS

This section provides a brief summary of hardware and software components needed to install the PIA system at a single site. An additional cabinet may be required if the existing cabinet does not have sufficient room to install system components.

Required Hardware and Software Components

Advanced Detector Trap

Advanced detection can be provided using inductive loops or video cameras. In addition, detector-to-cabinet connections can be hard-wired or wireless. Depending on the detection technology used (loops or video), the following items may be needed: loop detector amplifiers or video detection unit.

Field Hardened Personal Computer

A field-hardened PC is needed to run the PIA software and any additional software needed for monitoring and maintaining the system from a remote location.

Digital Input/Output Board

A digital I/O board with 48 (24 input and 24 output) channels is used to access the phase and detector status contact-closure connections on the cabinet back panel. Researchers used NI DAQ 6527 manufactured by National Instruments.

Classifier

A classifier is needed to detect individual vehicles in each lane and provide the lane number and vehicle speed in real time over a serial connection. Researchers used a Peak ADR-2000 classifier in this research project.

TS-2 Breakout Panel

A TS-2 breakout panel is needed only if the system is to be installed in a TS-2 cabinet. The breakout panel is connected to BIUs 3 and 4 to communicate the status of ABC pins from both rings in the controller to the PIA system.

Timer Relay

A timer relay is needed to provide a fail-safe operation. Its purpose is to terminate the controller override (preemption signal) issued by the PIA software after a preset time. It provides protection against any possibility of program malfunction before getting a chance to terminate its override. Such a situation may occur due to power failure or unknown bugs in the software.

Connector Panel

The connector panel, manufactured by researchers, is a resistor input interface circuit for NI DAQ 6527. The interface circuit consists of a double-layer terminal strip with 24 individual terminals. A bus connecting all 24 bottom level terminals supplies all 24 16 kilo-ohm resistors with 24 volt direct current (VDC). The supply to the bus is fused by a 1/5 amp fuse to protect the output of the traffic signal controller. The current flowing through each resistor is approximately 1 milli-ampere (mA) when the output from the traffic signal controller is "active low" on a particular output. Each input for the NI DAQ card requires 1 mA for its optical isolator's light-emitting diode (LED) to work reliably. The current from the 24 VDC supply flows through the fuse, through the resistor into the NI DAQ optical isolator, and into the output of the traffic signal controller. Current sinks into the output only when the output of the traffic signal controller is active low.

PIA Software

PIA software developed by TTI runs on the PC described earlier. It communicates with the cabinet and the classifier to obtain needed information to detect the existence of platoons and to override the normal controller operation to progress the detected platoon of vehicles.

OPTIONAL HARDWARE AND SOFTWARE

If the selected site is located in a remote location, additional hardware and software can be installed to provide remote communication with the PIA system. In this case, the following items will be needed:

- a telephone (standard or DSL) line to the controller cabinet,
- a modem,
- remote control software such as PcAnywhere, and
- a power on/off switch.

COMPREHENSIVE SYSTEM TESTING

Initial simulation-based tests described in the previous chapter used a controller directly connected to CORSIM. These tests were sufficient to analyze the performance of the platoon detection algorithm/software. However, because of the absence of additional hardware to be used for field installation, these tests were not sufficient to guarantee flawless installation and operation of the system at selected field sites. This is because of the limitations of the previous testing described below.

Internally, CORSIM performs calculations every tenth of a second; however, its communication with an external process is limited by a 1-second resolution. Because of this, controller-in-loop simulation does not guarantee timely information from each detector of a trap. However, the accuracy of such information is critical for correct platoon identification. Therefore, we decided to use a single simulated loop to emulate a trap. In addition, this testing did not use a classifier. Finally, interface to the controller cabinet, including software routines developed by researchers, could not be tested within the previous framework. Testing could not be performed without the needed hardware. At this point, the researchers ordered hardware for both sites and developed a plan to perform a round of comprehensive tests.

Additional in-lab testing was needed to not only ensure that the DC and the CI subsystems performed as intended, but to also ensure that the full system worked as designed. For this reason, researchers developed a cabinet-in-the-loop (CIL) simulation testbed and performed additional tests. Figures 13 and 14 illustrate the CIL flow diagram and a picture from the laboratory.
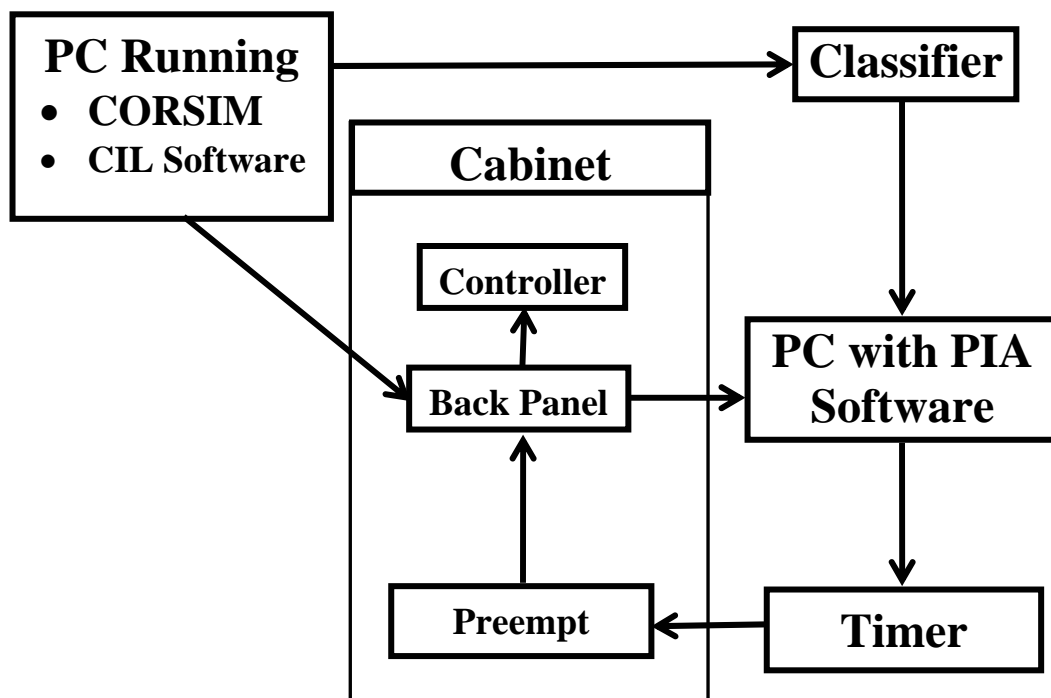
Figure 13. Flow Diagram of Cabinet-in-the-loop Simulation Testbed.
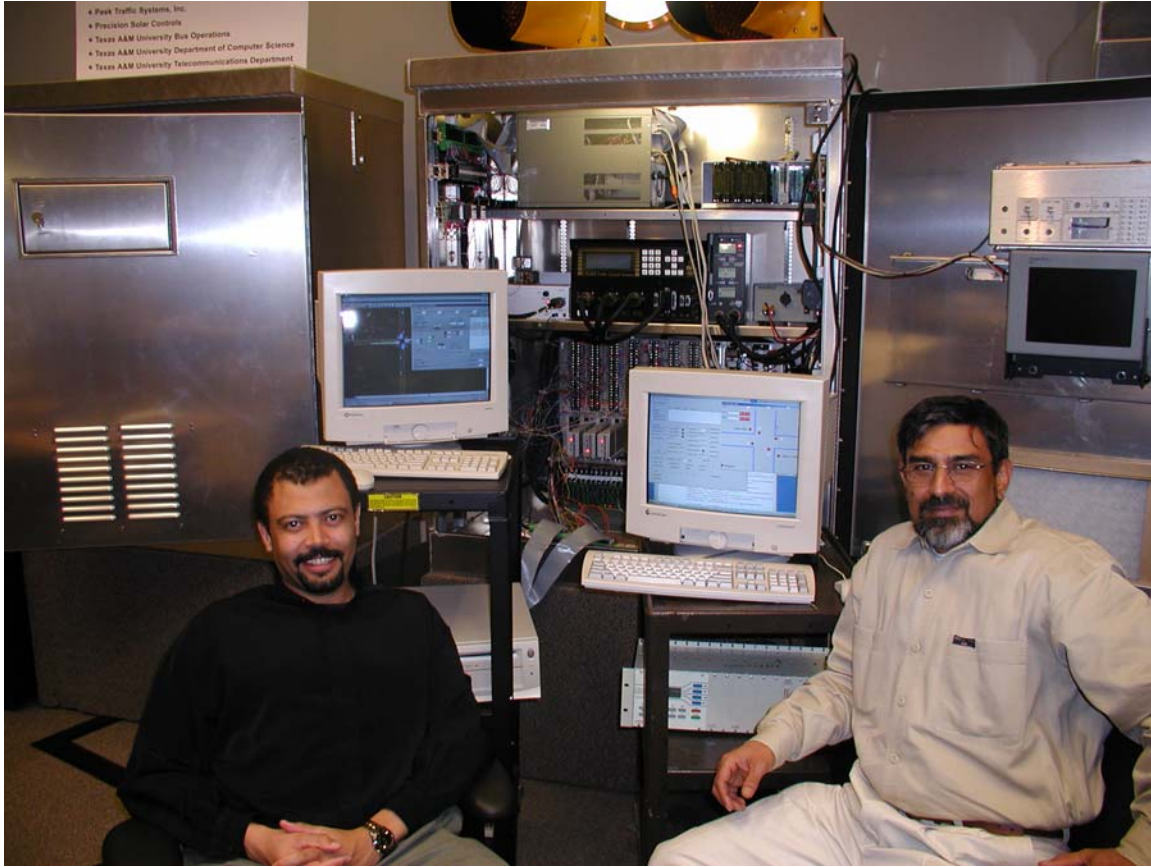
Figure 14. Picture of CIL Testbed.

