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16. Abstract

Video imaging vehicle detection systems (VIVDSs) are becoming an increasingly common means of detecting traffic at intersections and interchanges in Texas. This interest stems from the recognition that video detection is often cheaper to install and maintain than inductive loop detectors at multi-lane intersections. It is also recognized that video detection is more readily adaptable to changing conditions at the intersection (e.g., lane reassignment, temporary lane closure for work zone activities). The benefits of VIVDSs have become more substantial as the technology matures, its initial cost drops, and experience with it grows.

This manual assists engineers with the planning, design, and operation of a VIVDS. This assistance is provided in three ways. First, the manual provides information about critical issues associated with the planning, design, and operation stages. Second, it provides information to guide engineers in making appropriate decisions during each stage. Third, its comprehensive coverage should enable engineers to thoughtfully direct others during VIVDS installation and maintenance activities.

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INTERSECTION VIDEO DETECTION MANUAL

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NOTICE

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

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CHAPTER 1. INTRODUCTION

OVERVIEW

Video imaging vehicle detection systems (VIVDSs) are becoming an increasingly common means of detecting traffic at intersections and interchanges in Texas. This interest stems from the recognition that video detection is often cheaper to install and maintain than inductive loop detectors at multi-lane intersections. It is also recognized that video detection is more readily adaptable to changing conditions at the intersection (e.g., lane reassignment, temporary lane closure for work zone activities). The benefits of VIVDSs have become more substantial as the technology matures, its initial cost drops, and experience with it grows.

It is estimated that about 10 percent of the intersections in Texas currently use VIVDSs. The collective experience with the operation of these intersections has generally been positive; however, this experience is limited to a short amount of time (relative to the life of such systems). Moreover, experience with the design and installation of a VIVDS for intersection control has been limited. This limitation is due to the fact that most intersection control applications have been "turnkey" arrangements with the product vendors. Further increases in VIVDS application will require greater participation by TxDOT engineers in the planning, design, operation, and installation stages.

OBJECTIVE AND SCOPE

Objective

This manual is intended to assist engineers with the planning, design, and operation of a VIVDS. This assistance is provided in three ways. First, the manual provides information about critical issues associated with the planning, design, and operation stages. Second, it provides information to guide engineers in making appropriate decisions during each stage. Third, its comprehensive coverage should enable engineers to thoughtfully direct others during VIVDS installation and maintenance activities.

Some of the guidance provided in this document was obtained from a review of the literature and from interviews with TxDOT staff. Some guidance was also developed using the geometric relationships of camera optics and the principles of detection design. The report by Bonneson and Abbas (*1*) documents these development activities. In particular, it describes the rationale underlying the guidance and the validation of some guidelines based on simulation or field data.

Scope

The guidelines provided in this manual address the use of a VIVDS to provide vehicle presence detection at a signalized intersection or interchange in Texas. The facility can be new or existing. It can be in an urban or rural environment and on a collector or arterial roadway. To the

extent practical, the guidelines are applicable to all VIVDS products. They are applicable to detection designs that use one camera (for each intersection approach monitored) to provide detection at the stop line and, if needed, detection in advance of the stop line.

The guidelines are developed for intersections and interchanges that use one signal controller. The research does not explicitly address the use of a VIVDS to facilitate coordinated signal operation, beyond that needed to affect stop-line detection in support of such operation. The research does not address the use of a VIVDS for measuring vehicle count, speed, headway, occupancy, or other traffic characteristics beyond that needed for basic intersection (or interchange) control using presence-mode detection.

The terms "detection design," "detection layout," "detection zone," and "detection accuracy" are used frequently in this manual. *Detection design* refers to the selection of camera location and the calibration of its field of view. *Detection layout* refers to the location of detection zones, the number of detection zones, and the settings or detection features used with each zone. A *detection zone* is defined to be one or more VIVDS detectors that are configured (or linked) to act as one detector and that are separated from upstream and downstream detection zones by at least the effective length of a vehicle. *Detection accuracy* relates to the number of times that a VIVDS reports either a detection when a vehicle is in the detection zone or no detection when a vehicle is not in the detection zone. Violation of either condition represents a discrepancy between the phase-call information provided by the VIVDS and the true call information, as would be provided by a perfect detector.

APPLICATION GUIDELINES

This section describes VIVDS application guidelines. These guidelines can be used to identify situations where a VIVDS will be more effective or efficient than an inductive loop system. The following topics are addressed in this section: common applications, cost and performance considerations, and guidelines for planning VIVDS applications.

Common Applications

Common intersection applications for a VIVDS are described in this section. Intersection applications are categorized as stop-line-only detection and stop-line plus advance detection. Specific conditions and special situations where a VIVDS has been found to be cost-effective, relative to inductive loops, are identified.

Stop-Line Detection

For signalized intersection applications, a VIVDS is most often used to provide vehicle presence detection in the vicinity of the stop line. The VIVDS cameras are mounted on the mast arm or on the mast-arm pole. A VIVDS is found to provide reliable presence detection when the detection zone is relatively long.

Stop-Line Plus Advance Detection

A VIVDS is sometimes used to provide advance detection on high-speed intersection approaches. Some agencies are cautious about this use because of difficulties associated with the accurate detection of vehicles that are distant from the camera. However, experience with VIVDSs in Texas indicates that acceptable advance detection can be achieved at distances of up to 500 ft (as measured from the camera to the most distant point of advance detection).

Cost-Effective Applications

A VIVDS is primarily used in situations where its high initial cost is offset by that associated with installing and maintaining inductive loop detectors. VIVDSs have been generally recognized as cost-effective, relative to alternative detection systems, in the following situations:

- as a temporary detection system during intersection reconstruction (especially when lane assignments change during the course of the reconstruction project),
- as a temporary detection system at large intersections scheduled for overlay,
- as a permanent detection system when inductive loop life is short due to poor pavement,
- as a permanent detection system when it is anticipated that lane location or assignment may change in less than three years,
- when the loop detection zones equal or exceed 100 ft,
- when the loop installation is physically impractical due to poor pavement, and
- when the pavement in which the loop is placed will be reconstructed in less than three years or during overlay projects at large intersections where the cost of replacing all loops exceeds the cost of installing the VIVDS.

Special Applications

The flexibility of a VIVDS has been found useful at unusual intersection approaches where inductive loops (and associated lead-ins) cannot be installed or are prohibitively expensive to install. Situations where these conditions may exist include:

- approaches that cross railroad tracks,
- approaches where one or more detection zones are located on a bridge deck, and
- approaches where special permits are required for installation of one or more inductive loops or the associated lead-in cables.

The first situation recognizes the difficulties associated with obtaining permission from the railroad companies to install conduits under their railroad tracks. This need arises when the railroad tracks are located in the detection zone of one or more intersection approach legs. The second situation recognizes the reluctance of most agencies to cut loops into a bridge deck due to possible compromises in the bridge deck's structural integrity. The third situation is a more general variant

of the previous two situations and recognizes that underground utilities, machinery, and culverts sometimes pose special problems with the installation of loops or loop lead-ins.

In addition to vehicle control, the VIVDS can be used to provide a surveillance function at high-volume locations. Specifically, it can be used to remotely monitor intersection operations from a central control facility or a traffic management center.

Cost and Performance Considerations

Newly Constructed Intersections

The cost of installing and maintaining a VIVDS at a new intersection is described in this section. This cost is compared with that for an inductive loop system. The direct cost components of a VIVDS include the initial cost of the equipment, the cost to purchase and install the coaxial cable, the labor cost associated with the installation of the VIVDS cameras, and the cost of setting up the detection zones. These costs are estimated to total about $23,000 for a typical, four-camera VIVDS; a breakdown of cost components is shown in Table 1. The total 10-year cost represents a present-worth analysis based on a 3.0-percent annual interest rate.

Table 1. Representative Detection System Cost Comparison.

Detection System	Component	Direct Cost, $	Maintenance Costs, $/yr	Total 10-Year Cost, $
VIVDS	Hardware (processor + four cameras)	16,000		
	Install coaxial wire lead-ins for four cameras	3000		
	Install cameras and set up detection zones	4000		
	Total:	23,000	600	28,000
Inductive Loops [1,2]	Loops installed only at stop line	22,000	800	29,000
	Loops installed in advance and at stop line	37,000	1600	51,000

Notes:
1 - Loop costs are based on a high-speed, four-lane major road intersecting with a low-speed, two-lane minor road.
2 - Maintenance costs for loops are based on an average loop life of 10 years.

