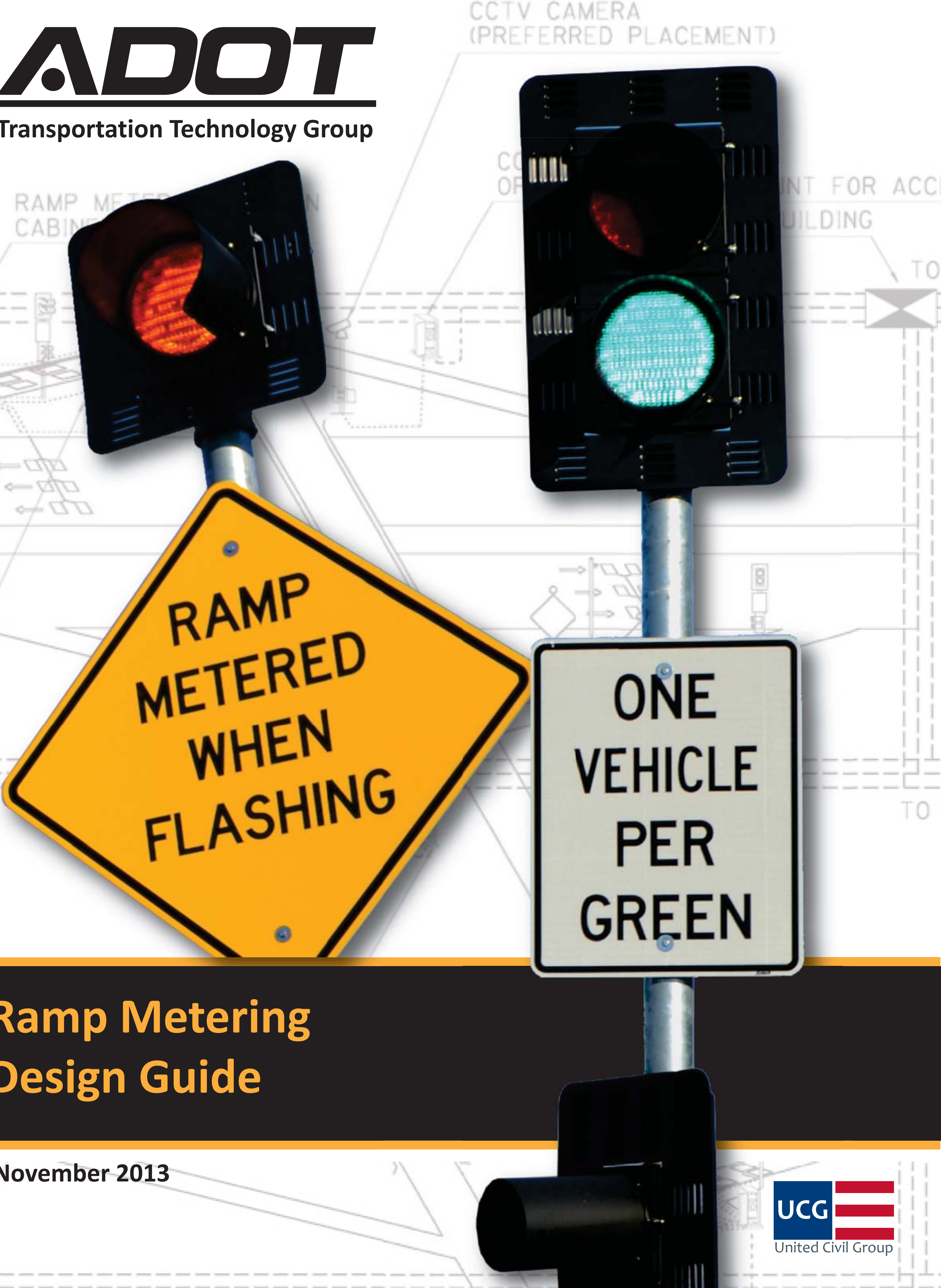
ADOT

Transportation Technology Group



Ramp Metering Design Guide

November 2013

UCG
United Civil Group

Ramp Metering Design Guide

Prepared for

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Acronyms

ADOT *Arizona Department of Transportation*
AASHTO *American Association of State Highway and Transportation Officials*
AWG *American Wire Gauge*
FMS *Freeway Management System*
GIS *Geographic Information System*
GPS *Global Positioning System*
IMSA *International Municipal Signal Association*
ITS *Intelligent Transportation System*
mph *Unit – Miles Per Hour*
MUTCD *Manual on Uniform Traffic Control Devices*
PHF *Peak-Hour Factor*
vph *Vehicles Per Hour*

1.0 INTRODUCTION

The Arizona Department of Transportation (ADOT) Transportation Technology Group provides this document to give designers and planners guidance for the design of ramp metering. Ramp metering designs will be approved by the ADOT Transportation Technology Group and project stakeholders. Standards, policies, and guidelines adopted by the Arizona Department of Transportation shall be considered in the design of ramp metering. These include, but are not limited to, the following alphabetically-listed documents:

- *Arizona Supplement to the Manual on Uniform Traffic Control Devices*, ADOT
- *Construction Standard Drawings*, ADOT
- *Freeway Management System Design Guidelines*, ADOT
- *ITS Standard Drawings*, ADOT
- *ITS Specifications*, ADOT
- *Geometric Design of Highways and Streets*, AASHTO
- *Manual of Approved Signs*, ADOT
- *Manual on Uniform Traffic Control Devices*, FHWA
- *Roadway Design Guidelines*, ADOT
- *Signing and Marking Standard Drawings*, ADOT
- *Standard Specifications for Road and Bridge Construction*, ADOT
- *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals,* AASHTO
- *Traffic Signals and Lighting Standard Drawings*, ADOT

It is not intended that any standard of conduct or duty toward the public shall be created or imposed by these guidelines. These guidelines do not cover every situation in ramp metering design. Engineering judgment shall be applied when deviation from these guidelines is required.

1.1 Purpose of Ramp Metering

Ramp metering is a traffic management strategy used to regulate the flow of traffic entering the freeway during peak traffic periods. This strategy is used to improve freeway throughput, travel time, travel time reliability, safety, fuel use, and emissions.

1.2 Design Traffic Data

Application of these ramp metering guidelines should be based upon traffic data that is less than 1 year old. The use of traffic data up to 3 years old is subject to approval by the ADOT Transportation Technology Group. 20-year traffic projections should be used to design new entrance ramps to accommodate ramp metering.