As illustrated in Figure 13, the CIL setup consisted of the complete PIA system (PC running PIA software, classifier, etc.) connected to a controller cabinet as it would be in the field. This system only differs from a real system in that it uses vehicle detections from a simulator. To make this testing possible, researchers had to develop a separate CIL interface program. The purpose of this software is to pass manual or CORSIM-generated calls from advance and stopbar detectors to the appropriate system component. This program communicates calls from advance detector(s) to the classifier and those from the stopbar detector to the back panel in the cabinet. Using this testbed, we performed a series of tests to ensure that each subsystem worked as designed. In addition, this testbed also allowed us to perform comprehensive testing of the complete PIA system and its interaction with the cabinet.

During this round of testing, we found some minor flaws in the software, corrected these flaws, and repeated the tests. After that, we were ready to install the first system. The next chapter highlights required system installation and testing at two selected sites.

5. FIELD IMPLEMENTATION AND TESTING

SITE SELECTION

The project required the researchers to install and test the PIA system at two sites. Therefore, it was essential to identify the two sites as quickly as possible. Early site selection would ensure that these sites were ready for installation as soon as the system was fully developed. Within a few months after project initiation, researchers requested TxDOT staff to identify potential sites and promptly received several recommendations. During the next few months, researchers traveled to several of these sites to determine which two sites would be most beneficial to the project. Two locations cannot possibly provide geometric and traffic conditions to cover all possible scenarios. Despite this fact, researchers wanted to include as many factors as possible. In addition, the researchers' desire was to have at least one site close to their base. Such a site would simplify the logistics of system installation and testing. Based on these considerations, researchers selected one site located in College Station (CS), Texas, and one site located in George West (GW), Texas.

The CS site is located at the intersection of Rock Prairie and Wellborn (FM 2154) Roads in College Station, Texas. This signalized intersection is located in a typical suburban setting with an at-grade railway crossing servicing approximately 27 to 30 trains per day. The main road (FM 2154) runs north-south and has high-speed single-lane approaches with left-turn bays. At this location, we selected the southbound approach on Wellborn Road for providing platoon progression. In this direction, the upstream signal is located approximately one mile away. Figure 15 provides a sketch of this site and the upstream intersection. Figure 16 shows a picture of the eastbound approach at this signal. At this approach, there is limited space between railway tracks and the stopbar. The left-turn bay can reliably store only two passenger cars. Furthermore, this section of the approach has an up-hill grade with a lagging left-turn phase. Because of these factors, drivers are extremely jumpy as they are waiting to make the left-turn maneuver. There are gas stations and restaurants in each of the two eastside quadrants. At this intersection, pedestrian traffic demand is not significant; however, the intersection experiences three distinct peak periods with heavy traffic demand during a normal day. During other time periods, there is constant and varying demand on all approaches.

The GW site represents a typical rural setting. Traffic characteristics and geometry at this site are significantly different from the CS site in that its main approaches (US 281) are low-speed with two through lanes, two-way left-turn lanes, and a left-turn bay in each direction. The upstream signal, located approximately 1500 ft south of this intersection, is not visible from this location because of a curve. This site is located near two schools, one on each side of US 281. Because of this, there is a significant number of crossing school buses and pedestrian traffic during mornings and late afternoons. One of the schools has an open campus. Because of this, there is also significant pedestrian activity during lunch times. The school zone flashers activate three times during each working day, during which approach speeds drop to 25 mph. Because US 281 is a major north-south highway, there is significant truck traffic to/from Mexico. At times, there are more than 50 percent large trucks in the traffic stream. This intersection experiences two short peak periods of moderate demand each day. During the rest of the day, traffic demand remains unpredictable. At this site, we selected the northbound approach (US 281) for testing the system.
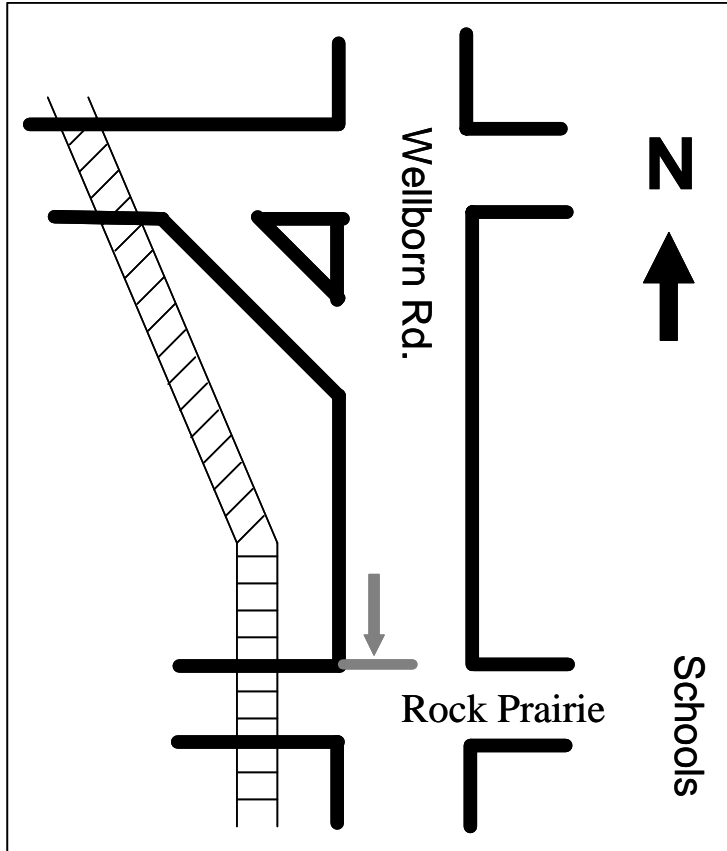
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Figure 15. Sketch of CS Site and Vicinity.

Figure 16. Railway Crossing at Rock Prairie Road.

Figure 17 provides a sketch of the GW system. Figures 18 and 19 show pictures of truck and bus traffic at this site. Table 1 provides a comparison of characteristics and available infrastructure at the two selected sites.
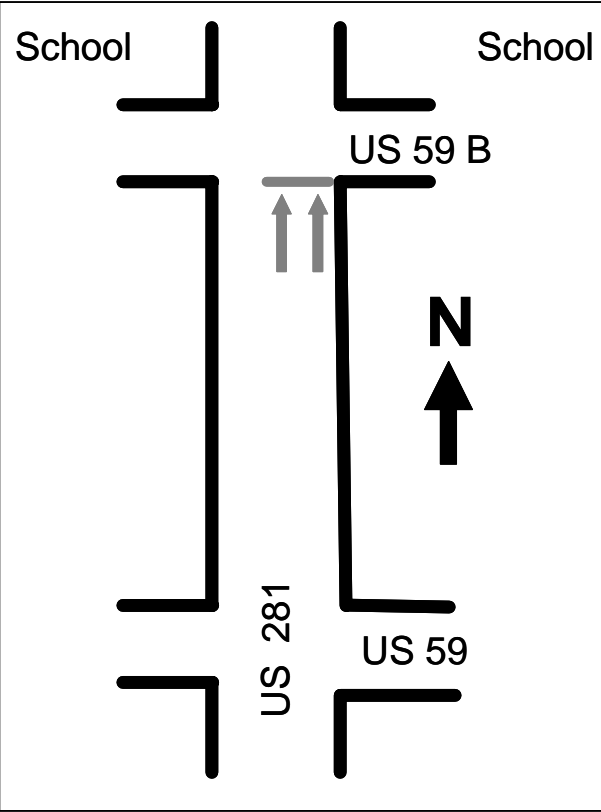

Figure 17. Sketch of GW Site and Vicinity.

Figure 18. Truck Traffic on Highway 281 in George West.

Figure 19. Crossing School Buses at the George West Site.

Table 1. Comparison of the Two Selected Sites.

Site/Characteristic	College Station	George West
Posted Approach-Speed Limit	High (65 mph)	Low (35 mph normal, 25 mph during school zone enforcement)
Lanes on Main Approaches	Single-lane with left-turn bays	Dual-lane with left-turn bays and two-way left-turn lanes
Significant Pedestrians?	No	Yes (during AM, Afternoon, and PM)
School Buses	Occasional	Significant cross traffic (during AM and PM)
Distance to Upstream Signal	5200 ft	1500 ft
Large Trucks	No	Significant (up to 50%) on main approaches
Cabinet Type	TS-1	TS-2
Detection for Signal Control	Inductive loops	Video-based (Iteris)
At-grade Railway Crossing	Yes, with 27 to 30 trains per day	No
Traffic Patterns	Predicable, with three distinct peak periods of heavy demand	Mostly unpredictable with low demand and short peak periods

SITE PREPARATION FOR INSTALLATION

As mentioned earlier, most of the hardware needed for installing the system at two sites had been ordered, received, and tested prior to comprehensive system testing described in the previous chapter. These pieces of hardware included:

- two field-hardened industrial PCs,
- two Peak classifiers,
- two digital input/output cards,
- loop amplifiers, and
- timer relays.

The CS site already had advance detector traps 1000 ft upstream of the stopbar on the southbound approach. In addition, the TS-1 cabinet at this site had ample space for additional equipment purchased for field installation. Therefore, no additional preparation was necessary at this site.