The costs listed in Table 1 are intended to illustrate the general trends in cost of the two detection systems. These costs can vary considerably among agencies; however, the relative trends should be substantially the same. The costs shown indicate that a VIVDS has an initial cost that is slightly higher than that of an inductive loop system for a stop-line-only application. The cost of the additional loops for an advance detection application reverses this trend. Regardless, the VIVDS has a much lower total cost (over a 10-year period) when the cost of loop replacement is considered.

Existing Intersections

Justifying the cost of a VIVDS at an existing intersection is complicated by the fact that the existing inductive loop system is often in place and providing some service. Under these circumstances, the wholesale replacement of the loops with a VIVDS is not always easy to justify. One TxDOT district has overcome this complication by using single-camera VIVDS products in a piecemeal replacement process. This district's policy is to install a single-camera VIVDS when one or more loops fail on a given intersection approach. Following this policy, when single-camera VIVDSs are in service on two approaches and the loops fail on a third approach, the entire detection system is then upgraded to a four-camera VIVDS.

Design Life

The majority of VIVDSs at TxDOT-operated intersections have been in service less than six years. As a result, TxDOT has not fully experienced the life cycle of its VIVDS equipment. To date, there appears to be no evidence to suggest that VIVDS hardware will not last at least seven to ten years.

Other Cost Considerations

Communications. Coaxial cable is the primary means of video communications. Although, systems that support twisted-pair or wireless communications are available, there has been only limited experience with them at the time of this research.

Lens Adjustment Module. A lens adjustment module (LAM) is an essential VIVDS-related installation device. This device connects to the back of the camera and is used during the camera installation to adjust the camera's zoom and focus settings. Some districts have found it necessary to have a LAM available to their staff to facilitate subsequent camera adjustments or replacements. This device is not standardized among VIVDS manufacturers; hence, a separate device is needed for each type of VIVDS product used in the district.

Controller Cabinet. A ground-mounted controller cabinet is preferred for the typical multiple-camera VIVDS installation. This cabinet provides the extra space needed for the VIVDS processor. It is particularly important when the VIVDS processor is accompanied by a monitor (a desirable arrangement that is available with some VIVDS products). A pole-mounted cabinet does not generally provide adequate space for VIVDS equipment, although at least one district has installed a VIVDS in a pole-mounted cabinet. Cabinet size will be less of an issue when rack-mounted VIVDS products are more readily available.

Field Setup Computer. Several VIVDS products can be set up or adjusted in the field with only a video monitor and a computer pointing device (i.e., a "mouse"). Because this equipment has a relatively low cost, it is routinely purchased for each intersection installation and left permanently inside the controller cabinet. Other VIVDS products require the use of a field setup computer

(typically a laptop computer) for setup or adjustment. This computer is generally too expensive to be purchased for each intersection; thus, the technician must carry it to the site for each maintenance visit.

Performance Considerations

It is generally recognized that inductive loop detectors provide more accurate information about vehicle presence than is provided by a VIVDS. Research indicates that VIVDS detectors are routinely in error by ±0.5 s relative to the vehicle's true arrival and departure from the detection zone. However, errors in this range have minimal impact on traffic operations when stop-line presence-mode detection is used.

Guidelines for Planning VIVDS Applications

A VIVDS should be considered for a signalized intersection or interchange when one or more of the following conditions are present:

- when more than 12 stop-line detectors are needed at the intersection or interchange,
- when inductive loop life is short due to poor pavement or poor soil conditions,
- when extensive intersection reconstruction will last for one or more years,
- when the loop installation is physically impractical due to the presence of a bridge deck, railroad tracks, or underground utilities, or
- when the pavement in which the loop is placed will be reconstructed in less than three years or during overlay projects at large intersections where the cost of replacing all loops exceeds the cost of installing the VIVDS.

With regard to the second condition listed, the life-cycle costs of a four-camera VIVDS and an inductive loop system were examined to determine when a VIVDS was cost-effective. The results of this examination are shown in Figure 1. The trend line in this figure identifies the minimum number of detection zones needed to justify the cost of a four-camera VIVDS. The figure is applicable to intersections with stop-line detection. Intersections with advance detection will always have sufficient detector needs to justify the use of a VIVDS (based on a cost analysis).

To illustrate the use of Figure 1, consider an intersection of a four-lane highway with a two-lane minor road. The major road has a left-turn bay on each approach. A total of eight stop-line detectors will be needed if VIVDS is not used. The area in which the intersection is located has an average loop life of six years. This combination of eight detectors and six years intersects above the trend line indicating that a four-camera VIVDS is cost-effective at this intersection. However, if average loop life is 10 years in this area, then an inductive loop system would be more cost-effective at this intersection.

Justification of a four-camera VIVDS at an existing intersection is sometimes complicated by the fact that the existing inductive loop system is often in place and providing some service.

Under these circumstances, the wholesale replacement of the loops with a VIVDS is sometimes difficult to justify. This complication can be overcome by incrementally installing single-camera VIVDS products as the existing loops fail on a given intersection approach.
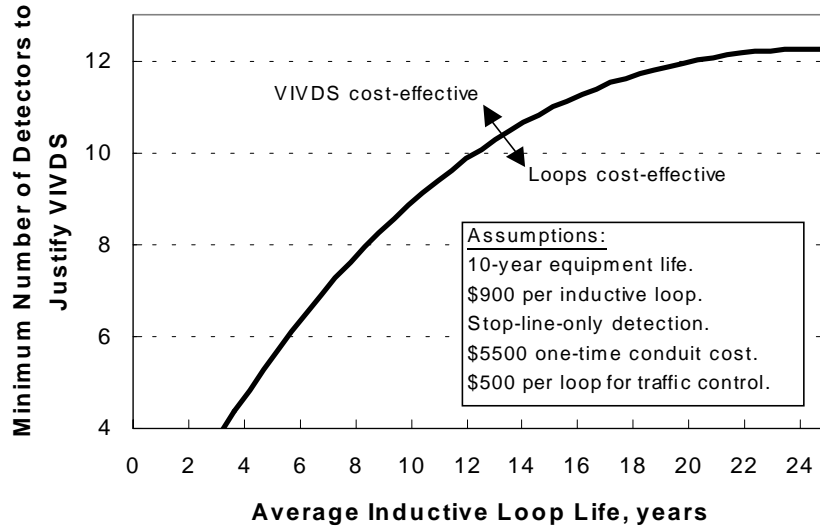
Figure 1. Minimum Number of Detectors to Justify VIVDS Cost.

CHAPTER 2. DESIGN GUIDELINES

OVERVIEW

This chapter addresses several important VIVDS design elements. These elements include camera mounting location and field-of-view calibration. Design considerations include the camera's height, offset, distance from the stop line, pitch angle (relative to a horizontal plane), and lens focal length. The first three considerations refer to "camera location" and the last two considerations refer to the "field-of-view calibration." The variables associated with these considerations are illustrated in Figure 2. Lens focal length refers to the degree to which the field of view is magnified (or "zoomed"). Intersection lighting is also an important design consideration as it relates to VIVDS performance. It is also discussed in this chapter.
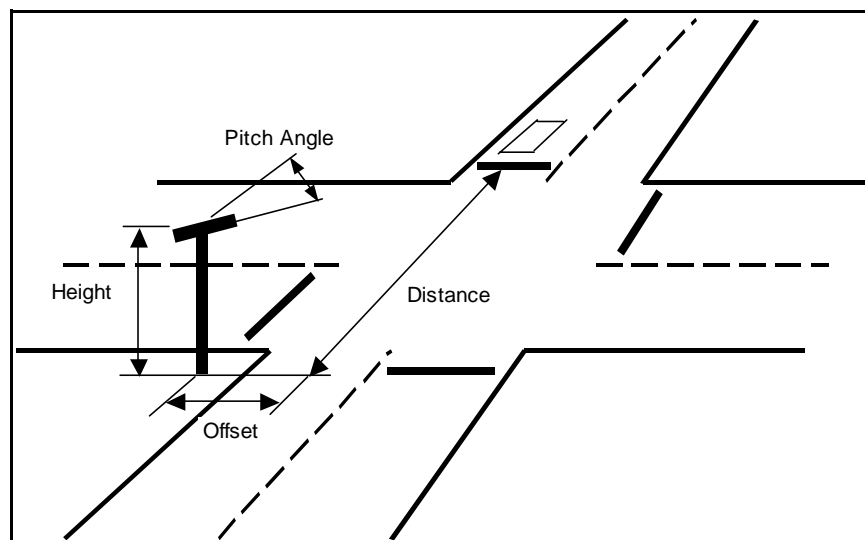
Figure 2. Variables Defining a Camera's Location and Field of View.