Traffic data should be evaluated in 5-minute increments. Traffic data should be collected in a maximum of 1-minute increments so that, if requested, it can be analyzed by ADOT in detail. Traffic data shall be collected using a method that distinguishes vehicles by lane. Special traffic data collection periods may be needed where nearby venues regularly-hold events with an attendance of over 30,000 people, such as a nearby professional sports stadium. The minimum traffic data required for application of these guidelines is as follows:

- Volume of the entrance ramp
- Volume of the rightmost freeway lane prior to the entrance ramp
- Speed of the freeway general purpose lanes (not including HOV, auxiliary, and entrance ramp lanes) adjacent to and within 2 miles downstream of the entrance ramp

Traffic data collected using an automatic detector device (pneumatic, video, radar, etc.), should be collected for 72 hours during a typical Tuesday through Thursday. An evaluation shall be presented that compares the daily traffic conditions and validates the data that will be used reflects recurring conditions.

Traffic data collected manually may be collected on a single day during peak periods. The off-peak times of day shall be evaluated and should consider times of day that are unlikely to meet ramp metering warrants or dictate ramp meter design. The times of day of the off-peak periods are subject to approval by the ADOT Transportation Technology Group. If traffic data is collected on a single day, the vicinity shall be observed in person for a non-recurring incident (example: crash, construction, disabled vehicle, debris, or weather) which affects traffic, and if such an incident occurs, data collection shall be aborted and restarted another day. A statement shall be provided that validates that no incidents were observed during the data collection that significantly affected the traffic data. If speed data is manually collected, a minimum of 50 samples per hour should be measured, and evenly collected from the lanes being studied.

2.0 RAMP METER INSTALLATION WARRANTS

These warrants are provided as a guide to determine the suitability of ramp meter installation only, and are not meant to convey when ramp meters should be on. These warrants do not address all factors that may affect the suitability of ramp meter installation, including:

- Is it safe to deploy ramp metering at this location?
- Is the roadway geometry adequate for ramp metering?
- Is a power source reasonably obtainable?
- Is there appropriate access for maintenance?
- Would ramp metering mitigate crashes?
- Is it desired to distribute traffic demand to other entrance ramps?

When a Freeway Management System (FMS) phase is designed, a ramp meter warrant analysis shall be conducted for all entrance ramp locations. If a ramp meter is not warranted at a specific entrance ramp, a fully-functioning traffic data collection station shall be provided. All vehicle detectors, the control cabinet, conduit, and pull boxes shall be installed and located according to these guidelines. The ramp meter signal assembly, warning flasher assembly, and stop bar shall be able to be installed in the future and located according to these guidelines without the need to relocate detectors, the control cabinet, lane geometry, or other elements.

Ramp metering is not used on freeway-to-freeway ramps.

Ramp metering is not typically used where the entrance-ramp lane continues as an added freeway lane for at least 1 mile, within which there are no exit ramps, entrance ramps, or other condition that would require any traffic to change lanes.

Ramp metering should only be considered if acceptable acceleration distance can be provided. Refer to section 3.2 Acceleration Distance for determining acceleration distance.

Ramp metering should only be considered if acceptable queue storage distance can be provided. Refer to section 3.3 Queue Storage Distance for determining queue storage distance.

Installation of a ramp meter is warranted if both warrants are satisfied. A flow chart is provided in Figure 2.0 to assist in determining whether installation of a ramp meter is warranted.

Warrant 1 – Freeway Right-lane and Entrance Ramp Flow Rate

During a typical 15-minute period, the combining flow rate of the entrance ramp and the rightmost freeway lane is greater than 2,050 vehicles per hour and during the same period, the entrance ramp flow rate is greater than 400 vehicles per hour.

Warrant 2 – Freeway Speed

During a typical 15-minute period, the speed of the freeway general purpose lanes (not including HOV, auxiliary, and entrance ramp lanes) is less than 50 mph due to recurring congestion adjacent to or within 2 miles downstream of the entrance ramp.

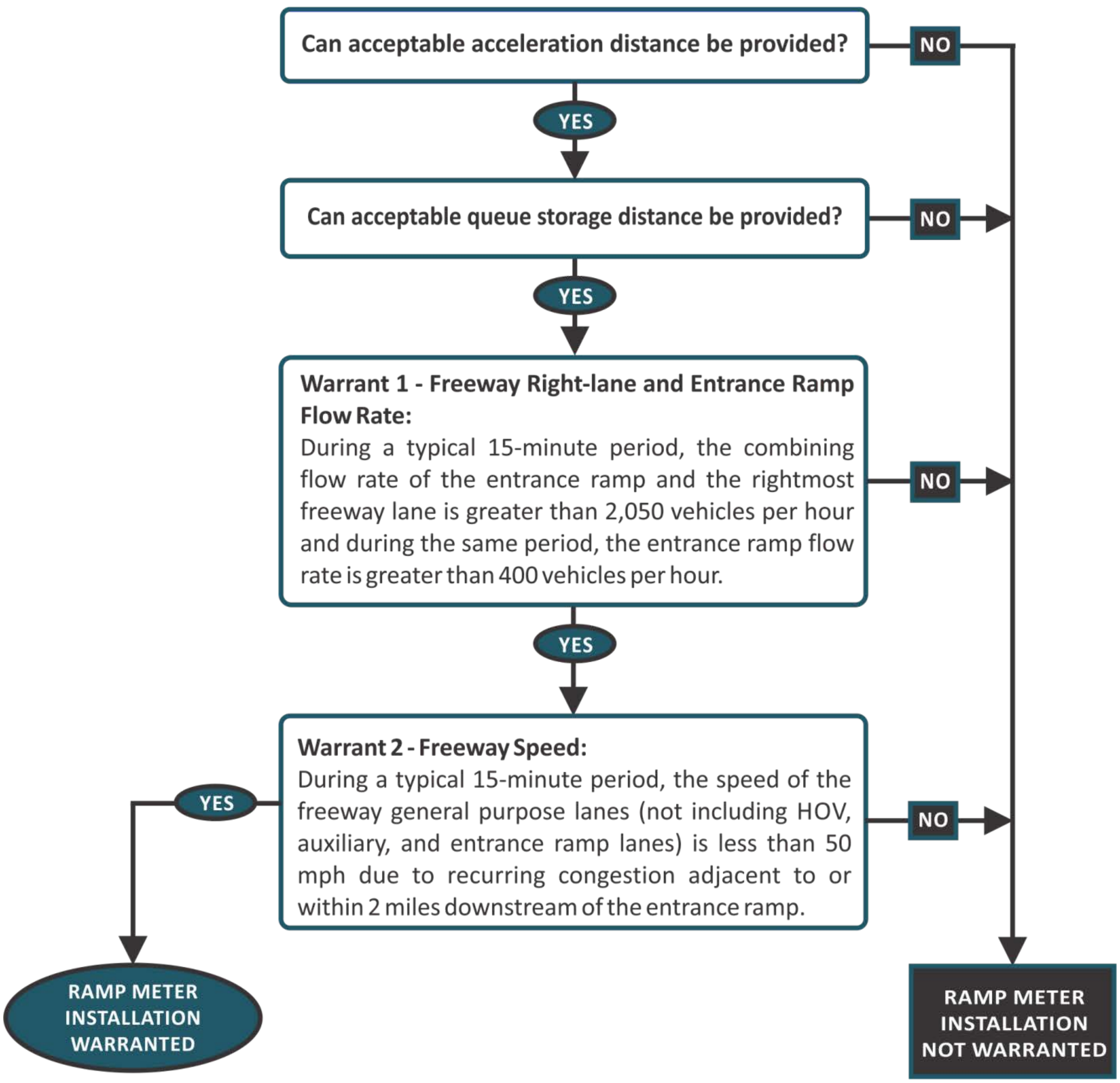


Figure 2.0: Ramp Meter Installation Warrant Flow Chart

3.0 RAMP METERING GEOMETRY

3.1 Number of Metered Lanes

Within the Phoenix metropolitan areas, new entrance ramps (excluding freeway-to-freeway connection ramps) shall be constructed to accommodate dual-lane ramp metering.