Because the GW site has a TS-2 cabinet, researchers had to order a breakout panel for use there. The breakout panel connects to BIUs 3 and 4 to provide access to phase- and detector-status information from the controller in a TS-2 cabinet. Furthermore, the existing controller cabinet in GW did not have sufficient room to house additional equipment. To accommodate this need, TxDOT staff installed an additional cabinet adjacent to the existing cabinet. The researchers installed an above-the-ground two-inch electrical conduit (tied to the two cabinets) for wiring equipment in the two cabinets, without exposing the wires. Finally, the vendor's representative installed the breakout panel in the spare cabinet. Also, in consultation with the TxDOT advisory panel, researchers had decided to use a video-based system for advance detection at this site. This decision was appropriate because the Corpus Christi District of TxDOT, responsible for future maintenance of the PIA system at this site, has completely switched to video-based detection for all signals in its jurisdiction. Because the purchase of such a system was not budgeted in the project, the TxDOT project director arranged for the acquisition of an Iteris intersection model processor, a solar panel, backup batteries, and two wireless cameras for use at this site. In addition, TxDOT installed a pole and a luminary arm for mounting the video cameras, the solar panel, and a pole-mounted cabinet for the backup batteries.

As stated in the previous chapter, researchers had tested and calibrated the platoon detection algorithm/software using CIL simulation. In our base simulation scenario, the priority direction had a high-speed approach similar to the CS site. Thus, the PIA software was already calibrated for use at this site. In other words, the software was ready for use at a site where advance detection is 1000 ft upstream of the stopbar. However, since the approach speeds at the GW site are much lower, additional simulation studies had to be conducted to identify the optimal location of advance detection at this site. We conducted these studies next.

For detector location studies, we performed CIL simulation studies using CORSIM. This procedure was sufficient because the process only required studying algorithm performance for a range of detector locations and different demand scenarios. The CORSIM simulation data for these studies consisted of a two-intersection system with stopbar detectors at all movements,

except for through movements on the main approaches. Researchers assumed main-street approach speeds of 35 mph. For priority- and opposite-approach demands of 600 and 400 vehicles per hour (vph), respectively, we studied algorithm performance for the following scenarios:

- side-street demands of 200 and 400 vph,
- zero, 10, and 30 percent trucks on the priority approach, and
- advance detector locations of 500, 600, and 700 ft.

From these studies we found the following:

- For all detector locations, platoon detection and progression significantly reduced delay on the priority approach by slightly penalizing the side-street traffic.
- For scenarios with low truck percentages, advance detection at 500 ft produced slightly lower delay to platoons than the other two detector locations.
- For scenarios with 30 percent trucks, advance detections at 600 to 700 ft produced significantly lower delay than the 500 ft location.

Since the selected priority approach at the GW site services a high percentage of trucks, we decided to install the camera at an appropriate location approximately 600 to 700 ft from the stopbar. The actual location of the detection zone (defined in the software) is different from the camera location because of camera height, angle, and direction.

FIELD IMPLEMENTATION AND OPERATION

System Testing in College Station

In December 2002, we installed the PIA system at the CS site (Figure 20) and started testing the system. Initial field testing revealed that one stopbar detector at the site was not operational. This finding identified the need for minor enhancements to the PIA software to handle a subset of detectors that are bad. Subsequently, we made these modifications and tested the software in the laboratory using CIL simulation. After successful testing in the lab, we upgraded the field computer and resumed field testing of the PIA system. This phase of testing continued through February 2003 and consisted of several visits to the site. During this testing phase, we performed several tasks described in the following subsections.

Verification of Platoon Identification and Preemption Schedule Generation

During this stage, we left the preempt connection from the PC to the cabinet disconnected and tested the system during different traffic conditions over a period of several days. This procedure ensured that the software/algorithm performed as designed and for all types of traffic conditions. Specifically, we tested the performance of the following software functions:

1. correct identification of each approaching platoon,
2. settings of initial preemption schedule, and
3. modification of the preemption termination time in the presence of additional vehicles in the detected platoon, or when the last vehicle needed dilemma-zone protection.

Figure 20. Researchers Installing the System in College Station.

For items 2 and 3, correct detection of individual speed for each vehicle was a key ingredient. In order to ensure that the system was accurately measuring these data, we compared output from the classifier with speed measurements taken using a radar gun. These comparisons showed that the system was accurately detecting speed data. Observations of the algorithm during this time revealed that the software/algorithm was correctly identifying platoons. In addition, it was correctly setting and updating the preemption schedule.

Least-Constrained Operation of PIA Software

This stage of field testing was similar to that described above. The only difference was that the wire from the PC carrying the preemption signal was connected to a preempt input in the controller cabinet, and the appropriate preempt was programmed/activated to provide low-priority preemption when needed. The following actions tested settings for the PIA software and controller program:

1. Requested PIA software to:
   - ignore demand at conflicting phases,
   - set Max-Preempt timer to 65 seconds (five more than Max times on main-street phases), and
   - set preempt revert to 15 seconds.

2. Programmed controller to:
   - dwell in priority phase and service any concurrent phase with demand,

- limit preemption length to less than or equal to 100 seconds,
- not extend preempt call duration,
- minimum preemption time equal to zero,
- use lockout values of 0 (lock controller until no demand exits) and 1 second (force lockout for the shortest duration), and
- use skip values of 0 (do not skip phases to service a preempt) and 1 (skip all phases in the sequence regardless of demand).

The last two controller settings determine the snappiness of the controller to service a preemption request based on the flexibility permitted by the user. This testing provided the following observations about the PIA system performance:

- The PIA system provided the best operation for the priority approach and its concurrent phases when it was the least constrained. In this case, the system identified and progressed each platoon. This operation worked well for all approaches during low- and moderate-demand periods. However, during periods of heavy demand, especially the PM-peak period, the system resulted in excessive delays to vehicles at the side-street phases. This was due to the fact that multiple back-to-back platoons were arriving continually on the priority approach and the unconstrained system was serving all these platoons without considering consequences to vehicles on side-street approaches. During these times, drivers wishing to turn left at the eastbound approach (on the train-track side of the intersection) were extremely jumpy. Based on these observations, researchers concluded that the unconstrained system operation is inappropriate for this site.
- When researchers repeated the same tests with a more constrained controller programming (lockout value equal to 0 and no skipping of conflicting phases), the PIA system's ability to provide progression to every detected platoon reduced significantly. Further investigation revealed that a major contributor to the reduced efficiency was a malfunctioning stopbar detector, which caused the controller to place a constant call on this detector. This caused the associated side-street phase to get service during each cycle regardless of demand. In addition, this phase maxed-out every time it was serviced.

Constrained Operation of PIA Software

This round of testing was similar to that described above. However, instead of programming the controller to provide constraints on the platoon progression, we used options provided in the PIA software. These options provide features similar to those provided by the traffic controller, but with more flexibility. Specifically, these features provide a user with the ability to select which phases can and cannot be skipped in the signal cycle immediately after a low-priority preemption is activated by the PIA system. This time, we programmed the software to ignore two phases. One of them was the side-street left-turn phase with the bad detector. The other was the left-turn phase opposing the priority through phase. Both of these phases experience low traffic demand that is adequately serviced during respective permitted phases for these movements. Observations of system operation with these settings showed a much-improved operation for the side street. In addition, platoon identification and progression was better than the most restrictive operation enforced through controller programming.

Summary of Field Testing in CS

Field testing in College Station showed that the PIA system provides accurate platoon identification and works best when platoons are forced to stop because of low demand on minor phases. In other words, this proof-of-concept system was successful in attaining its specified objectives. However, it is not possible to guarantee the existence of such conditions at all times, even at sites that meet the implementation criteria. The PIA system must be operated in a constrained mode by using appropriate settings provided in the software.

Field Testing in George West

As mentioned earlier, researchers had decided to use video-based advance detection at this site. However, because video detection has never been used in Texas for obtaining speeds of individual vehicles, system implementation at this site needed several steps in addition to those carried out for installing and testing the system at the CS site.

Starting in March 2003, researchers made several multiple-day trips to the GW site. During these trips, researchers installed the PIA system, evaluated several issues related to the use of video detection for obtaining speeds of individual vehicles and turned on the system. Different video detection options studied included various locations and positions of the video camera, and a comparison of the Iteris intersection and freeway models. Evaluation of each combination required defining detection zones, calibrating detectors, and comparison with data from a radar gun and a temporary trap installed for this purpose. The following subsections describe tasks conducted by researchers at this site.