Issues associated with the various VIVDS design elements are described in the first section of this chapter. Guidelines for VIVDS design are described in the second section. The guidelines provided are intended to minimize or avoid problems associated with the issues raised in the first section.

CONSIDERATIONS

This section describes the various issues associated with camera location and field-of-view calibration. These issues include occlusion, camera stability, shadows, glare, and reflections.

Camera Location

An optimal camera location is one that maximizes detection accuracy. As such, an optimal location is one that provides a stable, unobstructed view of each traffic lane on the intersection approach. The view must include the stop line and extend back along the approach for a distance equal to that needed for the desired detection layout. An example of an optimal camera location is identified by the letter "A" in Figure 3a. Its associated field of view is shown in Figure 3b. The factors associated with camera location that reduce detection accuracy are described in this section.
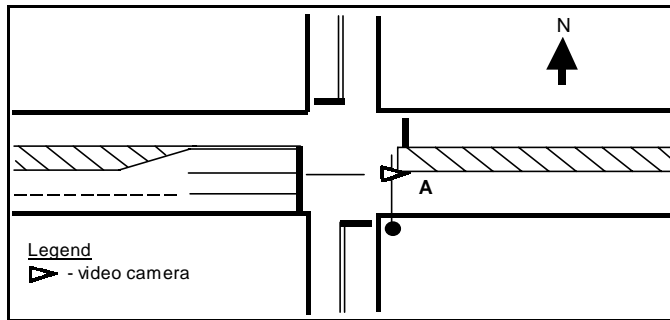
a. **Illustrative Optimal Camera Location.**   b. **Illustrative Optimal Field of View.**

Figure 3. Illustrative Optimal Camera Location and Field of View.

Occlusion

Detection accuracy is adversely affected by vehicle occlusion. Occlusion refers to a situation where one vehicle blocks or obstructs the camera's view of a second vehicle. Three types of occlusion are present with most camera locations: adjacent-lane, same-lane, and cross-lane.

Adjacent-lane (or horizontal) occlusion occurs when the blocked and blocking vehicles are in adjacent lanes. Figure 4 illustrates this type of occlusion. In this figure, the truck in the through lane blocks the camera's view of the left-turn lane. The truck is likely to inadvertently trigger a call for the left-turn phase (regardless of whether the phase is needed). Moreover, if the left-turn phase leads the through phase, the left-turn phase is likely to extend to its maximum duration.

Figure 5 illustrates the potential for adjacent-lane occlusion when the camera is mounted on the left side of the approach. Although occlusion by a vehicle is not explicitly shown in this figure, its potential is quite real given the flat angle of the camera and the location of the detection zones (the upstream corner of each zone is denoted by a numeral).

Figure 4. Adjacent-Lane Occlusion with Right-Side Camera.

Figure 5. Adjacent-Lane Occlusion with Left-Side Camera.

Adjacent-lane occlusion from a left-side camera can be caused by vehicles approaching or departing the intersection. A vehicle waiting in the left-turn bay will occlude the camera's view of the adjacent through lane. A tall vehicle departing the intersection in the inside through lane will occlude the left-turn bay. Either type of occlusion can lead to unneeded calls for the left-turn or through phase. In Figure 5, a truck departing from the intersection in the outside lane casts a shadow (from the luminaire) and triggers an unnecessary call for the left-turn phase (as denoted by the four highlighted corners for each of two detection zones in the left-turn bay).

Same-lane (or vertical) occlusion occurs when the blocked and blocking vehicles are in the same lane. Figure 6 illustrates this type of occlusion. The tall truck at the stop line blocks the camera's view of the lane just behind the truck's trailer. Same-lane occlusion prevents the separate detection of successive vehicles as they cross the stop line. This type of occlusion is not problematic when presence-mode operation is combined with a stop-line detection zone. Same-lane occlusion is largely a problem when count measurements are needed by the controller (such as for volume-density operation). The extent of this problem increases as the distance between the location of measurement and the stop line increases.

Figure 6. Same-Lane Occlusion.

Cross-lane occlusion occurs when a vehicle crosses between the camera and the intersection approach being monitored. This crossing vehicle momentarily obstructs the camera view of the subject approach and prohibits the VIVDS from sensing vehicle presence. There is also the possibility that the crossing vehicle will trigger an unnecessary call to the subject approach.

Camera Stability

Desirable camera heights and offsets are often limited by the availability of structures that can provide a stable camera mount. Most VIVDS products have an image stabilization feature that can compensate for some camera motion. However, excessive camera motion can adversely affect detection accuracy. Figure 7 illustrates the impact of camera motion on the field of view.

a. Camera Sways to Left Position   **b. Camera Sways to Right Position.**
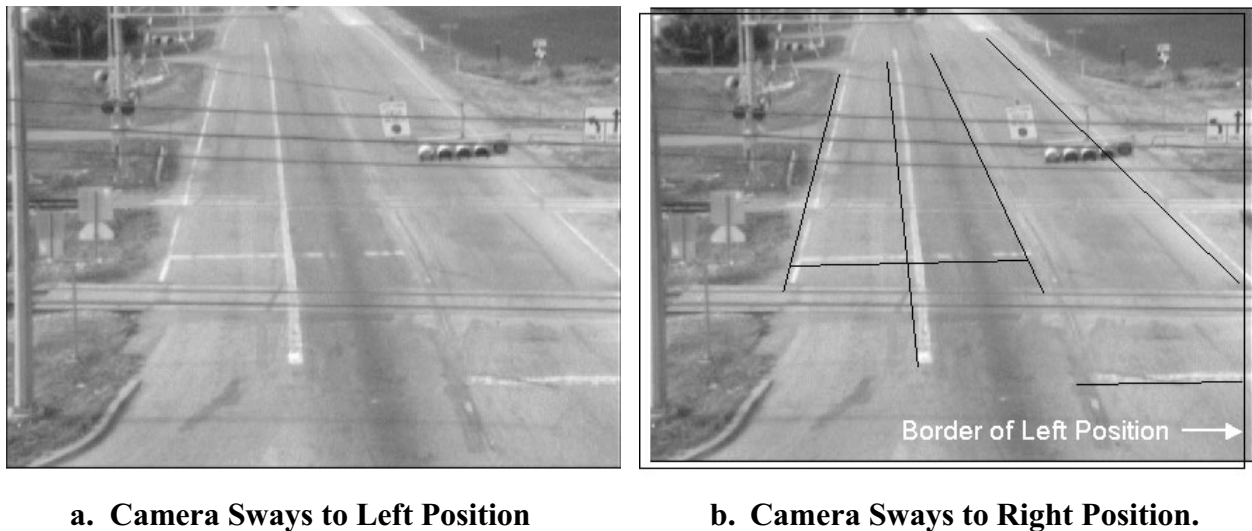
Figure 7. Effect of Camera Motion on Image Stability.

Figure 7 shows two images recorded from a camera during a gusty wind. The image in Figure 7b was recorded 0.07 s after the image in Figure 7a. The black lines shown in Figure 7b were initially drawn over the lane and stop lines in Figure 7a. These lines were then imposed on Figure 7b, to illustrate the extent of the camera motion. The motion shown represents a 1.8-percent horizontal shift and 1.0-percent vertical shift for a total shift of 2.0 percent. A 2.0-percent shift equates to a 6.0-ft shift at 300 ft. The TxDOT VIVDS specification (*2*) requires that a VIVDS compensate for shifts up to 2.0 percent. Therefore, the camera mount must be sufficiently stable as to ensure that the image shifts by no more than 2.0 percent on windy days.

Field-of-View Calibration

Calibration of the camera field of view is based on a one-time adjustment to the camera pitch angle and the lens focal length. An optimal field of view is one that has the stop line parallel to the bottom edge of the view and in the bottom one-half of this view. The optimal view includes all approach traffic lanes. The focal length would be adjusted such that the approach width, as measured at the stop line, equates to 90 to 100 percent of the horizontal width of the view. Finally,

the view must exclude the horizon. An optimal field of view is shown in Figure 3b. The factors that must be overcome to obtain an optimal field of view are described in this section.