The lane and shoulder widths shall be provided according to the *ADOT Roadway Design Guidelines, Section 301.3 – Lane Width and Pavement Width* and *Section 302.4 – Shoulder Width*.

When installing ramp metering on an existing entrance ramp, dual-lane metering should be provided. Widening the entrance ramp may be needed to provide adequate lane and shoulder width. In some cases, fitting a dual-lane ramp meter on an existing entrance ramp may not provide adequate queue storage distance and a single-lane ramp meter can provide more queue storage distance by allowing the ramp meter stop bar to be placed further down the entrance ramp. If it is not feasible to provide dual-lane ramp metering that satisfies these design guidelines, the designer shall notify the ADOT Transportation Technology Group project manager for further direction.

3.2 Acceleration Distance

Acceleration distance should be provided on the entrance ramp after the ramp meter stop bar to allow traffic proceeding from a stop at a ramp meter to reach adequate speed prior to merging onto the freeway.

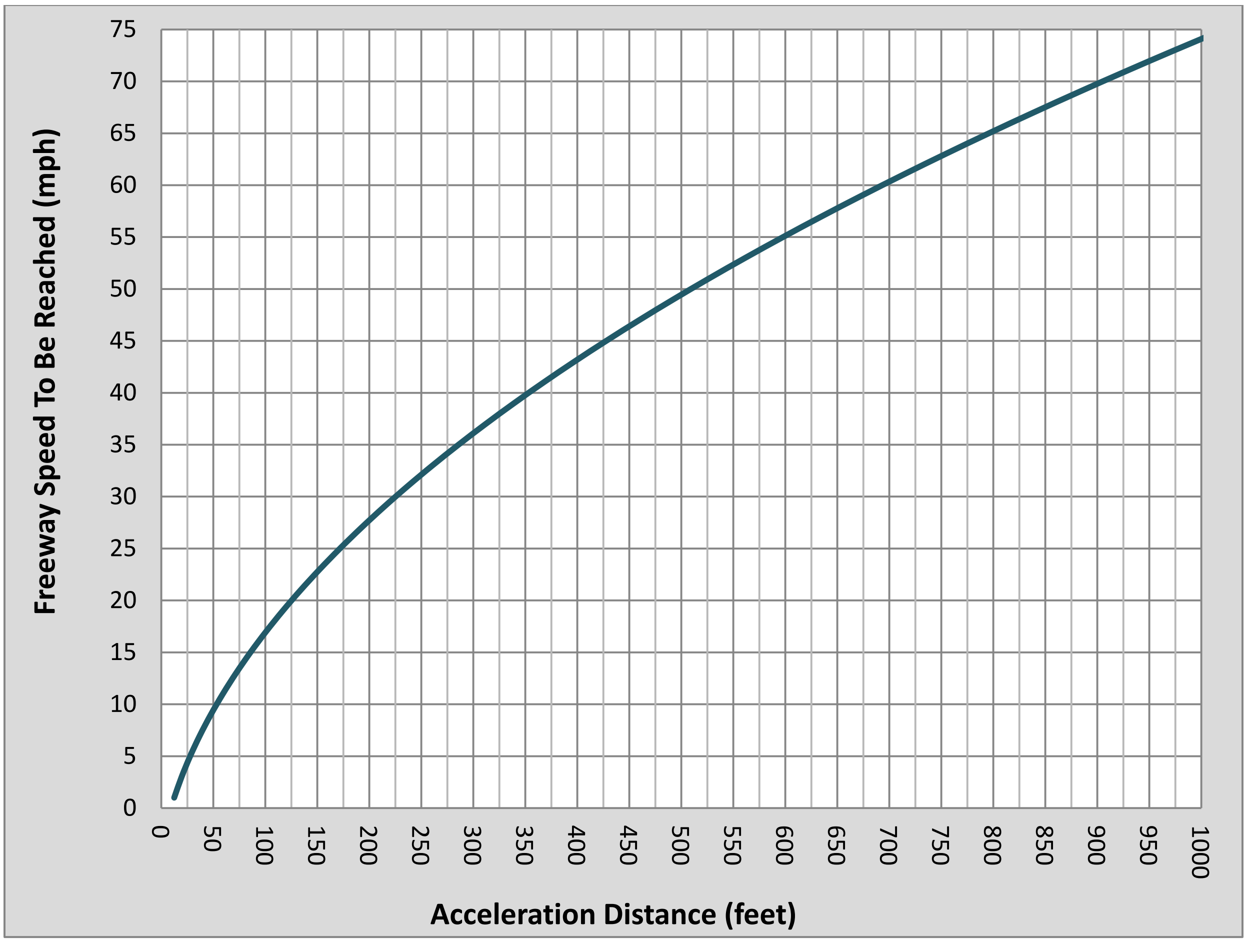
Acceleration distance is measured from the ramp meter stop bar to the tip of the painted gore of the entrance ramp at the freeway merge point. Refer to Figure 3.4 for a graphical depiction.

The freeway's posted speed or 85^{th} percentile speed may be used to determine the acceleration distance. If the 85^{th} percentile speed is used, the speed data shall be collected according the *ADOT Traffic Engineering Policies, Guidelines, and Procedures,* section "222 Speed Studies."

Table 3.2 provides the acceleration distance to reach a freeway speed of 55 mph or 65 mph on an entrance ramp with a grade less than 1% and less than 3% trucks. For other freeway speeds to be reached, use Figure 3.2.