Evaluation of Iteris Intersection Model

As stated earlier, TxDOT acquired and installed an Iteris intersection system for providing advance detection. As per the manufacturer's recommendations, researchers installed one camera on a luminary arm attached to a pole with an above ground height of 30 ft. As shown in Figure 21, researchers placed the camera directly above and in the center of the two travel lanes at an angle of approximately 45 degrees looking down at oncoming traffic. Then, researchers defined one speed trap per lane and calibrated each trap by using a 16-ft minivan rented for this trip. After calibrating the detectors, researchers recorded speed data from the classifier and compared these data with data collected from a radar gun and data collected from another classifier connected to temporary detectors (pneumatic tubes) placed at the physical location covered by the video-based traps. From these comparisons, researchers found that the system was accurately detecting speeds and lengths of passenger cars similar to the minivan used for calibrating the system. However, the speeds and vehicle lengths had large inaccuracies for trucks. These inaccuracies resulted from double detection of a significant number of, but not all, trucks (cab and trailer being detected as two vehicles). Next, researchers experimented with different shapes and sizes of detection zones. Each change required recalibration of the detection zones. These additional experiments also did not result in any improvement for trucks. At this point, researchers contacted the vendor's representative and requested assistance. Based on his suggestion, researchers reversed the camera position and pointed it at the back of vehicles (Figure 22) and repeated experimentation with various shapes and sizes of video zones. However, researchers observed no significant reductions in the double detection of trucks.
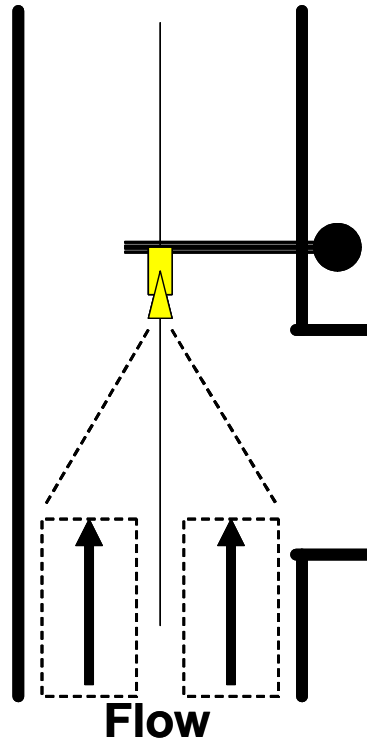
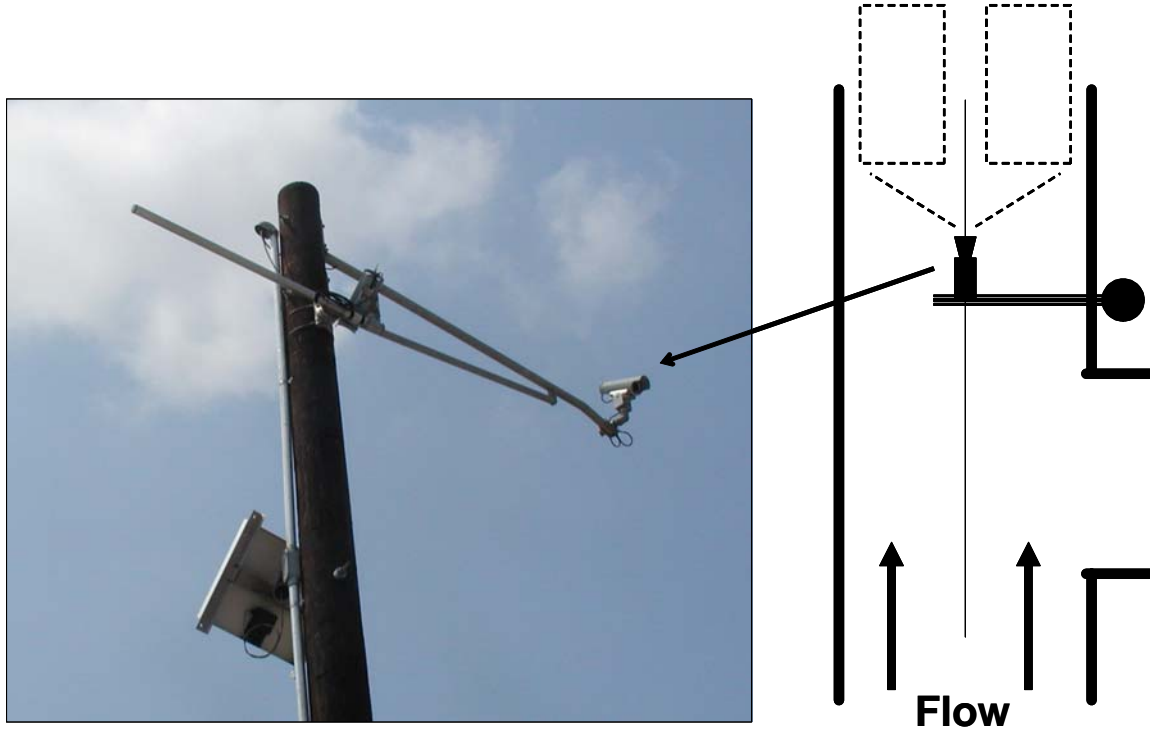**Figure 21. Initial Camera Placement.**

Figure 22. Reverse Direction of Camera.

One member of the research team has had recent experience with video-based detection of vehicle speeds on a freeway in Austin, Texas. This system uses the freeway model of the Iteris system and has shown to produce good speed observations. Therefore, researchers requested Iteris to provide an evaluation copy of this software for use in the project. This request was accepted, and an Iteris representative installed this software on a spare processor available at TxDOT's district office in Corpus Christi. The next section provides results from research to evaluate this model.

Evaluation of Iteris Freeway Model

Researchers installed the Iteris freeway model in the cabinet and proceeded with another round of testing similar to that performed for the intersection model. Primarily, the Iteris freeway model is only different from its intersection counterpart in that it uses a different software, employing a more advanced detection algorithm. This algorithm uses a single detection zone to emulate a speed trap. Because of this, previously defined, calibrated, and saved detector-zone settings could not be used. Researchers experimented with both camera positions (Figures 21 and 22) and various shapes and sizes of detector zones. Testing revealed a slight improvement in speed estimates for trucks, but double detection of trucks remained a significant source of errors. The results obtained so far were puzzling. Determined to find the cause, researchers decided to investigate if these double detections were caused by any identifiable features of large trucks. In order to perform a systematic analysis, researchers observed video from the camera and correlated what they saw in the video with data coming out of the classifier. It did not take long to determine that double-detections were caused whenever the roof of the cab had a significantly different color from the trailer. Based on this finding, researchers decided to change the location of the camera to allow catching trucks from the side instead of the top. Figure 23 illustrates this position.

This camera position significantly improved the results. The errors reduced from approximately 50 percent to about 5 percent. Some inaccuracies in detection of speeds, mostly for trucks, remained unaccounted for. Further investigation revealed that these inaccuracies were introduced due to trucks decelerating in the presence of the visible red signal indication at the downstream signal (priority approach). Many times, this deceleration was occurring as the vehicles were going through the detection zone. Such discrepancies could be eliminated by moving the detection zones away from the area where vehicles are accelerating or decelerating. However, the best option is to use a trap with two detection zones. Researchers believe that modifications can be made to the PIA software to deal with the small number of remaining problems.

The next logical step would have been a repetition of experimentation with the Iteris intersection model using the last optimal camera position shown in Figure 23. However, the enormous time consumed in testing video systems had left no slack. If it can be made to work as intended, the Iteris intersection model is preferable because of the following two reasons:

1. It uses two detection zones per trap. Because of this, it can better handle accelerating or decelerating vehicles.
2. This system is the easiest and most economical for TxDOT to acquire.

Thus, researchers recommend that this issue be further investigated in a subsequent project.
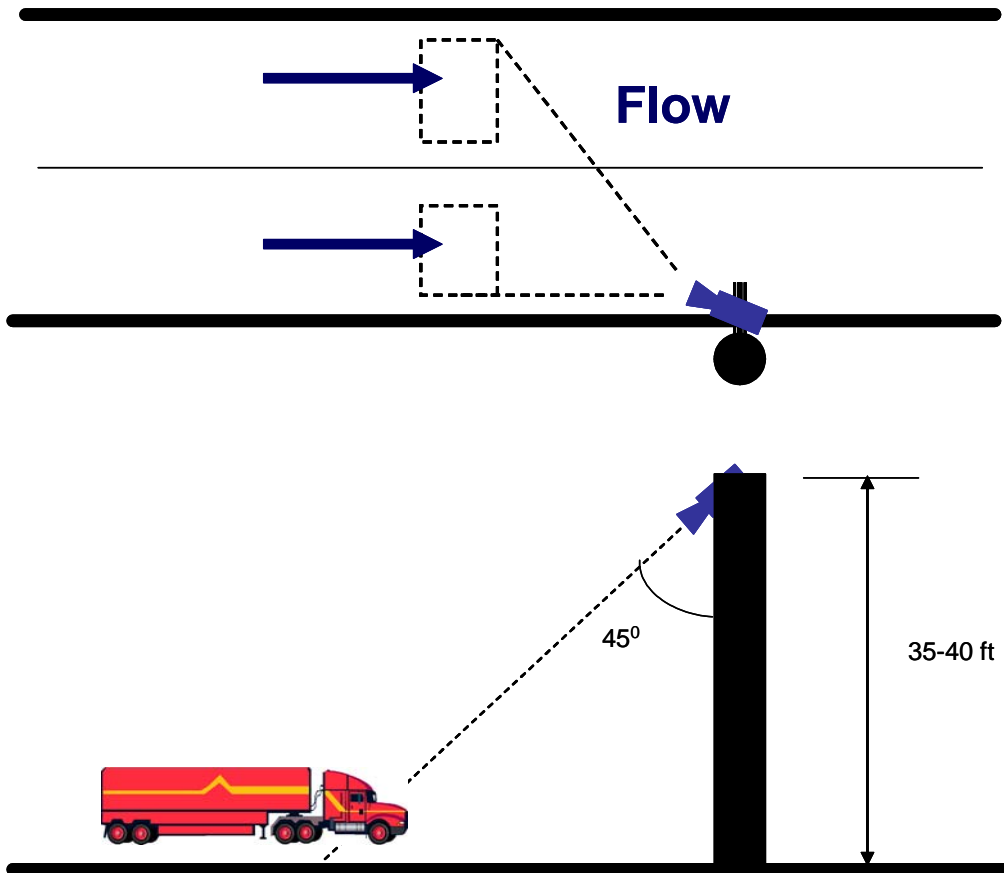
Figure 23. Third and Final Camera Location.