Sun Glare and Reflection

Detection accuracy is significantly degraded by glare from the sun and, sometimes, from strong reflections. Both reflection and sun glare are illustrated in Figure 8. Sun glare represents direct sunlight entering the camera (typically during dawn or dusk hours). Reflections emanate as "stars" of bright light coming from vehicle corners or edges.

Figure 8. Reflection and Glare from the Sun. (*3*)

Glare causes the video image to lose contrast and severely limits the VIVDS processor's ability to identify the outline of a vehicle. Larger pitch angles can reduce the impact of sun glare. Sun glare typically causes problems for the eastbound and westbound approaches.

Reflections have both positive and negative effects on detection accuracy. On the positive side, a reflection represents a very significant change in contrast that ensures detection of a vehicle. The negative element of a reflection is that it can sometimes over-represent the actual size or location of the vehicle (especially at night).

Image Size

Detection accuracy is dependent on the size of the detected vehicle, as measured in the field of view. Accuracy improves as the vehicle's video image size increases. Image size, in turn, can

be increased by increasing the lens focal length. Figure 9 illustrates the effect of focal length on vehicle image size. Figure 9a illustrates the field of view with an 8 mm focal length. Figure 9b illustrates the field of view with a 16 mm focal length. The larger image size of the vehicles in Figure 9b provides more pixels of information for the VIVDS processor to analyze.

a. **Focal Length of 8 mm.**   b. **Focal Length of 16 mm.**

Figure 9. Effect of Focal Length on Vehicle Image Size.

Other Considerations

In addition to pitch angle and focal length, several additional design factors can compromise detection accuracy. These factors include light sources, power lines, and headlight glare.

Lights in the Field of View. The camera field of view should be established to avoid inclusion of objects that are brightly lit in the evening hours, especially those that flash or vary in intensity. These sources can include luminaires, signal heads, billboard lights, and commercial signs. The light from these sources can cause the camera to reduce its sensitivity (by closing its iris), which results in reduced detection accuracy. If these sources are located near a detection zone, they can trigger unnecessary calls. Figure 5 illustrates a case where the signal indications are sufficiently close to the detection zones as to cause an occasional unnecessary call.

Power Lines and Cables. The presence of overhead power lines or span-wire-mounted signal heads can pose problems during windy conditions. During daytime hours, the swaying lines or heads can trigger unnecessary calls if they move into and out of a detection zone. During the nighttime hours, a swaying signal head is likely to reduce the effectiveness of the camera lens' automatic iris (or electronic shutter) feature and, thereby, reduce detection accuracy.

The effect of various light sources on the video image is shown in Figure 10. Fixed lighting for adjacent parking lots are shown in the upper corners of the photographs. The two smaller points

of light above the vehicles are span-wire-mounted signal heads. Figures 10a and 10b were taken about 0.5 s apart on an evening with moderate winds. A comparison of the two figures illustrates significant variation in light level in a short span of time. Figure 10b is also slightly darker overall indicating that the automatic iris (or electronic shutter) has started to close in response to the excessive glare.

a. Heads at Minimum Light Position.   b. Heads at Maximum Light Position.

Figure 10. Swaying Span-Wire-Mounted Signal Heads.

Headlight Glare. Most VIVDSs have separate image-processing algorithms for daytime and nighttime conditions. The daytime algorithm searches for vehicle edges and shadows. During nighttime hours, the VIVDS searches for the vehicle headlights and the associated light reflected from the pavement. Research has found that the nighttime algorithm is less accurate than the daytime algorithm and also has a tendency to place calls before the vehicle actually arrives to the detection zone. Specifically, many VIVDS products tend to have difficulty distinguishing between a vehicle and the segment of roadway it lights with its headlights. This problem is illustrated in Figure 11.

Figure 11 shows a vehicle approaching the stop-line detection zone at a frontage road intersection. The light from the vehicle's headlights illuminates the pavement in the detection zone and triggers a call for service (this call is indicated in the figure by the four highlighted corners of the upstream detector). The consequences of this "early" detection are minimal if it occurs during the red indication. If it occurs during the green indication, the phase would be unnecessarily extended and further delay the conflicting traffic movements.
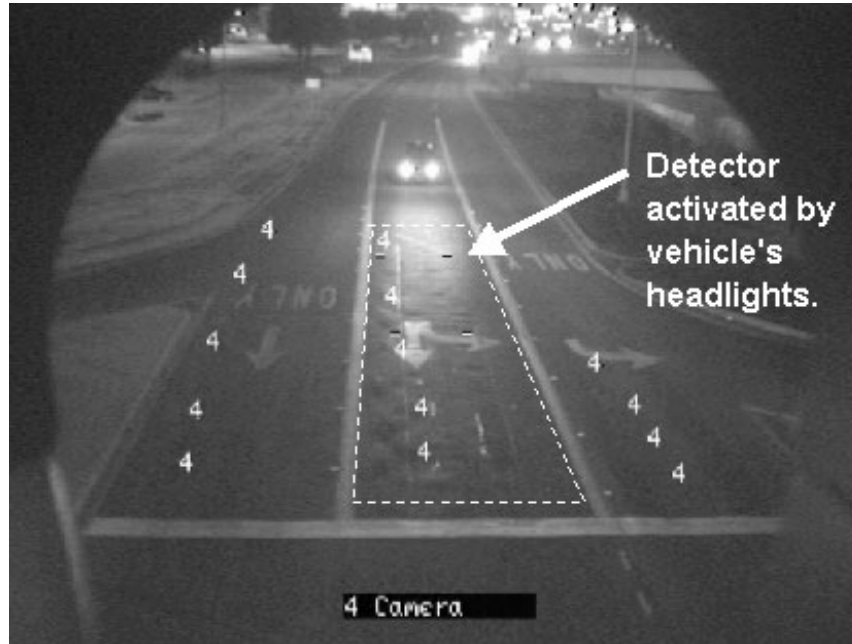
Figure 11. Detection of Headlight Reflection.

Special Interchange Issues

Communications

VIVDS cameras are typically connected to the VIVDS processor with coaxial cables. The type of cable used depends on the distance between the camera and the VIVDS processor. Standard RG-59 coaxial cable has been used routinely at distances up to 500 ft. Some degradation in signal quality has been observed when the cameras are more than 1000 ft from the cabinet. Distances of this magnitude are common at diamond interchanges controlled by a single controller. The addition of splices in the cable adds to the image degradation. The use of a common conduit for both the coaxial cable and the power cable can also cause image degradation, especially for longer cable lengths.

Shadows

Shadows extending across an intersection approach can present challenging problems for some VIVDS products. These shadows can extend into a detection zone and trigger false calls or compromise the VIVDS processor's ability to detect vehicles. Shadows diminish the brightness and contrast information available to the image processor and, thus, make it difficult for the processor to discern the outline of the actual vehicle. Shadows can extend from trees, signs, buildings, or bridge structures adjacent to the roadway. They can also extend from tall vehicles into an adjacent lane.

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Figure 12 illustrates the shadow problem inherent to a diamond interchange where the major road passes over the cross road. The shadow of the overhead bridge structure may cause problems for some VIVDS products during bright sunlight conditions. The vehicles in the shadow of the bridge are likely to be more challenging for the VIVDS to detect than vehicles not in this shadow.

Figure 12. Shadows from Tall Vehicles and Bridge Structures.

GUIDELINES

This section describes VIVDS design guidelines. These guidelines can be used to define a camera location and field of view that maximize detection accuracy. The following topics are addressed in this section: camera location and field-of-view calibration.

Camera Location

Desirable camera heights and offsets are often limited by the availability of structures that can provide a stable camera mount. Considerations of height, offset, and stability often require a compromise location that is subjectively determined to provide the best performance. Camera mounting locations vary widely with each intersection. Typical locations include luminaire arms, signal head mast arms, and signal poles. Figure 13 shows two commonly used camera mounts. Figure 13a shows a camera mounted on a mast arm. Figure 13b shows a camera mounted on a luminaire arm on a mast arm pole.

a. Mast Arm Camera Mount.   **b. Luminaire Arm Camera Mount.**
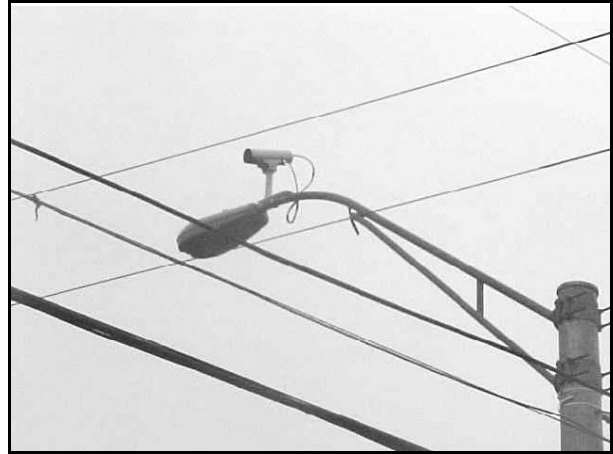
Figure 13. Common Camera Mounts.