Freeway Speed To Be Reached (mph)	Acceleration Distance (feet)
55	600
65	800

Table 3.2: Acceleration Distance



Source: Lehman Center for Transporation Research. Integrated Database and Analysis System for the Evaluation of Freeway Corridors for Potential Ramp Signaling. *Florida Department of Transportion, 2011.*

Figure 3.2: Acceleration Distance

When the average grade of the entrance ramp after the ramp meter stop bar exceeds 1%, increase the acceleration distance by the following calculated value:

$$\mathrm{G \; x \; 65}$$

Equation 3.2a

Where:

G = Grade of Entrance ramp after the ramp meter stop bar (expressed as a percentage)

When the percentage of trucks and heavy vehicles exceeds 3% on an entrance ramp, increase the acceleration distance by the following calculated value:

$$(\mathrm{T} - 3) \; \mathrm{x} \; 100$$

Equation 3.2b

Where:

T = Percentage of trucks and heavy vehicles on an entrance ramp (percent) (2 percent trucks may be used as a typical design value unless field-observation indicates classification data needs to be collected to determine the actual percentage of trucks)

3.3 Queue Storage Distance

Queue storage should be provided on the entrance ramp to keep queued ramp meter traffic from blocking the cross-street intersection and frontage road.

If a frontage road is not present, the queue storage distance is measured from the ramp meter stop bar to the near-edge of the traveled way of the cross-street. The queue storage distance is measured the same for single-point-urban interchanges (SPUI). Refer to Figure 3.4 for a graphical depiction.

If a frontage road is present, the queue storage distance is measured from the ramp meter stop bar to the point where a ramp meter queue would block the path of a vehicle using the frontage road. Refer to Figure 3.4 for a graphical depiction.

The queue storage distance is calculated as follows:

$$Queue = \frac{\left(Rate_{ramp} - Rate_{meter}\right) * \; Time * \; \left(L_{car}\left(1 - \frac{T}{100}\right) + L_{truck}\left(\frac{T}{100}\right)\right)}{Lanes}$$

$$\text{Minimum } Queue = 400 \text{ feet}$$

Equation 3.3a

Where:

$Queue$ =	Queue storage distance (ft)
$Rate_{ramp}$ =	Entrance ramp design flow rate (vph). A 20-year traffic projection should be used for design of new entrance ramps to accommodate ramp metering.
$Rate_{meter}$ =	Design metering rate (vph) (840 vph is the typical design value)
$Time$ =	Design period that ramp metering operates at design metering rate (hour) (0.5 hr is the typical design value)
$Lanes$ =	Number of metered lanes
L_{car} =	Average car plus gap length (ft/veh) (28 ft/veh is the typical design value when traffic is at less than 5 mph)
L_{Truck} =	Average truck plus gap length (ft/veh) (75 ft/veh is the typical design value when traffic is moving slowly)
$T =$	Percentage of trucks in entrance ramp traffic (percent) (2 percent trucks may be used as a typical design value unless field-observation indicates classification data needs to be collected to determine the actual percentage of trucks)

Equation 3.3a can be simplified when the typical design values apply that are listed in the above descriptions of the variables. The simplified equations below incorporate the typical design values into Equation 3.3a. A minimum queue storage distance of 400 feet should be used regardless of the calculated queue storage distance.

Single-Lane Ramp Meter: $Queue = (14.5\ x\ Rate_{ramp}) - 12{,}180$

Minimum $Queue$ = 400 feet

Equation 3.3b

Dual-Lane Ramp Meter: $Queue = (7.25\ x\ Rate_{ramp}) - 6{,}090$

Minimum $Queue$ = 400 feet

Equation 3.3c

3.4 Stop Bar Placement

The location of the ramp meter stop bar divides the length of entrance ramp into two segments (refer to Figure 3.4 for a graphical depiction):

- Acceleration after the stop bar
- Queue storage before the stop bar

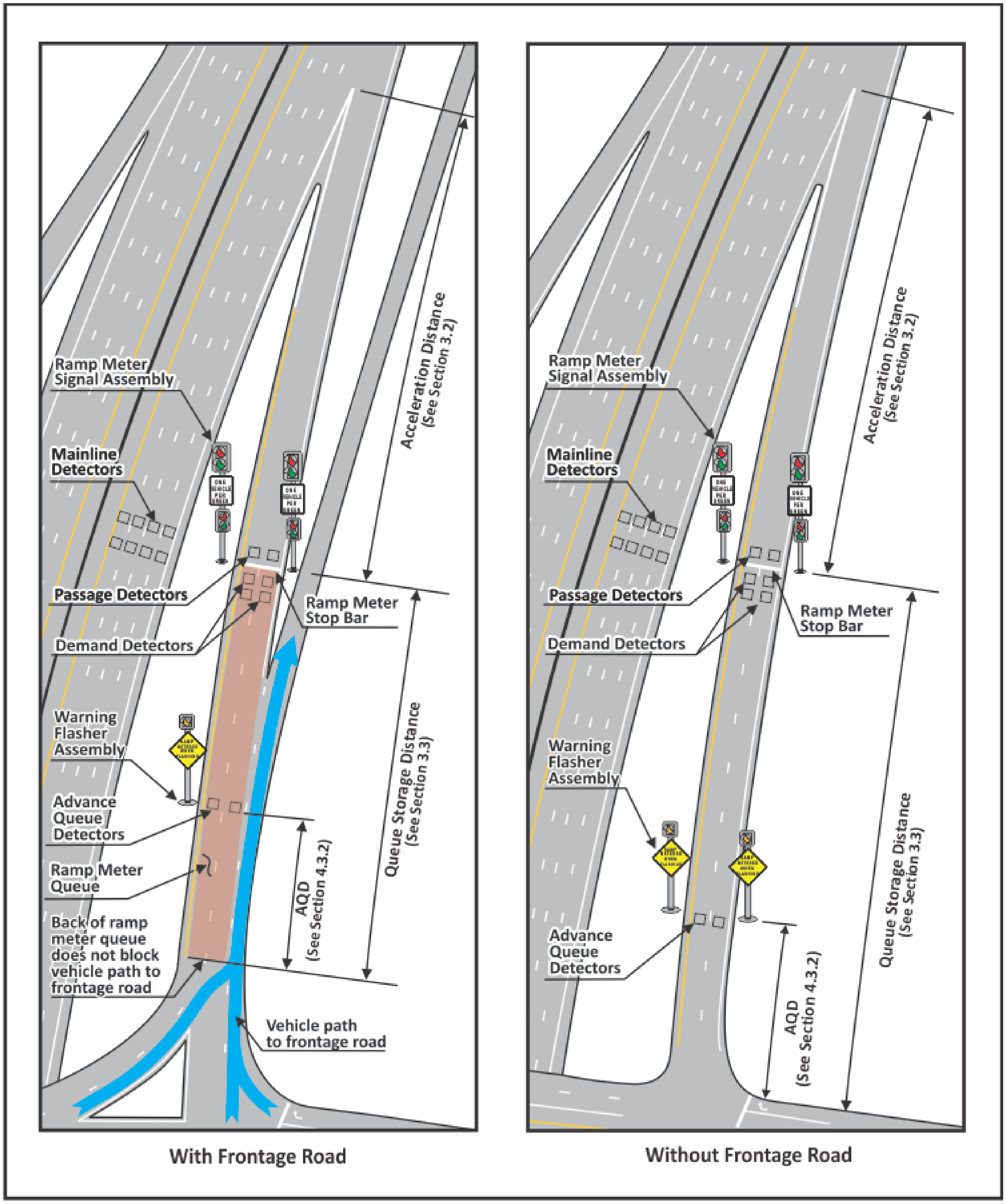
When the distances for acceleration and queue storage are both met, excess length may be provided for additional acceleration distance and/or queue storage distance.