PIA System Testing and Operation

Now that most of the issues with video-based advance detection were resolved, it was time to turn on and test the PIA system. As mentioned earlier, this site experiences significant pedestrian demand. To ensure that system operation did not adversely affect pedestrians, researchers conducted a series of tests by activating pedestrian push buttons at all signal approaches before, during, and after preemptions. Researchers also observed the system operation during one noontime peak period with significant pedestrian traffic. Once satisfied, researchers observed the system operation using existing controller settings. Then, researchers revised controller programming to make its operation snappier. Researchers achieved this by revising the minimum phase times, maximum phase times, and gap settings. Also during one site visit, the TxDOT project director added a delay on a detector call for a shared through-right phase on one approach. During a significant number of signal cycles, the shared lane faces right-turn demand only. Most of these times, there is no need for a protected phase because these vehicles go through the signal during the red indication. These changes significantly improved the performance of the PIA system.

Summary of Findings

The following summarizes the findings from field studies:

- The PIA system accurately identifies platoons when it receives accurate data from the advance detectors.
- The PIA system is able to reliably and efficiently accommodate the detected platoons when there is light demand at conflicting phases.
- The operation of the PIA system can be improved by making the controller operation snappier. This is especially true when the PIA system is working under constraints to ensure that all or some conflicting phases receiving calls during a preemption must be serviced prior to issuing another preemption. Furthermore, researchers recommend a properly constrained system.
- For advance detection, an inductive loop trap is more accurate than video-based detection.

6. GUIDELINES AND RECOMMENDATIONS

SYSTEM INSTALLATION GUIDELINES

System installation requires several preliminary steps listed below:

1. Determine if a candidate site is appropriate for installing the PIA system.
2. Identify and acquire the components needed to install the system.
3. Inspect the site to determine the location for installing a detector trap.
4. Inspect the existing cabinet to determine if there is room to install the selected (required and optional) hardware.

Advance Detection

The PIA system requires the ability to detect individual vehicles and measure their speeds well in advance of the stopbar to allow sufficient time to detect platoons and provide controller override before the platoon arrives at the intersection. Either inductive loops or video cameras can be used for such advance detection. This section provides information needed to determine which of these technologies are to be selected for installation at a selected site.

Detector Trap Location

The detector trap should be placed such that the trailing edge (illustrated in Fi24) of the second detector meets the following criterion:

- For a high-speed (55 mph or higher) approach, the detector should be placed approximately 1000 ft from the stopbar.
- For a low-speed approach (40 mph or lower), the detector should be placed 600 to 700 ft from the stopbar.
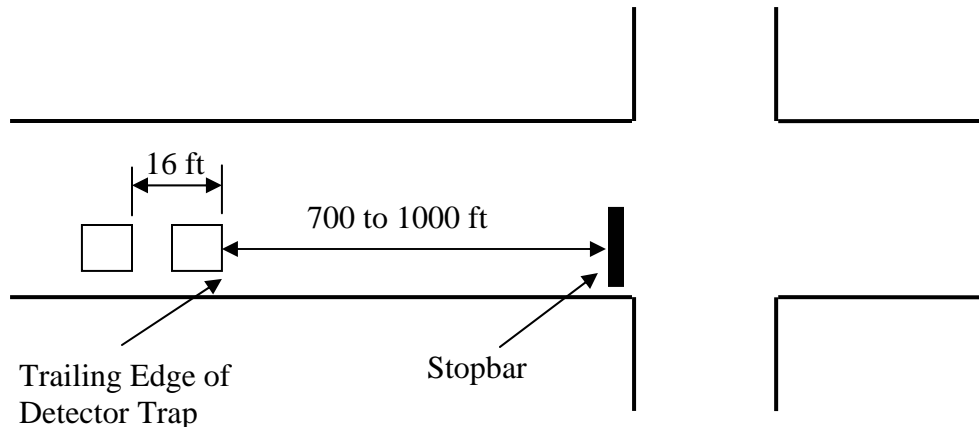
Figure 24. Placement of Detector Trap.

Video-Based Detection

In this project, TTI research shows that inductive loops are more reliable and more accurate than video-based detection for detecting speeds of individual vehicles. However, if video-based detection is selected, the system should be installed using the guidelines provided here.

Video-based speed detection can be of the following two types:

- using two detectors as shown in Figure 24 (i.e., Iteris Intersection Model), or
- using one detector to emulate a trap as shown in Figure 25 (i.e., Iteris Freeway Model).

In either one of the above cases, one camera can be used to provide detection in one or two lanes of an approach. Researchers recommend that the camera be installed on the near side at angles, as shown in Figure 25. These angles ensure that the top plus side of each vehicle is captured as it approaches the camera. This type of camera placement results in better detection of trucks.
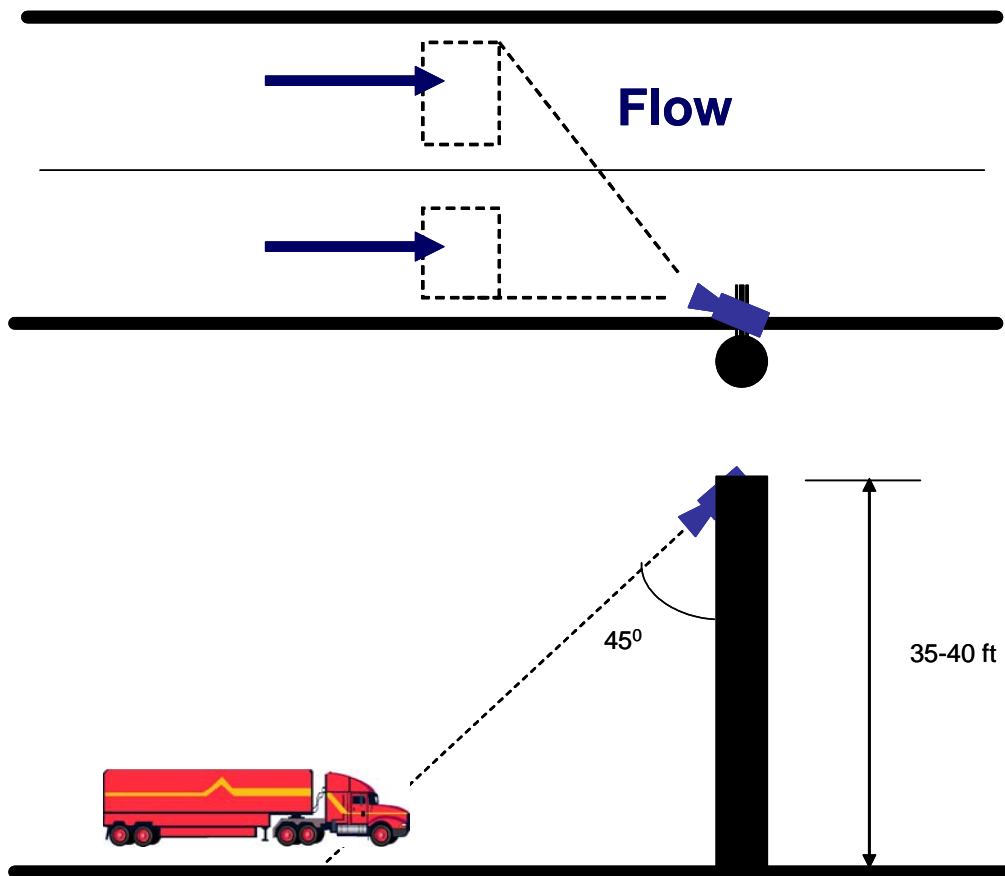
Figure 25. Camera Installation Guidelines.

In addition, for systems that emulate a trap using a single detector, the detector should be placed on a section of roadway over which the vehicles are moving at a constant speed because accelerating or decelerating vehicles may introduce errors in speed measurement.