Camera Offset

As shown in Figure 3, the optimal camera offset is approximately in the center of the approach being monitored. However, this location can vary slightly, depending on whether the approach being monitored has a left-turn bay. If it has a left-turn bay, the preferred camera location is over the lane line separating the left-turn bay and the adjacent (oncoming) through lane. This location is shown as point "A" in Figure 14, as applied to the eastbound approach. If the approach does not have a left-turn bay, the preferred location is centered on the approach lanes, as shown by location "B" for the westbound approach. Other camera locations, denoted by locations "C" and "D," can be used when locations "A" or "B" are not available or when they do not provide the desired camera height.
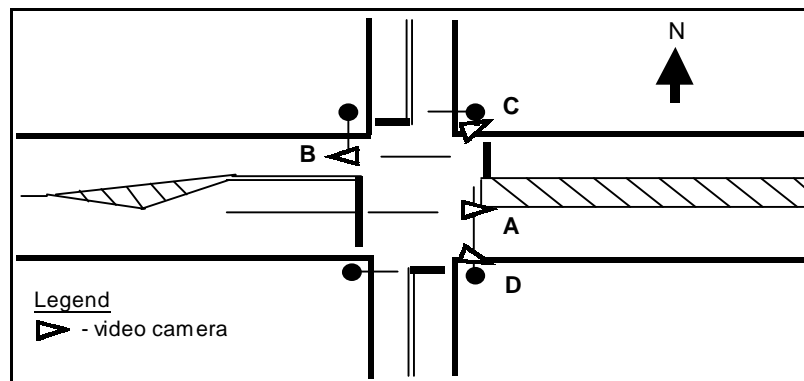

Figure 14. Alternative Camera Locations.

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Camera Height

This section describes guidelines for determining the minimum camera height for a specified camera offset and distance to the stop line.   Two minimum height controls are defined. The first minimum height control is intended to minimize the effect of adjacent-lane occlusion. The second control is intended to provide acceptable detection accuracy. The first control applies to all VIVDS installations. Both controls are applicable to high-speed approaches where advance detection is needed.   In this situation, the larger of the two minimum values would define the applicable minimum height criterion.

Minimum Height to Reduce Occlusion. The minimum height needed to reduce adjacent-lane occlusion is obtained from Table 2. Interpolation between cell values is appropriate for offsets intermediate to the values listed. A minimum height of 20 ft is recommended in recognition of the dirt, spray, and mist that can collect on the camera lens at lower heights. Camera locations that require a camera height in excess of 42 ft should be avoided.

The trends in Table 2 indicate that a camera mounted on a mast arm in the center of the approach is associated with the lowest minimum height. This minimum increases with offset and is particularly large for cameras located on the left side of the approach.

The underlined values in Table 2 correspond to typical lateral offsets for the associated number of lanes *when* the camera is mounted within 10 ft of the edge of traveled way. For example, a camera mounted on the right side of a single-lane approach (with one left-turn bay) is likely to have an offset of about 15 ft, which corresponds to a minimum camera height of 20 ft. A camera mounted on the left side of this same approach is likely to have an offset of about 25 ft and require a minimum height of 21 ft.

Minimum Height for Advance Detection. The minimum heights needed for advance detection are listed in Table 3.   Interpolation between cell values is appropriate for distances intermediate to the values listed. The distances shown in this table indicate that minimum camera heights range from 24 to 36 ft, depending on the distance between the camera and stop line and on the approach speed limit. The heights shown will always provide a view of the approach between the stop line and the upstream detection zone (provided that a lens focal length of 6.0 mm or larger is used).

Tables 2 and 3 should be used together to determine the minimum camera height for approaches with advance detection. The higher value obtained from either table would represent the required minimum height.

Table 2. Minimum Camera Height to Reduce Adjacent-Lane Occlusion.

Camera Location	Lateral Offset [1], ft	No Left-Turn Lanes Through+Right Lanes [2]			One Left-Turn Lane Through+Right Lanes [2]			Two Left-Turn Lanes Through+Right Lanes [2]		
		1	2	3	1	2	3	1	2	3
		Minimum Camera Height and Typical Camera Mount [3, 4], ft								
Left Side of Approach	-65			P,R 38			P,R,L42			
	-55		P,R 35	P 30		P,R 39				
	-45		P 27		P,R 36	P 32		P,R,L41		
	-35	P 24	P 20		P 29			P 33		
	-25	P 20			P 21					
	-15	P 20						M 20	M 20	M 20
	-5				M 20	M 20	M 20	M 20	M 20	M 20
Center	0	M 20	M 20	M 20	M 20	M 20	M 20	M 20	M 20	M 20
Right Side of Approach	5	P 20	M 20	M 20	M 20	M 20	M 20	M 20	M 20	M 20
	15	P 20	P 20	P 20	P 20	P 20	M 23	P 20	M 20	M 20
	25	P 20	P 20	P 20	P 21	P 26	P 30	P 20	P 21	P 26
	35		P 20	P 20	P 29	P 33	P,R 38	P 24	P 29	P 33
	45								P,R 36	P,R,L41

Notes:

1 - Lateral offset of camera measured from the center of the approach traffic lanes (including turn lanes).

2 - Total number of through and right-turn lanes on the approach.

3 - Underlined values in each column correspond to typical lateral offsets when the camera is mounted within 10 ft of the edge of traveled way.

4 - Camera mounting hardware and maximum camera mounting height supported by the hardware:

    M - mast arm (24 ft maximum).

    P - strain pole (34 ft maximum).

    P,R - camera on 5-ft riser on top of strain pole (39 ft maximum).

    P,R,L - camera on 5-ft riser on luminare arm attached to the top of strain pole (41 ft maximum).

Table 3. Minimum Camera Height for Advance Detection.

Distance Between Camera and Stop Line [1], ft	Approach Speed Limit, mph			
	45	50	55	60
	Minimum Camera Height, ft			
50	24	26		
80	25	28	30	32
100	27	29	31	34
150	30	32	34	36

Note:

1 - Distance between the camera and the stop line, as measured parallel to the direction of travel.

To illustrate the use of Tables 2 and 3, consider a four-lane highway with intersection approaches that include two through lanes and one left-turn bay. The distance between the mast-arm

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pole and the stop line is 100 ft, as measured in the direction of travel. The approach speed limit is 55 mph. Table 3 indicates that the minimum height needed for advance detection is 31 ft. This height exceeds that available from a mast-arm mount (i.e., 24 ft), so a right-side pole mount is considered for the camera. Table 2 indicates that a camera mounted just outside the edge of traveled way (i.e., offset 18 ft from the center of the three-lane approach) will require a minimum height of about 22 ft (by interpolation). Of the two minimum heights specified (i.e., 31 and 22 ft), the larger value of 31 ft represents the minimum for this approach. Thus, the camera should be mounted at a height of 31 ft or more on the right-side mast-arm pole.

Height and Stability. Research indicates that increasing camera height tends to improve accuracy, provided that there is no camera motion. However, there is a "point of diminishing returns" with respect to camera height when the camera support structure is susceptible to instability. Specifically, data indicate that camera heights of 34 ft or more may be associated with above-average errors *unless* the camera is mounted on a stable pole.

Combined Offset and Height Considerations

The preferred camera offset and height are often achieved for low-speed approaches by locating the camera on a 5-ft riser attached to the signal head mast arm. This type of mounting is shown in Figure 13a. Unfortunately, the minimum camera height for high-speed approaches typically requires a right-side or left-side mount (as denoted by the letters "C" and "D" in Figure 14). Both locations have the camera mounted on the signal pole at the necessary height or on a luminaire arm extending from the pole. This type of mounting is shown in Figure 13b.