If the recommended acceleration distance and queue storage distance cannot be met with the existing entrance ramp geometry, changes to the pavement width, entrance ramp length, pavement marking, or single-lane versus dual-lane ramp metering may be made to provide the recommended acceleration distance and queue storage distance. If changes are not feasible to provide the recommended acceleration distance and queue storage distance, the following options may be implemented:

a. Place the ramp meter stop bar to provide a reduced queue storage distance and confirm with the Transportation Technology Group that the ramp metering programming will have adequate mitigation measures to prevent queue spillback into the cross-street.

b. On entrance ramps with a parallel lane-type merge or an auxiliary lane, a distance beyond the tip of the painted gore may be considered and as acceleration distance and included in the measurement of acceleration distance. This additional distance should not extend beyond the point at which most merging occurs which is typically 200 feet or the length of the parallel/auxiliary lane, whichever is less.

c. In special cases the Transportation Technology Group may approve a reduced acceleration distance. If approved, the Transportation Technology Group can implement special ramp meter programming that turns the ramp meter off during periods when the speed of the right lane of the freeway exceeds the speed that can be reached by entrance ramp traffic. The speed that can be reached by entrance ramp traffic may be estimated using Figure 3.2 and the reduced acceleration distance.



Source: United Civil Group, 2013

Figure 3.4: Stop Bar Placement

3.5 Stop Bar Placement Example

An example is provided for placing the ramp meter stop bar on an entrance ramp. The example conditions are as follows:

- 1,800 foot entrance ramp
- 2 metered lanes
- 65 mph posted freeway speed limit
- +1.2% grade beyond the stop bar
- 4% trucks
- entrance ramp flow rate of 940 vph in the peak 15-minute period

Example Acceleration Distance Calculation

Using Table 3.2, the acceleration distance is 800 feet for a 65 mph posted freeway speed. Because the grade (*G*) is greater than 1%, the acceleration distance is increased by the following calculated value: *G x 65* or 1.2 x 65 = 78 feet. Because the percentage of trucks (*T*) is greater than 3%, the acceleration distance is further increased by the following calculated value: *(T - 3) x 100* or (4 - 3) x 100 = 100 feet. The resulting acceleration distance is: 800 + 78 + 100 = 978 feet.

Example Queue Storage Distance Calculation

Using Equation 3.3c for a dual-lane metered entrance ramp with a flow rate of 940 vehicles per hour and 4% trucks, the calculated queue storage distance is 747 feet.

Since the entrance ramp is 1,800 feet long and the recommended acceleration distance of 978 feet and calculated queue storage distance of 747 feet can both be met, the excess length is provided for additional queue storage. This results in 822 feet being provided for queue storage distance. Figure 3.5 shows the resulting placement for the ramp meter stop bar for the example entrance ramp.

The advance queue detector (AQD) location is calculated by multiplying the actual queue storage distance by 0.36. Refer to section 4.3.2 Advance Queue Detection for details. For this example, AQD = 822 x 0.36, results in 295 feet.

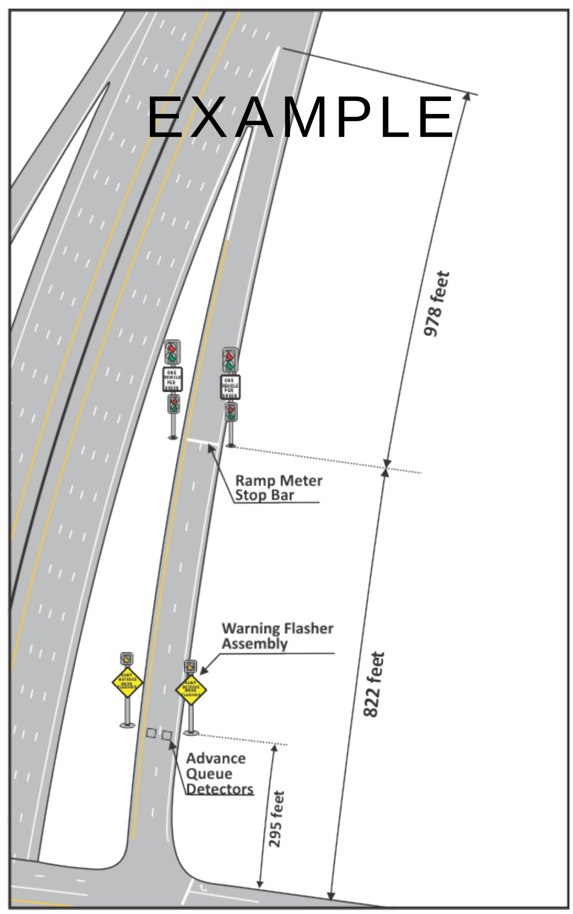


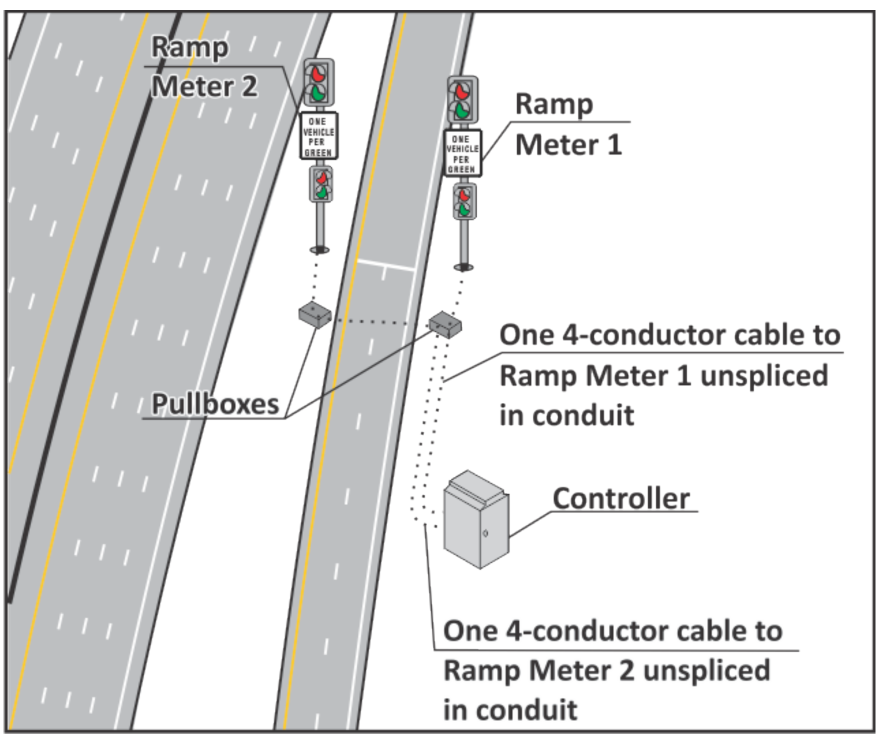
Figure 3.5: Example Stop Bar Placement

4.0 RAMP METERING HARDWARE

The typical ramp metering hardware that should be installed at each entrance ramp is described below. However, some locations may require additional equipment. The following sections provide guidance in the selection and placement of ramp metering hardware.