Installation and Wiring of Remaining Components

Figure 26 illustrates how various components are connected to complete system installation. Chapter 4 provides detailed descriptions of these components. Note that the breakout panel is not needed if the system is to be installed in a TS-1 cabinet. Furthermore, with video-based advance detection, the video processor will replace the inductive loop amplifier shown in Figure 26.
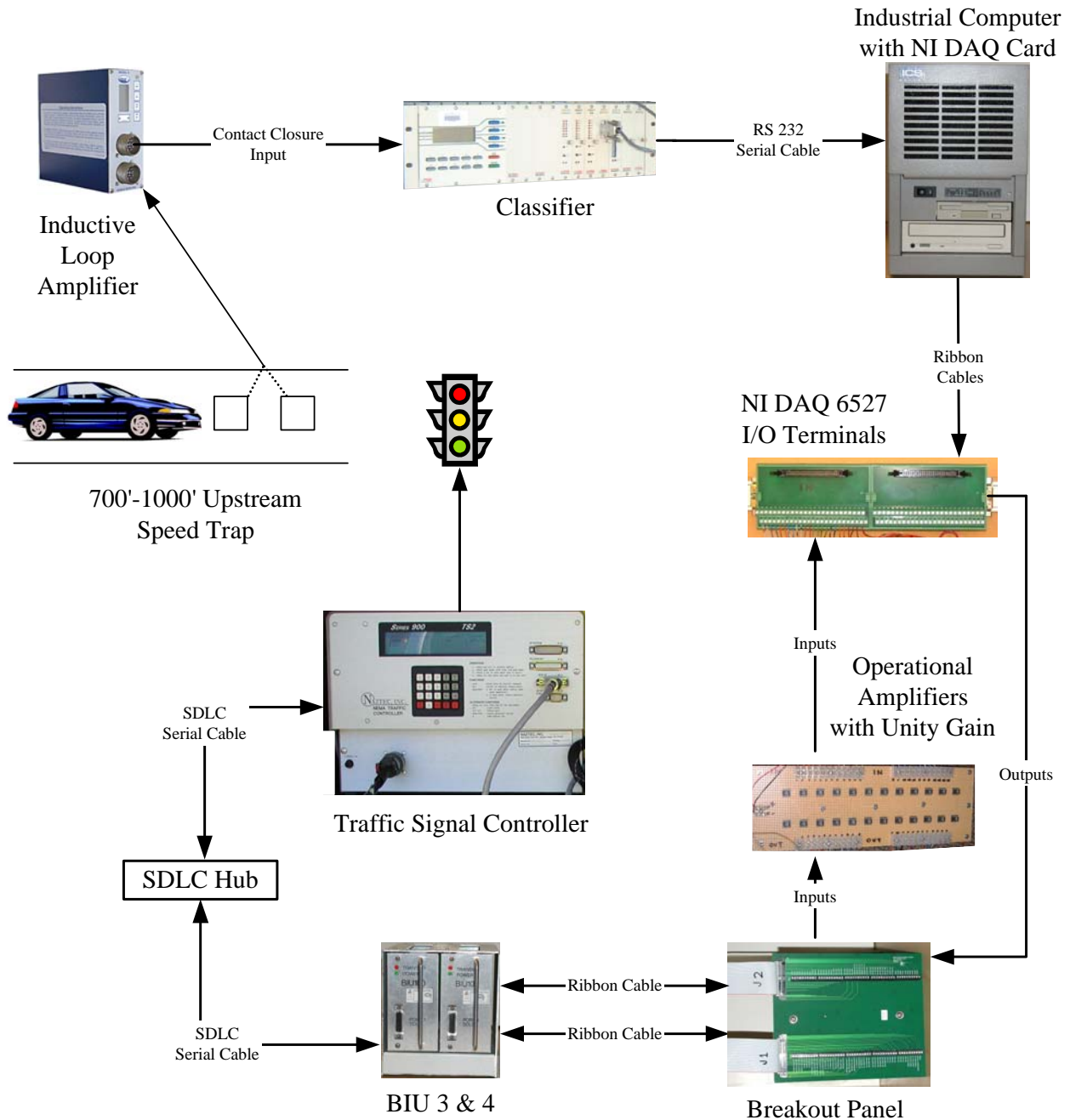
Figure 26. System Connection Diagram for a TS-2 Cabinet.

As illustrated in Figure 26, the PIA software resides on an industrial PC that can withstand extreme temperatures and other field conditions. This PC also houses the digital I/O card. A PC with the following specifications is recommended:

- 500 MHz or better CPU,
- 20 GB or larger hard disk drive (useful when user desires to log operational data),
- 256 megabytes of RAM, and
- Windows® 2000 operating system.

The PIA software needs phase and detector status inputs from the controller cabinet. Thus, the phase and detector status contact-closure connections on the controller's back panel (or breakout panel) need to be wired and mapped to the proper channels on the digital I/O card used by the PIA system to access these inputs from the controller cabinet. In addition, the low-priority preemption outputs from the PIA system need to be wired to the proper contact-closure connections on the controller back panel. Researchers recommend that preempt number 3 or higher be used. The next steps are to wire loop lead-ins to proper classifier input channels and to connect the classifier to the computer using a serial cable. The final step is to set the timer relay. Using a value slightly larger than the maximum preempt time (described below) set in the PIA software will ensure that the relay does not override normal operation.

SYSTEM CONFIGURATION GUIDELINES

System configuration requires programming preempt parameters in the controller and setting up the PIA software. These steps are described below.

Controller Setup

The controller should be programmed to provide a snappy operation. If the controller operation is sluggish, it will also make the PIA system sluggish because the PIA software has been designed to work within the constraints of controller operation. The following guidelines will ensure a more responsive preemption operation:

- Set preemption delay to zero. Delay is the amount of time the controller waits before activating a preempt signal.
- Set the controller to skip conflicting phases in the presence of a preemption signal. The PIA software provides an enhanced capability to skip selected phases. This feature is better than the all-or-nothing selection for these data in the controller.
- Set the value of the preemption extension to zero. The controller should not extend signal preemption beyond the signal from the PIA software.
- Set the preempt lockout to the smallest value possible without forcing the controller to service all conflicting phases. The PIA software provides a programmable lockout option.
- Set preemption to call the priority through phase only. This will allow the controller to time any concurrent phase with a call on its detector.

In addition to the above, researchers also recommend that other parameters in the controller be programmed with values to provide a snappy operation as well. These parameters include gap

(passage) settings for phases, minimum times for phases, and detector options. For instance, if through and right movements share a lane, a delayed call on the detector will improve operation.

PIA Software Setup

Appendix A provides examples of screens, along with descriptions of data on these screens. Data described below are important for setting up optimal operation.

Algorithm Parameters

These parameters appear on the Edit Parameters screen (Appendix A). Except for Detector Distance, Max Preempt, and Preempt Lock Duration, all values should be left at their default values. Class Distance specifies the distance between the stopbar and the speed trap. This value is dependent on trap installation. The other two parameters should be selected based on field observations.

Phase Configuration Data

Identify which conflicting phases are not to be skipped when demand is present on corresponding movements. These phases are referred to as Unprivileged Phases. For Phase Configuration data, check the box for each identified unprivileged phase. This will ensure that vehicles arriving on these phases during preemption are serviced before the software issues another preemption signal.

INITIAL OPERATION

To ensure safe and efficient operation, it is important to observe the operation of the system for a variety of prevalent traffic conditions. Such observations will more than likely identify parameters needing adjustments.

RECOMMENDATIONS FOR FUTURE

The PIA system developed in this project can be implemented at additional sites using the software developed by TTI and by acquiring additional hardware needed for system installation. We recommend that TxDOT consider the PIA system for implementation at other isolated signals where platoon progression is an important objective during a significant part of the day, but vastly varying traffic conditions or other constraints do not warrant interconnection with any adjacent signals. We also recommend that the use of video-based systems for advance detection of individual vehicle speeds be further investigated.

The cost of equipment needed for installing a system can be can be significantly reduced by implementing the following enhancements to the PIA system:

1. Replacing the hardware classifier with a software classifier developed recently by TTI researchers will save approximately $3000 in equipment costs. The software classifier can also be easily modified to take care of any false and double detection, resulting in a more efficient system.

2. Standardizing installation in a TS-2 cabinets using BIUs with serial ports will eliminate the need for a breakout panel (savings of $1000 per site). TTI researchers have recently developed specifications for these BIUs and successfully tested the first batch manufactured by Naztec, Inc. of Sugar Land, Texas.

Researchers recommend that a follow up project be initiated to incorporate the above implementation-based improvements and for field testing modified/enhanced systems at existing sites.

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APPENDIX A: PIA SOFTWARE

PIA Main Screen

The PIA Main Screen displays the current system activity such as the vehicles classified and detected by the system, various calculated values that the PIA system uses to determine if a platoon is detected or not, low-priority preemption status (on/off), and if a preemption is allowed during the current cycle or not. The main screen also provides the user with a set of menus that enables him/her to configure the PIA system and display other interface screens.
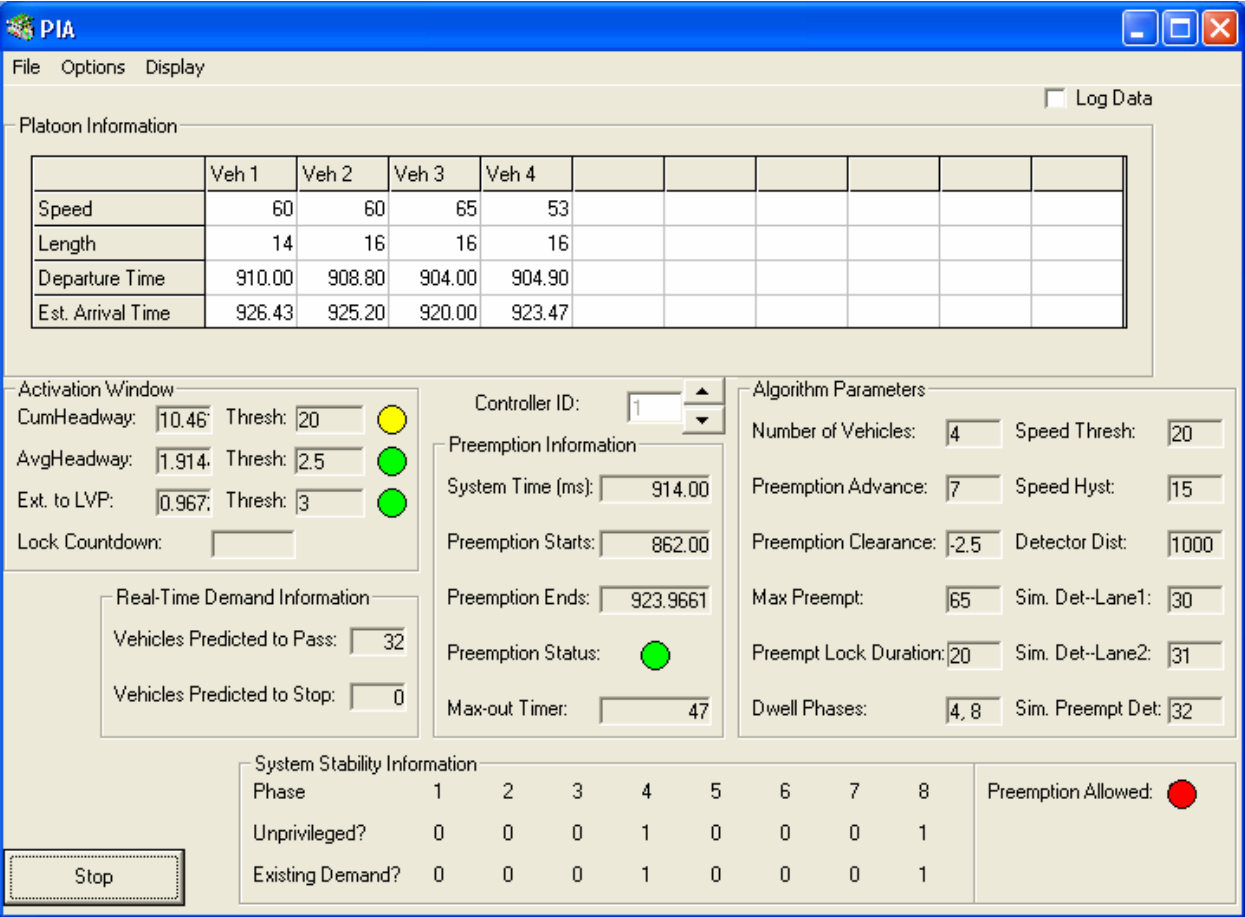
PIA File Menu