The choice between a right-side or a left-side mount is dependent on the phase sequence used to control the subject approach. For approaches without a left-turn phase, the camera is mounted on the right-side, far corner of the intersection (i.e., "D" in Figure 14).

For approaches with a left-turn phase and bay, location "D" is problematic because the projected outline of a tall through vehicle can extend into the left-turn bay and unnecessarily call the left-turn phase. To avoid this problem, the camera is mounted on the left-side, far corner of the intersection (i.e., "C" in Figure 14). This location minimizes false calls for service to the left-turn phase; any false calls for the through phase by a tall left-turn vehicle would have limited impact because through vehicles are present during most cycles. A 10-s delay setting should be used for the left-turn detectors to prevent unnecessary calls by departing vehicles.

Field-of-View Calibration

Calibration of the camera field of view is based on a one-time adjustment to the camera pitch angle and the lens focal length. An optimal field of view is one that has the stop line parallel to the bottom edge of the view and in the bottom one-half of this view. The optimal view also includes all approach traffic lanes. The focal length would be adjusted such that the approach width, as

measured at the stop line, equates to 90 to 100 percent of the horizontal width of the view. Finally, the view must exclude the horizon. An example of an optimal field of view is shown in Figure 3b.

The optimal field of view is not achievable for some right-side and most left-side camera offsets. In these situations, the approach width may not be parallel to the bottom of the view and it may not equate to 90 percent of the horizontal width of the view. A 90-percent width for the approach may be particularly difficult to achieve when advance detection is used. Nevertheless, the field of view should always be adjusted to maximize the approach width (as a percent of the view) at the stop line. Practical minimum widths are 40 and 60 percent for left-side and right-side camera offsets, respectively.

Two camera adjustments are available to minimize the deleterious effects of sun glare (or reflection) on detection accuracy. In some instances, glare can be blocked by adjusting the visor on the camera housing. If this adjustment does not eliminate the problem, then the camera pitch angle can be increased such that the horizon is excluded from the field of view. A minimum pitch angle of about 3.0 degrees (from horizontal) should be provided in all cases. Finally, VIVDS processors have the ability to minimize the effect of occasional glare by automatically invoking a maximum recall on the troubled approach whenever glare is detected.

The camera field of view should be established to avoid inclusion of objects that are brightly lit in the evening hours, especially those that flash or vary in intensity. These sources can include luminaires, signal heads, billboard lights, and commercial signs. The light from these sources can cause the camera to reduce its sensitivity (by closing its iris), which results in reduced detection accuracy. If these sources are located near a detection zone, they can trigger unnecessary calls.

If the pitch angle or focal length cannot be adjusted to avoid glare and brightly lit objects, then alternative camera locations should be considered. If such locations cannot be found, then careful detection zone layout can minimize the effect of light sources or power lines on detection accuracy.

Intersection Lighting

Intersections that have a minimal level of area lighting may experience a higher level of unneeded calls. These calls are triggered by the light from vehicle headlights in departing lanes and crossing lanes. Unneeded calls are likely to increase intersection delay. This problem can be avoided by increasing the number of luminaires at the intersection. The benefit to having several luminaires at the intersection is that they collectively minimize the problems associated with vehicle shadows and the degree of shadow contrast.

Communications

Significant signal degradation can occur when coaxial cable lengths of 1000 ft or more are used. When a length of 1000 ft or more is anticipated, the splices in the cable should be avoided, and separate conduits should be considered for the coaxial cable and the power cable.

Wireless communication between the VIVDS cameras and processor is an alternative to the use of coaxial cable. At least one VIVDS manufacturer offers a wireless camera. In this instance, the video information is transmitted to a receiver in the controller cabinet. Power for the camera is provided by a cable or solar panel.

CHAPTER 3. OPERATIONS GUIDELINES

OVERVIEW

This chapter addresses VIVDS operation and maintenance. VIVDS operation is defined by its detection zone layout, which includes consideration of zone location, detection mode, detector settings, and controller settings. VIVDS maintenance is defined by the on-site performance checks conducted after the initial installation and the routine maintenance activities that follow installation.

Issues associated with detection zone layout and performance are described in the first section of this chapter. These issues include sources of false detection, distorted vehicle length, contrast loss, camera realignment, lens cleaning, and layout verification. Guidelines for detection zone layout are described in the second section. These guidelines are intended to minimize or avoid problems associated with the issues raised in the first section.

CONSIDERATIONS

Once installed, the performance of the VIVDS is highly dependent on the manner in which its detection zones are defined and operated. Decisions associated with detector layout and operation include: zone location to minimize false calls, controller settings that accommodate vehicle length, special features that can minimize the effect of contrast loss, and verification of daytime and nighttime performance. These issues are discussed more fully in this section.

Detection Zone Layout

Detection zone layout is an important factor influencing the performance of the intersection. There are several factors to consider when laying out each zone. These factors include: zone location relative to the stop line, the number of VIVDS detectors used to constitute the zone, whether the detectors are linked using Boolean logic functions, whether the zone monitors travel in a specified direction, and whether the zone's call is delayed or extended. An example of an optimal detection zone layout is illustrated in Figure 15. The factors that are associated with zone layout that reduce detection accuracy or improve traffic operations are described in this section

Sources of False Detection

A VIVDS detector is sensitive to any change of image contrast within its borders, regardless of whether that change is caused by a vehicle, a shadow cast from a vehicle in an adjacent lane, a camera swaying with its mast-arm support, or a swaying signal head on span wire. The motion associated with a swaying camera is problematic if the detection zone crosses a pavement marking or similarly bright object. The latter three causes of contrast change are likely to trigger an unneeded call. Problems associated with these three causes are illustrated in Figures 5, 7, and 10 (in the order

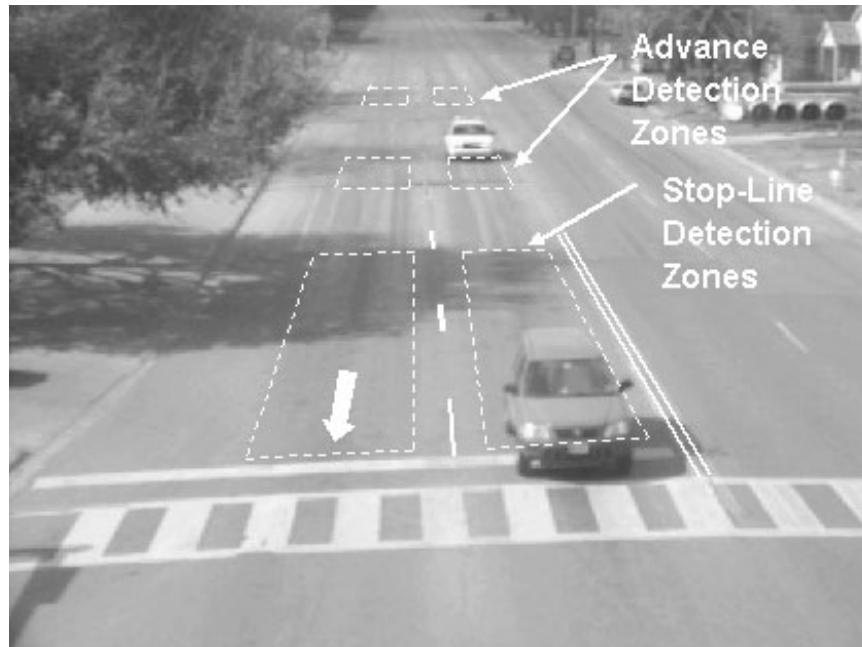listed). To some extent, the adverse effects of each problem can be minimized by thoughtful detection zone layout.

Figure 15. Illustrative Optimal Detection Zone Layout.

Limited Selectivity

A VIVDS has limited ability to count (or measure gaps between) closely spaced vehicles. This limitation is due to the occlusion that occurs when a vehicle's image, as projected onto the two-dimensional video image plane, obstructs the camera's view of a following vehicle. This problem is shown in Figure 16. This occlusion tricks the VIVDS into reporting the presence of one long vehicle instead of two separate vehicles. This limitation compromises the usefulness of several controller features that rely on such information. These features include volume-density control and adaptive protected-permissive left-turn phasing.