4.1 Ramp Meter Signal Assembly

The desirable ramp meter signal assembly includes a Type-A pole with a break-away base, pole foundation, Type-E 12-inch red/green signal head, Type-B 8-inch red/green signal head, ONE VEHICLE PER GREEN (R10-28) sign, tattle tale light, and mounting hardware. Louvers on the signal indications should not be used due to past experience with them coming loose over time. One Type-A pole ramp meter signal assembly per lane shall be placed adjacent to the ramp meter stop bar. Each Type-A pole ramp meter signal assembly shall be wired with one IMSA 4-conductor #14 AWG cable, continuous (no splices) in conduit from the controller to the terminal block of the lower signal head, refer to Figure 4.1a.



Source: United Civil Group, 2013

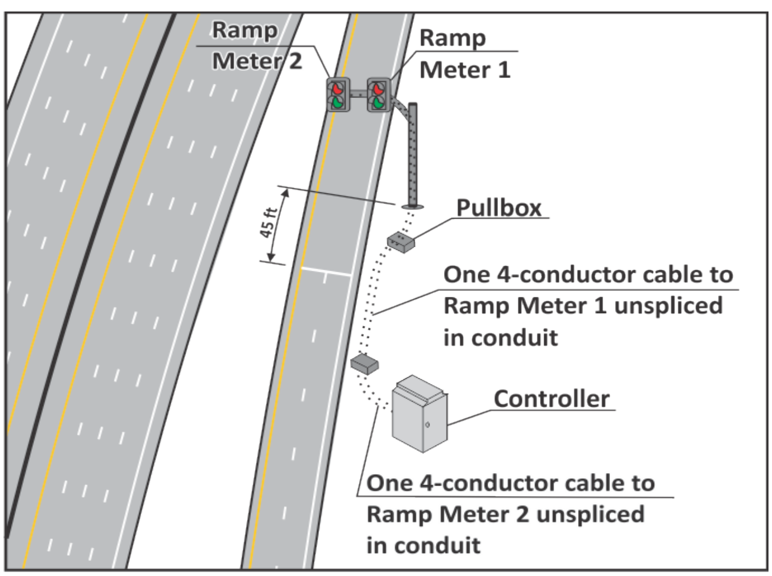
Figure 4.1a: Type A-Pole Wiring

When proper placement of a Type-A pole ramp meter signal assembly is prevented by site conditions, an overhead ramp meter signal assembly, utilizing a pole and mast arm, may be used. For new ramp meter installations, the pole for the overhead ramp meter should be located behind barrier. If the pole for the overhead ramp meter cannot reasonably be located behind barrier, it should be offset from the back of curb a minimum of 18 inches and made crashworthy using a breakaway base. A Type-J or larger pole may only be used when located behind barrier or outside the clear zone because a crashworthy breakaway base is not approved. Crashworthy breakaway bases are available for Type-E poles. When a breakaway base designated for use with an 11-inch bolt circle is used with a Type-E pole, structural capacity testing and analysis may be omitted for typical overhead ramp meters based on adequate past performance history of these breakaway bases in use.

When an overhead ramp meter is used, the signal pole should be placed 45 feet (40 feet minimum) downstream from the ramp meter stop bar.

The minimum overhead clearance above the traveled-way to the signal heads, mast arm, and other equipment should be 18 feet. To achieve the minimum overhead clearance for signal heads, a Type 1 mount may be attached below the green indication or a Type 2 mount may be attached between the red and green indications. Mast arms 25 feet and shorter should be used with caution due to the potential for overhead clearance issues. If either a Type-J pole with a 25-foot mast arm or a Type-E pole, with a 17-inch tall breakaway base and 20-foot mast arm is placed level with the pavement and with the signal heads centered over two metered lanes, the resulting overhead clearance to the mast arm will be approximately 17 feet measured at the edge of lane nearest to the pole.

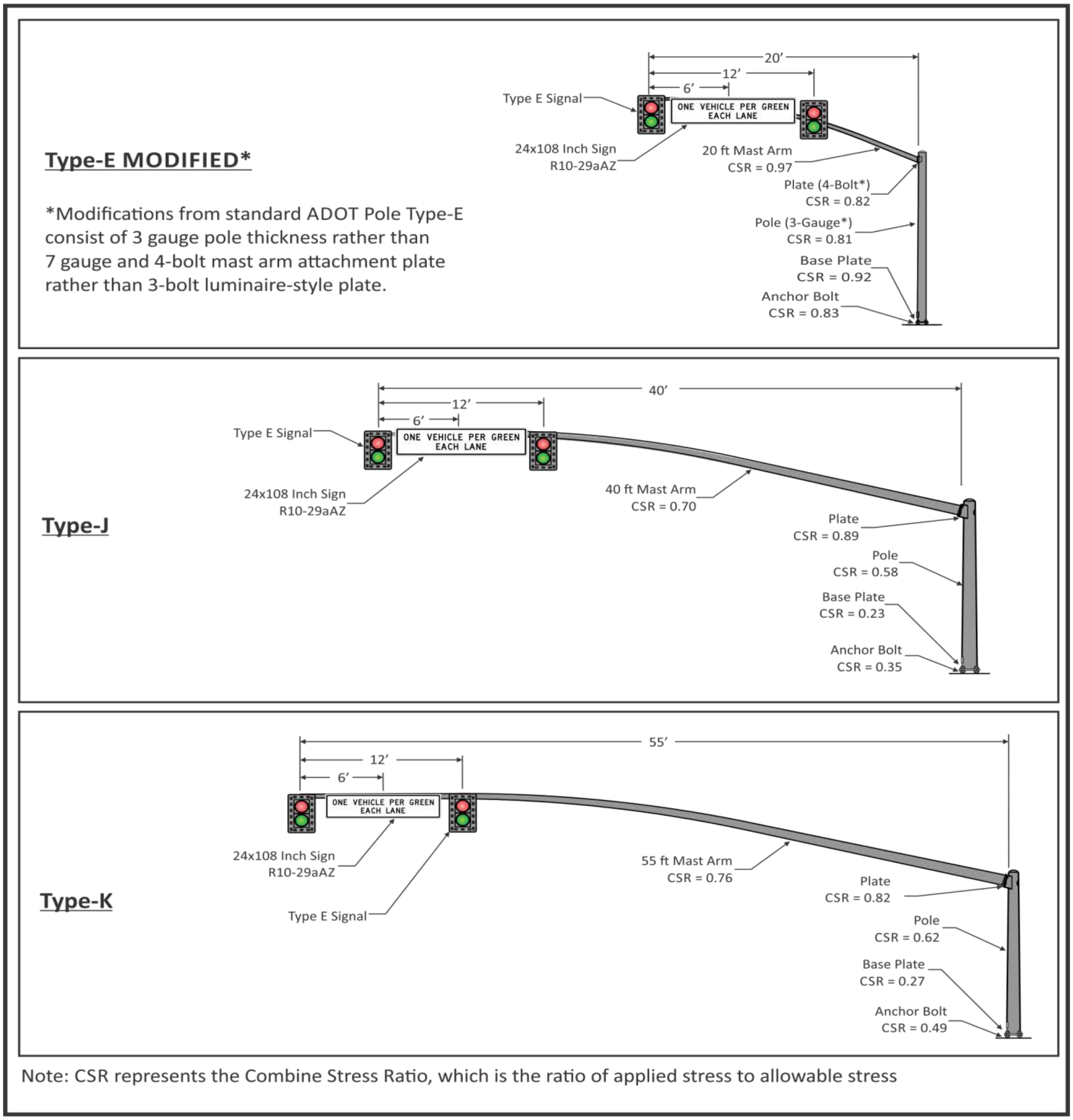
Each overhead signal head shall be wired with one IMSA 4-conductor #14 AWG cable, continuous (no splices) in conduit from the terminal block of the signal head to the controller, refer to Figure 4.1b.