The PIA system relies on a configuration file to remember the user settings from one session to another. The PIA File Menu provides the user with the options of loading the default PIA system parameters or saving the current PIA system parameters into a configuration file that will be used the next time the system is started. The PIA system provides the user with a number of screens that enable him/her to customize the system configuration to a specific intersection.
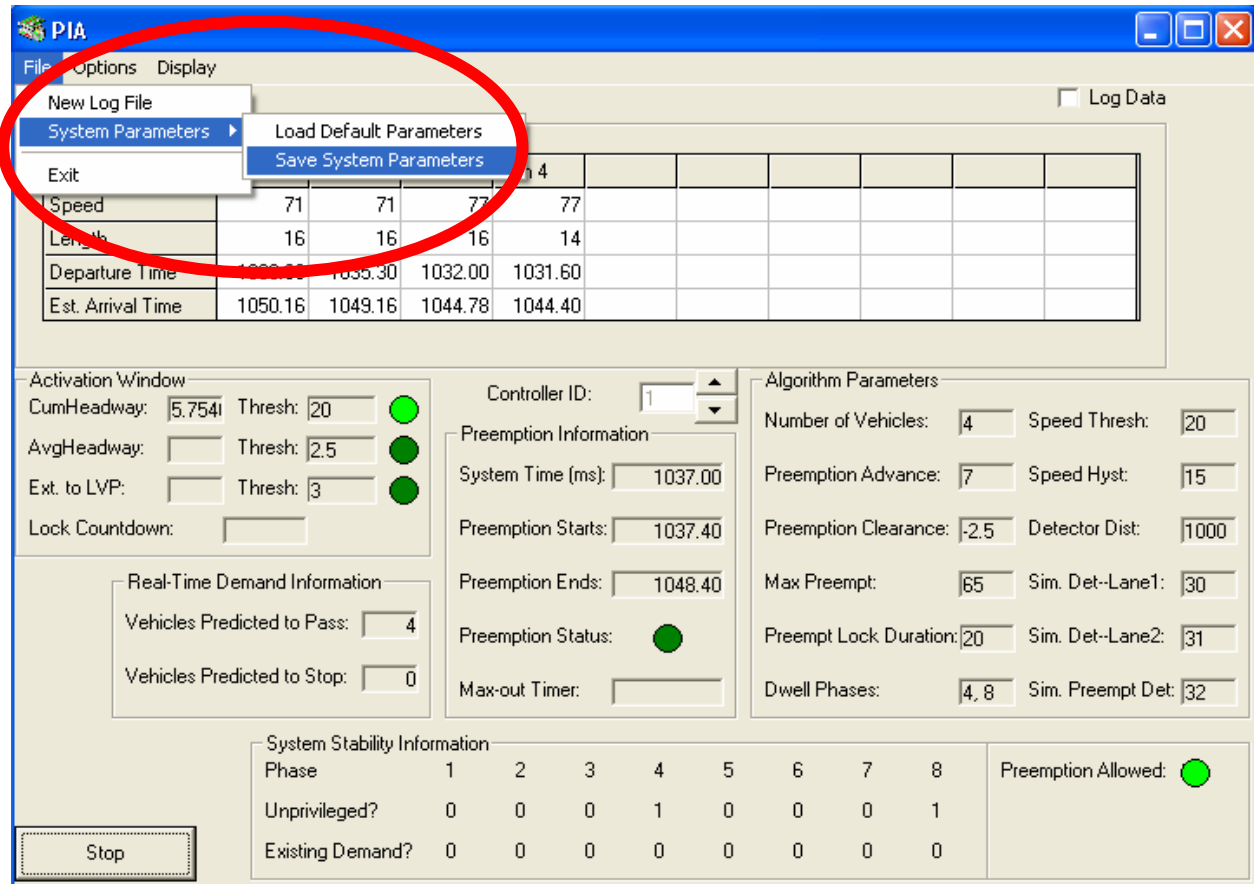
PIA Options Menu

The PIA Options Menu allows the user to edit and set the PIA system parameters through a series of user interface screens that include the Platoon Phase, Edit Parameters, Edit Phases, Edit Preempts, Edit System Parameters, and Edit CommPort Settings screens. The following figures explain these screens.
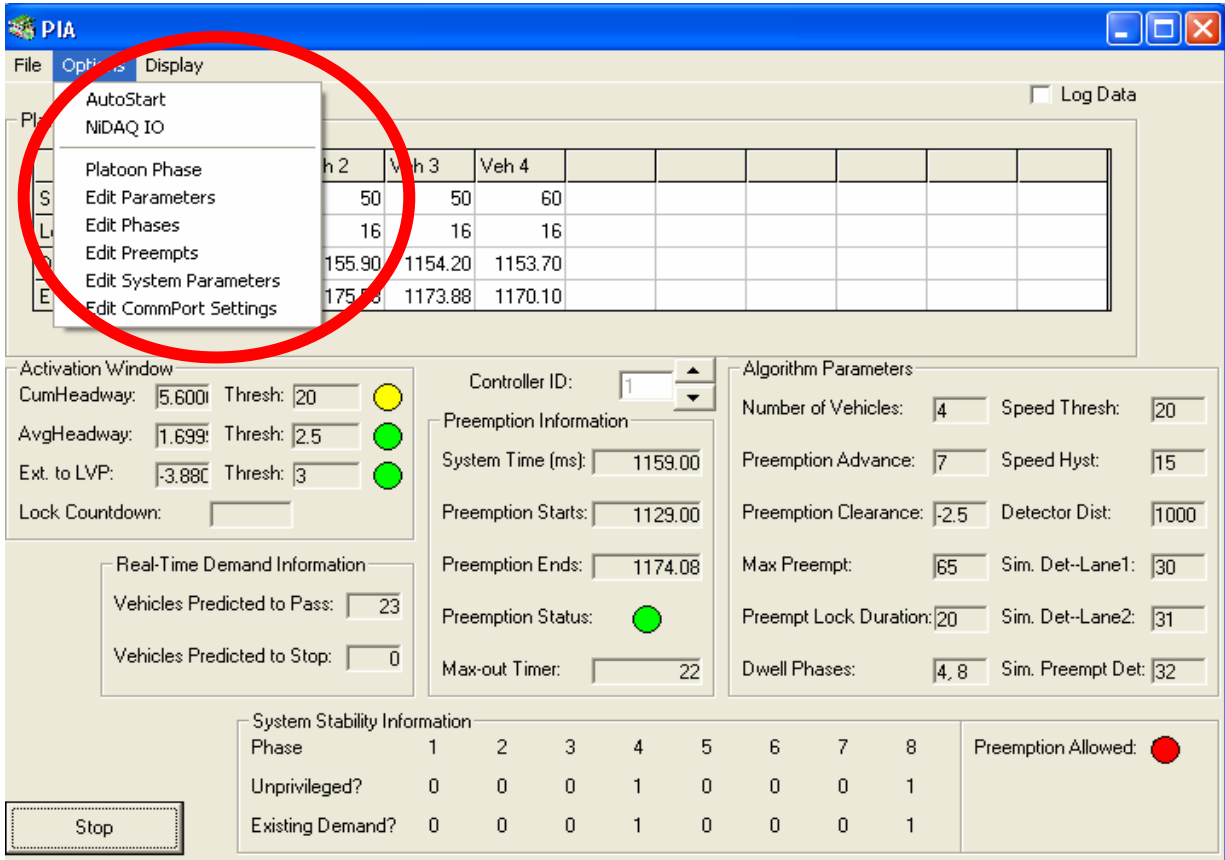
Platoon Phase Screen

In the Platoon Phase Screen, the user specifies the main street phase or approach for which platoons need to be detected.

Edit Parameters Screen

The Edit Parameters Screen allows the user to change some or all of the PIA parameters. Post-Preemption-Dwell-Phases setup is an optional feature provided to dwell on user-defined phases until the next platoon is identified. This is an advanced feature where the user, for example, can opt to provide green to the side street until a platoon is identified on the main street. The number of vehicles defined as a platoon in such a case could be as small as one vehicle.