Distorted Vehicle Length

In addition to the occlusion cited in the preceding paragraph, the projection of a vehicle into a two-dimensional video image plane also increases the effective (or detected) length of the vehicle. This problem is also illustrated in Figure16, as it affects the detected length of the bus. In this figure, the bus's detected length is almost twice its actual length. This elongation of detected vehicles can reduce the controller's ability to identify when the queue has been served and may unnecessarily extend the phase.   This extension often translates into additional delay to waiting motorists.
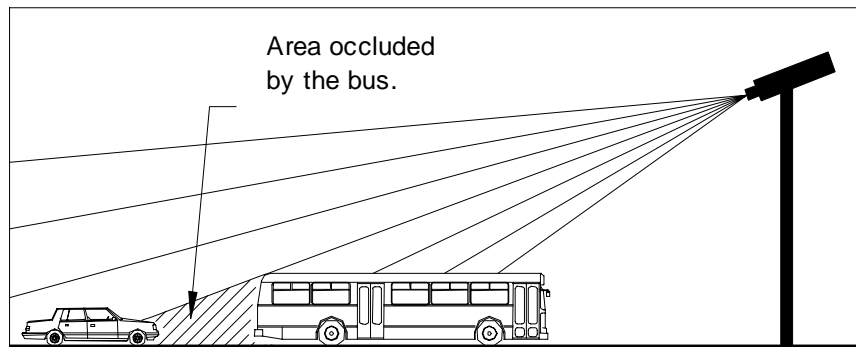
Figure 16. Effect of Same-Lane Occlusion on Detected Vehicle Length. (*3*)

Contrast Loss

The performance of VIVDS products is adversely affected by both environmental and temporal conditions. Environmental conditions include fog, rain, wind, and snow. These conditions have a direct effect on the contrast and brightness information captured by the camera. Indirectly, they cause condensation and dirt buildup on the camera lens that further degrade VIVDS performance. Temporal conditions include changes in light level and reflected light that occur during a 24-hour period and during the course of a year (i.e., seasonal changes in sun position).

On-Site Performance Checks

Several maintenance issues are associated with a VIVDS. Most of these issues are related to the cameras and their ability to sustain the field of view established on the day they were initially installed. These issues are related to camera replacement, realignment, and lens cleaning, as well as detection zone layout verification. Each issue is discussed in this section.

Camera Replacement

Each VIVDS product has a unique set of camera cable connectors on the back of the camera housing. This unique arrangement requires districts that use multiple VIVDS products to maintain an inventory of several different types of cameras to ensure quick repairs.

Camera Realignment

Camera alignment may need to be checked and realigned after a storm. Seasonal changes in the sun's position can cause a glare to occur in the camera during some months of the year. Given the unpredictability of these events, the need for a follow-up adjustment is not often known until poor service is reported by a motorist.

Camera Lens Cleaning

A VIVDS located in a coastal area may need to have its camera lenses cleaned relatively often due to the high humidity of the coastal air. The frequency of this activity varies, depending on the proximity of the intersection to sources of airborne dust. For example, an intersection near a bauxite plant may need to have its camera lenses cleaned every six weeks, while an intersection near a residential subdivision may need to have its camera lenses cleaned every six months.

Detection Zone Layout Verification

Routine service checks of VIVDS operation have been found to take more time than was previously spent at intersections with inductive loop detectors. This added time stems partly from the VIVDS's inability to provide an electronic report that records the detection zone layout. Without this report, the service technician must rely on his or her judgment and recollection as to whether the detection zones or their settings are unchanged. If the location of a detector is determined to be changed (say, due to movement of the mast arm supporting the camera), the report could be used to quickly restore the original location.

GUIDELINES

This section describes guidelines for detection zone layout and operation. Detection zone layout guidelines include zone location, detection mode, detector settings, and controller settings. VIVDS operation guidelines describe activities needed to verify the adequacy of the initial installation and the checks needed during a routine maintenance visit.

Detection Zone Layout

Detection Zone Location

Like inductive loops, VIVDS detectors can be placed within a lane or across several lanes. They can be placed at the stop line or several hundred feet in advance of it. The VIVDS product manuals offer some guidance for locating a VIVDS detection zone and the detectors that comprise it. These guidelines are summarized and described in Table 4.

Stop-Line Detection. This section describes guidelines for determining an efficient detection zone layout for stop-line detection. Stop-line detection is typically used on low-speed intersection approaches and in left-turn bays. Guidelines for determining the layout for advance detection zones are provided in the next section.

The recommended stop-line detection zone lengths are listed in Table 5. Interpolation between cell values is appropriate for distances or heights intermediate to the values listed. The recommended lengths require a 0.0-s controller passage time. These recommended values should result in lower delay than that realized by longer passage times or shorter detection zone lengths.

Table 4. Guidance for Locating Detection Zones and Individual Detectors.

Application	Guideline	Rationale
Stop-Line Detection	Stop-line detection zone typically consists of several detectors extending back from the stop line.	For reliable queue service, stop-line detection typically requires monitoring a length of pavement 80 ft or more in advance of the stop line.
	Put one detection zone downstream of the stop line if drivers tend to stop beyond the stop line.	Avoid having one long detector straddle a pavement marking.
	Use specific techniques to heighten detector sensitivity (e.g., overlap individual detectors slightly).	Vehicle coloration and reflected light may combine to make some vehicles hard to detect.
Advance Detection	Advance detection typically consists of two detectors strategically located on the approach.	Advance detection uses passage time to extend the green for vehicles in the dilemma zone.
	Advance detectors can reliably monitor vehicles at a distance (from the camera) of up to 500 ft, provided the field of view is optimal.	Detection accuracy degrades as the location being monitored by the VIVDS becomes more distant from the camera.
Individual Detector	Avoid having pavement markings cross or straddle the boundaries of the detection zone.	Camera movement combined with high-contrast images may confuse the processor and trigger an unneeded call.
	The individual detector length should approximately equal that of the average passenger car.	Maximize sensitivity by correlating the number of image pixels monitored with the size of the typical vehicle being detected.

Table 5. Stop-Line Detection Zone Length for VIVDS Applications.

Distance Between Camera and Stop Line [1], ft	Camera Height, ft				
	24	28	32	36	40
	Stop-Line Detection Zone Length [2], ft				
50	100	100	100	100	100
100	90	90	95	95	95
150	80	85	85	90	90

Notes:
1 - Distance between the camera and the stop line, as measured parallel to the direction of travel.
2 - Lengths shown are based on a 0.0-s passage time setting.

During the initial VIVDS setup, the detection zone length should be measured along the roadway with a distance wheel. The most distant upstream edge should be marked with a traffic cone placed on the outside edge of the traveled way. One or more VIVDS detectors should then be drawn on the VIVDS monitor such that the entire length of the resulting detection zone is monitored by the VIVDS processor. The traffic cone can then be removed.

Stop-Line Plus Advance Detection. This section describes guidelines for determining an efficient detection zone layout when advance detection is needed. This type of detection is typically used to provide a safe phase termination for the high-speed through movements on an intersection

approach. Stop-line detection is also included with the advance detection to provide efficient service to the queue during the initial portion of the phase.

The recommended advance detection zone locations and extension settings for VIVDS applications are listed in Table 6. Interpolation between cell values is appropriate for distances or heights intermediate to the values listed. The recommended advance detection design requires a passage time of 1.0 s. These recommended values should provide lower delay than that incurred with other locations or passage times.

Table 6. Advance Detection Zone Layout for VIVDS Applications.

Approach Speed Limit, mph	Distance to 1st Det. Zone[1], ft	Distance Between Camera and Stop Line[2], ft	Camera Height, ft									
			24	28	32	36	40	24	28	32	36	40
			Distance to 2nd Det. Zone[1], ft					Extension on 2nd Det. Zone, s				
60	470	80	280	295	305	310	315	0.0	0.0	0.0	**0.5**	**0.5**
		150	270	285	295	300	310	0.0	0.0	0.0	0.0	**0.5**
55	430	80	255	265	275	280	285	0.0	0.0	0.0	**0.5**	**0.5**
		150	245	255	265	275	280	0.0	0.0	0.0	0.0	**0.5**
50	390	50	235	245	250	255	260	0.0	0.0	**0.5**	**0.5**	**0.5**
		150	220	230	240	245	250	0.0	0.0	0.0	0.0	**0.5**
45	350	50	210	215	220	225	230	0.0	0.0	**0.5**	**0.5**	**0.5**
		150	190	200	210	215	220	0.0	0.0	0.0	0.0	**0.5**

Notes:
1 - Distances shown are based on a 20-ft detection zone length and a 1.0-s passage time setting.
2 - Distance between the camera and the stop line, as measured parallel to the direction of travel.