Source: United Civil Group, 2013

Figure 4.1b: Overhead Wiring

Figure 4.1c depicts typical loading conditions for dual-lane overhead ramp meter signal assemblies. To provide the worst-case loading condition for the pole, each type of pole is shown with the longest mast arm available for use with that pole. A combined stress ratio (CSR) is provided in Figure 4.1c for each pole type at typically-critical structural points. The CSR is the ratio of applied stress from loads (wind, gravity, and seismic) to the allowable stress. A CSR greater than 1.0 would indicate that the structural component is over-capacity. The signal assemblies shown satisfy the 1994 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals* and the prescribed wind speeds for the Phoenix-metro region.



Source: United Civil Group, 2013

Figure 4.1c: Typical Loading for Overhead Ramp Meter Signal Assemblies

The standard ADOT Type-E pole assembly is not structurally adequate to support the equipment for a typical dual-lane ramp meter. Therefore, a Type-E Modified pole and mast arm is shown, with modifications as noted. The standard Type-J and Type-K pole and mast arm assemblies are structurally adequate with the equipment shown.

If a ramp meter signal assembly design deviates from the typical loading conditions shown, a structural investigation should be performed if it is believed to be warranted. The CSR values may be used as a gauge of structural capacity and aid in determining whether a structural investigation is warranted.

4.2 Warning Flasher Assembly

The warning flasher assembly is active while the ramp meter is in operation to provide warning of the traffic control. The warning flasher assembly consists of a Type-A pole with break-away base, pole foundation, Type-D flashing yellow beacon, RAMP METERED WHEN FLASHING (W3-8) sign, and mounting hardware.

The warning flasher assembly should be placed adjacent to the Advance Queue Detector. Where sight distance of the ramp meter or warning flasher assembly is limited, the warning flasher assembly may be placed in an alternate location or more than one warning flasher assembly may be used. A warning flasher assembly shall be placed in advance of a ramp meter a minimum of 250 feet.

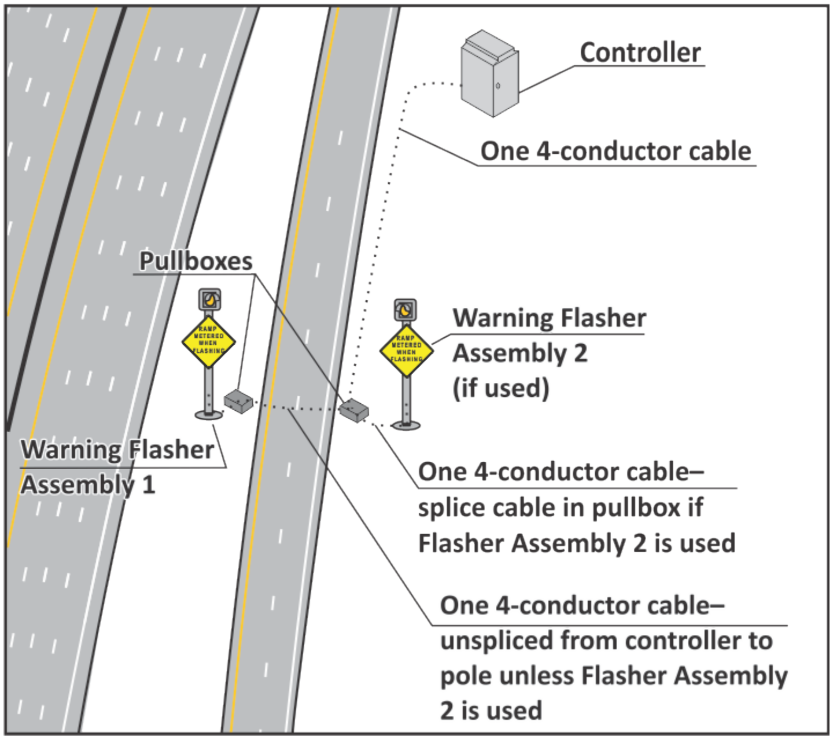
One warning flasher assembly should be used on the left side of the entrance ramp if one entrance ramp lane exists where the warning flasher assembly will be placed.

Two warning flasher assemblies should be used, one on each side of the entrance ramp, if two or more entrance ramp lanes exist where the warning flasher assembly will be placed.

If a frontage road lane is present where the warning flasher assembly will be placed, one warning flasher assembly should be used on the left side of the entrance ramp.

When two warning flasher assemblies are used on each side of the road, wire one IMSA 4-conductor #14 AWG cable continuously (no splices) in conduit from the controller to the pull box adjacent to the warning flasher assembly. From the pull box, run one IMSA 4-conductor #14 AWG cable to each warning flasher assembly.

When one warning flasher assembly is used, wire one IMSA 4-conductor #14 AWG cable continuously (no splices) from the controller to the warning flasher assembly, refer to Figure 4.2.



Source: United Civil Group, 2013

Figure 4.2: Warning Flasher Assembly Wiring

4.3 Vehicle Detection

4.3.1 Mainline Detection

Freeway mainline detection is used for traffic responsive ramp metering and traffic data collection. Inductive loop detectors should be utilized for mainline detection.