Edit Phases Screen

The Edit Phases Screen provides the user with the capability of setting the direction of each phase, especially the main-street phases and other parameters that are used to provide the user with a display showing the status of each phase (green/yellow/red) and each stopbar detector (on/off). The Edit Phases Screen also allows the user to set the unprivileged flag for each phase, the SBDetector (stopbar detector) flag for phase, and the SBFunctional flag (that tells whether the stopbar detector for that phase is functional or not). The PIA algorithm uses these flags in making a decision whether to allow a low-priority preemption or not, even if there is a platoon. The Edit Phases Screen is used to configure the mapping between the digital I/O card channels and the phases these channels are connected to.

Edit Preempts Screen

The Edit Preempts Screen allows the user to map low-priority preemption contact-closure connections on the controller's back panel to the corresponding channels they are connected to on the digital I/O card that is being used by the Controller Interface subsystem to activate the low-priority preemption based on requests from the PIA algorithm.
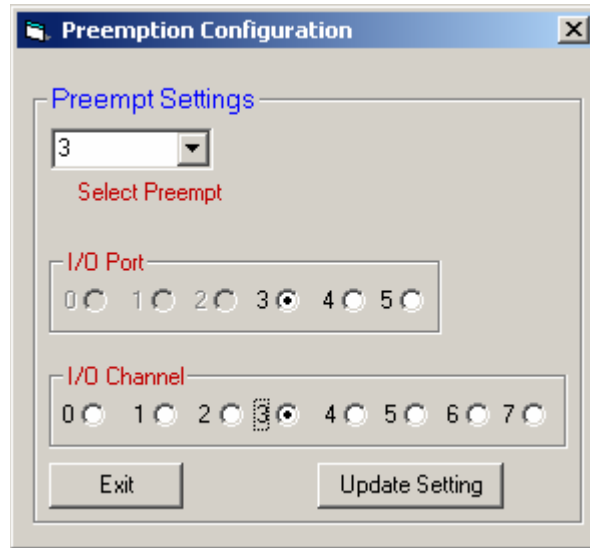
Edit System Parameters Screen

The Edit System Parameters Screen allows the user to specify the port on the digital I/O card including which channels are being used to get the phase status, detector status, and the ring-status bits. The user can also set the ports that are being used to send signals to activate the phase hold and low-priority preemption.
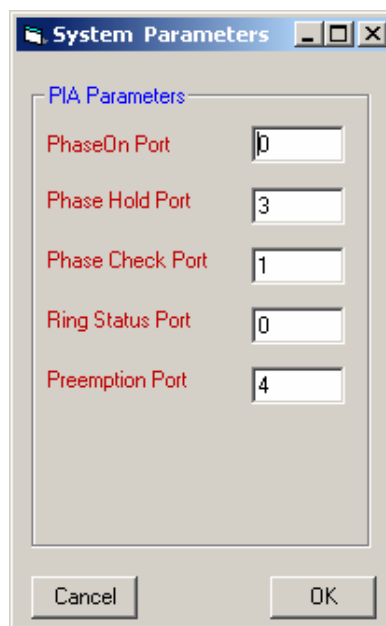
Edit CommPort Settings Screen

The Edit CommPort Settings Screen enables the user to specify the serial port number on the PC to be used by the PIA algorithm to communicate with the Peek ADR-2000 classifier. The classifier provides the PIA algorithm with length and speed of vehicles detected by the upstream speed trap detectors. The screen also allows the user to set the baud rate for communicating with the classifier.

Display Menu

The Display Menu provides the user with access to other user interface screens to monitor the status of main-street and side-street phases, stopbar detectors, and classifier output.

Intersection Display Screen

The Intersection Display Screen provides the user with the ability to monitor the status of main-street and side-street phases in addition to stopbar detectors and the status of the low-priority preemption activated by the PIA algorithm.
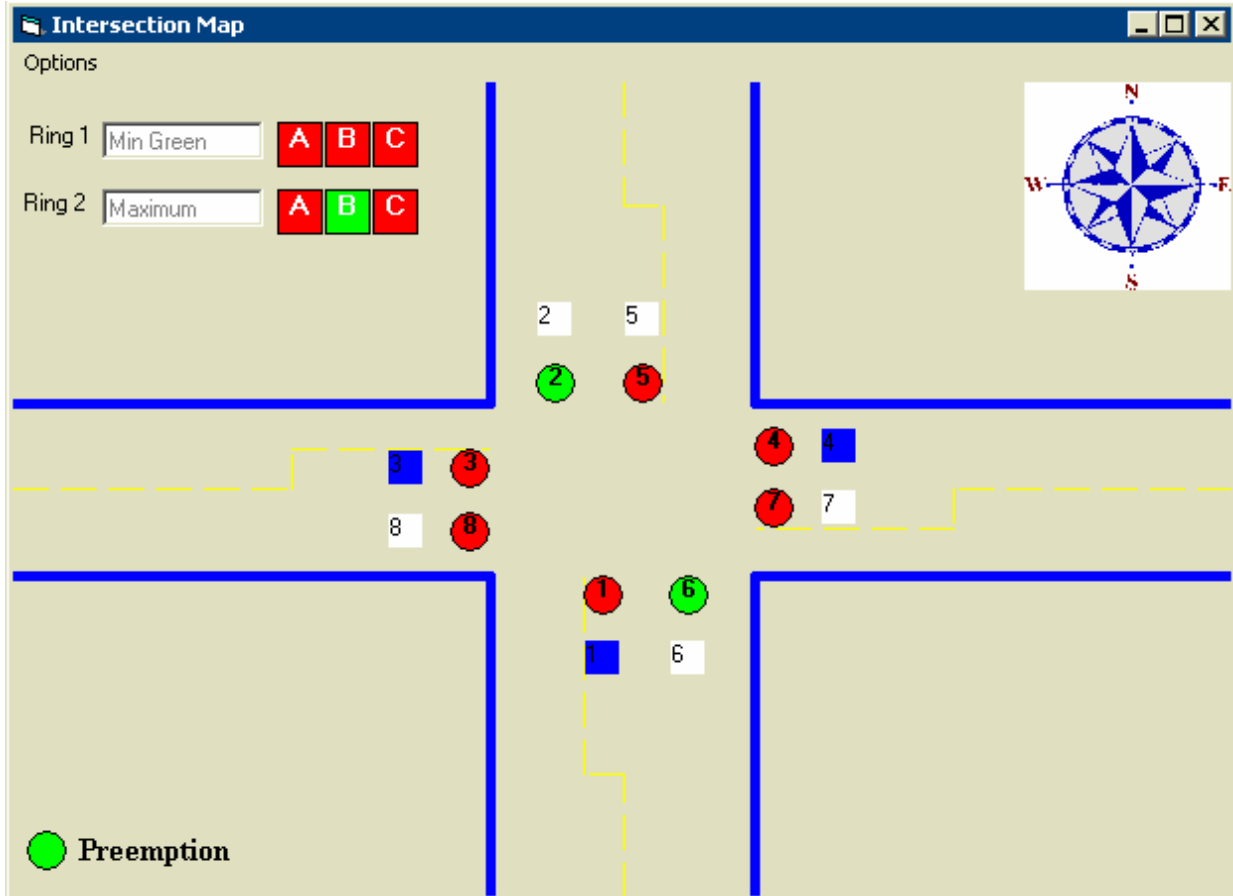
APPENDIX B: WIRING GUIDELINES

The National Instruments' 6527 digital I/O (NIDAQ 6527) card consists of six ports. The ports are numbered 0, 1, 2, 3, 4, and 5. Ports 0, 1, and 2 are input ports, and ports 3, 4, and 5 are output ports. Each port consists of eight channels. The card has a total of 24 input channels and 24 output channels. The 24 input channels are used to get the advanced detector, stopbar detector, and phase status from the corresponding contact-closure connection on the cabinet's back panel. One output channel is used to send a signal to the low-priority preemption used to bring back or hold the main phase where platoons are detected and served. The following provides a listing of the digital I/O channel configurations by port used in George West, Texas.

INPUT PORT 0
Channel 0   Ring 1 – Status Bit A
Channel 1   Ring 1 – Status Bit B
Channel 2   Ring 1 – Status Bit C
Channel 3   Ring 2 – Status Bit A
Channel 4   Ring 2 – Status Bit B
Channel 5   Ring 2 – Status Bit C
Channel 6
Channel 7

INPUT PORT 1
Channel 0   Phase 1 Check or Phase 1 Stopbar Detector
Channel 1   Phase 2 Check or Phase 2 Stopbar Detector
Channel 2   Phase 3 Check or Phase 3 Stopbar Detector
Channel 3   Phase 4 Check or Phase 4 Stopbar Detector
Channel 4   Phase 5 Check or Phase 5 Stopbar Detector
Channel 5   Phase 6 Check or Phase 6 Stopbar Detector
Channel 6   Phase 7 Check or Phase 7 Stopbar Detector
Channel 7   Phase 8 Check or Phase 8 Stopbar Detector

INPUT PORT 2
Channel 0   Phase 1 On
Channel 1   Phase 2 On
Channel 2   Phase 3 On
Channel 3   Phase 4 On
Channel 4   Phase 5 On
Channel 5   Phase 6 On
Channel 6   Phase 7 On
Channel 7   Phase 8 On

OUTPUT PORT 3
Channel 0
Channel 1
Channel 2   Low-priority Preempt #3
Channel 3
Channel 4
Channel 5
Channel 6
Channel 7