When used with advance detection, the stop-line detection zone layout should follow the guidelines described in the previous section, "Stop-Line Detection." Specifically, the length of this zone should be obtained from Table 5.

One difference exists between the layout of the stop-line detection zone *with* advanced detection and the layout of the stop-line zone *without* advance detection. When used with advance detection, the controller has a 1.0-s passage time that is required by the advance detection zones. When used without advance detection, a 0.0-s passage time is required. Because the 1.0-s passage time is required when the stop-line detection zone is used with advance detection, it is necessary to make a slight modification to the stop-line detection zone's operation. Specifically, the detector channel serving the stop-line detection zone should have the "inhibit" feature (e.g., Special Detector Mode 4 in Eagle controllers) invoked. The stop-line detector channel in the controller should also have 0.0 s set on its delay and extend timers. The inhibit feature disables the stop-line detection zone

after the queue, waiting at the start of the phase, has been served. It should be noted that the advance detection zones should be served by a detector channel that is separate from that of the stop-line detection zone.

During the initial VIVDS setup, the beginning and end of each advance detection zone should be measured along the roadway with a distance wheel. The location of the beginning of the zone is listed in Table 6. The end of the zone is 20 ft closer to the stop line. Each edge should be marked with a traffic cone placed on the outside edge of the traveled way. One or more VIVDS detectors should then be drawn on the VIVDS monitor such that the entire length of the resulting detection zone is monitored by the VIVDS processor. The traffic cones can then be removed.

As a last step in the setup, the extension setting on the second advance detection zone should be set at the value listed in Table 6. This setting should be set in the VIVDS. It should be applied to all detectors that comprise the second detection zone. The delay and extend timers provided in the controller for each detector channel should be set at 0.0 s.

Detection Mode

One benefit of a VIVDS is the large number of detection zones that can be used and the limitless ways in which they can be combined and configured to control the intersection. Both pulse-mode and presence-mode detectors can be used, where the latter can have any desired length. In addition, VIVDS detectors can be set to detect only those vehicles traveling in one direction (i.e., directional detectors). They can also be linked to each other using Boolean functions (i.e., AND, OR). The use of these features is shown in Figure 17. The detector labeled "delay" in this figure is described in the next section.

Figure 17 is an idealized illustration of alternative detection modes. The approach shown has presence-mode stop-line detection in each of the through and left-turn lanes. The zones in the two through lanes are linked using an OR logic function. Detection of a vehicle in either lane will trigger a call to the through phase. This operation is identical to that achieved when both detectors are assigned to the same channel. However, the linkage allows for the specification of a common delay or extension time for both detectors.

The left-turn bay in Figure 17 uses two parallel detection zones for improved selectivity and sensitivity. Specifically, the right-side camera offset raises the possibility of an unneeded call from a tall vehicle in the adjacent through lane. The AND linkage for the two left-turn detection zones minimizes this problem. Also, for some VIVDS products, the use of two detectors in the same lane improves detection sensitivity.

Lastly, the intersection approach shown in Figure 17 is skewed from 90 degrees, which results in a large distance between the stop line and the cross street. This setback distance is especially significant for the left-turn movements. In anticipation that left-turn drivers may creep past the stop line while waiting for a green indication, additional detectors are located beyond the

stop line. However, they are directional detectors (as denoted by the word DOWN), such that they prevent crossing vehicles from triggering an unneeded call.
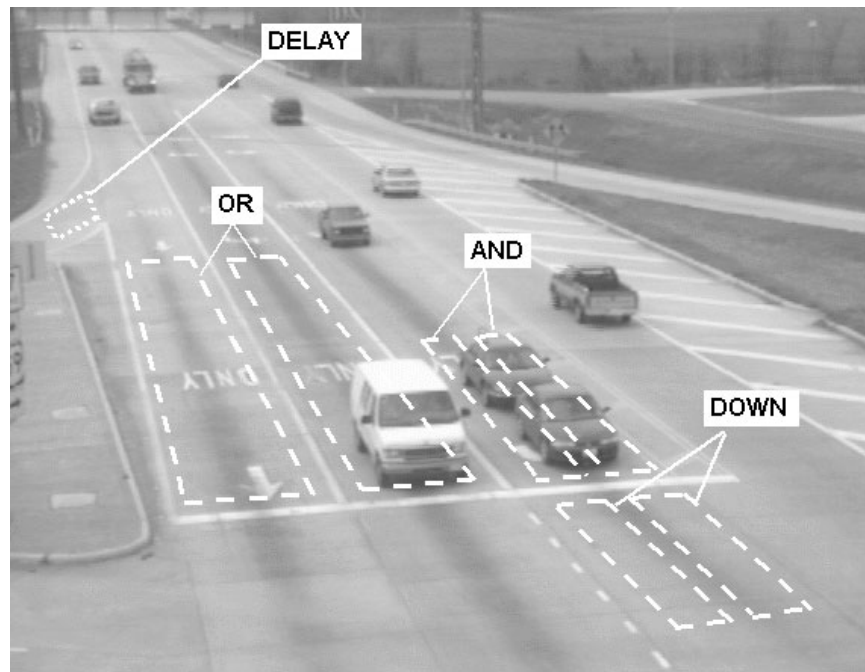

Figure 17. Alternative Detection Modes.

Detector Settings

Video detectors have delay and extend settings that can be used to screen calls or add time to their duration, as may be needed by the detection design. These settings are identical in performance and purpose to those available with inductive loop amplifiers. The use of the delay setting is shown in Figure 17. The detector in the right-turn lane is used as a queue detector to trigger a call to the through movement in the event that the right-turning drivers cannot find adequate gaps in traffic. The delay is set to about 2 s, such that a turning vehicle does not trigger a call unless it is stopped in queue.

The delay setting is also used to reduce the frequency of unneeded calls. Specifically, a few seconds of delay is often set on the detectors in the stop-line detection zone of each minor-road approach. This setting offers two benefits. First, it eliminates false calls to the minor-road phases by major-road vehicle headlights (such as when a major-road vehicle makes a right turn and its headlights sweep across the minor-road stop-line detection zone). Second, it eliminates false calls to the minor-road phases by tall major-road vehicles (i.e., when tall vehicles cross the view of the

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minor-road camera and momentarily project their image onto the minor-road stop-line detection zones).

The delay setting is also appropriate for the detectors in the left-turn bay when monitored by a left-side-mounted camera. This delay setting will screen unneeded calls for the left-turn phase that are placed by a tall through vehicle traveling away from the intersection, as shown in Figure 5. A 10-s delay setting should be sufficient to prevent unnecessary calls by departing vehicles.

On-Site Performance Checks

Return Visit to Verify Operation

In the days following the VIVDS installation, the engineer or technician should return to the intersection on one or more occasions and reevaluate the VIVDS performance. The purpose of each visit is to verify that the intersection is operating in an acceptable manner and that the VIVDS detectors are detecting vehicles with reasonable accuracy. In general, operation and accuracy should be checked at midday and during the late afternoon, nighttime, and early morning hours. In most cases, each time period is checked during a separate return visit. If sun glare or reflection is a problem during the late afternoon or early morning, it might be mitigated by adjusting the visor on the camera housing. If this adjustment does not eliminate the problem, then the camera pitch angle should be increased.

Maintenance

A periodic check (say, every six months) of the camera field-of-view and detection layout is encouraged. During this check, the engineer or technician should: (1) verify that the detection zones are still in the proper location relative to the traffic lanes, (2) assess the impact of seasonal changes in the sun's position on detection accuracy, (3) verify that the VIVDS is using the latest software version and upgrade it if needed, and (4) check the camera lens for moisture or dirt buildup and clean if needed. In areas with high humidity and extended concentrations of smoke, dust, or other airborne particles, the camera lens may need to be cleaned as frequently as every six weeks.

REFERENCES

1. Bonneson, J., and M. Abbas. *Video Detection for Intersection and Interchange Control.* FHWA/TX-03/4285-1. Texas Transportation Institute, Texas A&M University System, College Station, Texas, September 2002.

2. *Special Specification 6959: Video Imaging Vehicle Detection System.* Traffic Operations Division, Texas Department of Transportation, Austin, Texas, 1993 (updated January 1999).

3. Baculinao, N. Associate Traffic Engineer, City of Santa Clarita, California. Personal e-mail correspondence with James Bonneson on February 14, 2001.