The mainline detectors are placed relative to the location of the ramp meter stop bar. Mainline detection is typically placed in each freeway lane, adjacent to the ramp meter stop bar. The mainline detectors should not be placed in lane tapers or heavy merging and weaving areas. The mainline detectors should be clearly visible from the controller.

Preformed loop detectors should be used when installed in new pavement construction. Saw-cut loop detectors may be installed in existing pavement. Loop detectors should not be placed in pavement with reinforcing steel such as concrete bridge decks. Avoid lateral pavement joints when installing loops.

These detectors consist of two 6x6-foot loops, placed within the lanes per the ADOT *ITS Standard Drawings*. Use a separate lead-in cable for each loop.

4.3.2 Advance Queue Detection

The purpose of the advance queue detector is to cause the ramp meter to cycle at a faster rate when a queue is detected so that the queue does not spillback onto the cross-street.

The advance queue detector consists of one 6x6-foot loop centered in each metered lane. If more than one loop is used the loops shall be wired in series.

The location of the advance queue detector is calculated using the following formula:

$$AQD = 0.36\, x\, QueueProvided$$

Equation 4.3.2

Where:

AQD = The advance queue detector distance, measured in feet, from the trailing edge of the advance queue detector loop to the near-edge of the traveled way of the cross-street as depicted in Figure 3.4. The minimum AQD distance is 150 feet. At single-point-urban-interchanges (SPUI) the minimum AQD distance is 150 feet or the distance to the downstream nose of the SPUI ramp median, whichever is greater. The minimum distance from the stop bar to the advance queue detector should be 250 feet. The maximum distance from the stop bar to the advance queue detector should be 900 feet.

$QueueProvided$ = The queue storage distance that will be provided, measured in feet. This value is measured from the ramp meter stop bar to the near-edge of the traveled way of the cross-street as depicted in Figure 3.4. If a frontage road is present, this value is measured from the ramp meter stop bar to the point where a ramp meter queue would block access to the frontage road. This value is the queue storage distance that will be provided and may be different than the calculated $Queue$ value from section 3.3 Queue Storage Distance.

4.3.3 Demand Detection

Demand detectors, also known as input detectors, sense the presence of a vehicle at the ramp meter stop bar. This detector is placed relative to the location of the ramp meter stop bar.

Use two 6x6-foot loops in each metered lane. Place the trailing edge of the loop nearest the stop bar 3 feet upstream of the stop bar. Separate the trailing edges of the two loops in each lane by 16 feet. Center the detectors in the lane for lanes 12 feet or wider. For narrow lanes, offset the detectors away from the center of the ramp, so that the edge of each loop is 2 feet from the shoulder. Both demand detectors within a single lane shall be connected in series. One lead-in cable shall be provided for both loops in each lane.

4.3.4 Passage Detection

Passage detectors, also known as output detectors, terminate the green interval after a vehicle clears the stop bar. The leading edge of this detector is placed 6 feet downstream from the ramp meter stop bar. Use one 6x6-foot loop in the travel path of each metered lane. Center the detector in the projection of each lane for lanes 12 feet or wider. For narrow lanes, offset the detector away from the center of the ramp, so that the edge of each loop is 2 feet from the shoulder. A single lead-in cable is provided from each passage detector loop to the controller.

4.4 Control Cabinet Assembly

A Type 341A control cabinet assembly with a Dooley Sump shall be used for ramp metering. The control cabinet should be located a minimum of 20 feet upstream from the ramp meter stop bar and shall be positioned so that the ramp signal heads are visible when facing the front door of the cabinet. The controller cabinet shall be placed outside the clear zone. The control cabinet should be placed on the right side of the entrance ramp and should provide a safe work environment for people servicing the cabinet. When the cabinet is placed behind guardrail, it shall be placed at least 6 feet away from the guardrail to allow for deflection of the guardrail upon impact, and room to work near the cabinet. The control cabinet shall be located so that the distance to the loop detectors is within the loop detector manufacturer's recommended limits. A unique cabinet identification number shall be clearly labeled on the design plans for each cabinet as specified per the ADOT *ITS Standard Drawings*. Refer to the *ADOT Freeway Management System Design Guidelines* for additional control cabinet assembly guidelines.

4.5 Conduit and Pull Boxes

Refer to the ADOT *ITS Standard Drawings* for typical conduit and pull box layout.

4.6 Ramp Metering Pavement Marking

Pavement markings shall conform to the MUTCD and Arizona Supplement to the MUTCD. Exceptions shall be reviewed and subject to approval by ADOT. The designer should verify with ADOT Traffic Engineering Group the striping material (paint, thermoplastic, pre-formed tape, epoxy) to be used.

The stop bar shall be 18 inches wide and extend from the lane's edge line to edge line.

The edge lines of the entrance ramp should be striped per ADOT *Traffic Signing and Marking Standard Drawing M-15*.

The center lane line of a dual-lane metered entrance ramp shall be a white 6 inch wide broken lane line. A solid center lane line at the ramp meter stop bar should not be used. The center lane line of a dual-lane metered entrance ramp should typically terminate at the ramp meter stop bar.

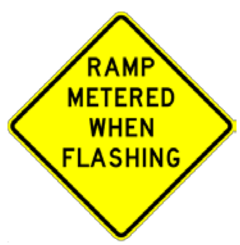
Striping should not be located in gutters. If geometric constraints require striping to be placed in gutter, this should be reviewed on a case-by-case basis with ADOT Traffic Engineering Group.

Refer to the *ADOT Roadway Design Guidelines*, Table 302.4 for shoulder width and taper guidelines, and Section 301.3 for lane width guidelines.

4.7 Ramp Metering Signing

This section includes ramp metering signing typically used by ADOT, additional ramp meter signing may be used to provide additional warning or improve ramp metering compliance.

The RAMP METERED WHEN FLASHING (W3-8) sign shall be installed in advance of the ramp meter on a warning flasher assembly that includes a warning beacon that flashes when the ramp meter is in operation. The size should be 36x36 inch when installed on ramps which connect to conventional roadways. Refer to section 4.2 Warning Flasher Assembly for details.



W3-8

A 24x30 inch ONE VEHICLE PER GREEN (R10-28) sign shall be installed on each Type-A ramp meter signal pole. Refer to section 4.1 Ramp Meter Signal Assembly for details.

R10-28

When an overhead ramp meter is used, one 24x108 inch ONE VEHICLE PER GREEN EACH LANE (R10-29aAZ) sign shall be installed on the mast arm. Because of the large size of the sign panel, it shall be installed using clamps (not bands) per ADOT *Signing and Marking Standard Drawing S-9*, sheet 1 of 3.

R10-29aAZ

When an overhead ramp meter is used, a STOP HERE ON RED (R10-6a{R or L}) sign shall be installed adjacent to the stop bar. Dual-lane ramp meters should have a sign on each side of the entrance ramp. Single-lane ramp meters should have a sign on the left side of the entrance ramp.

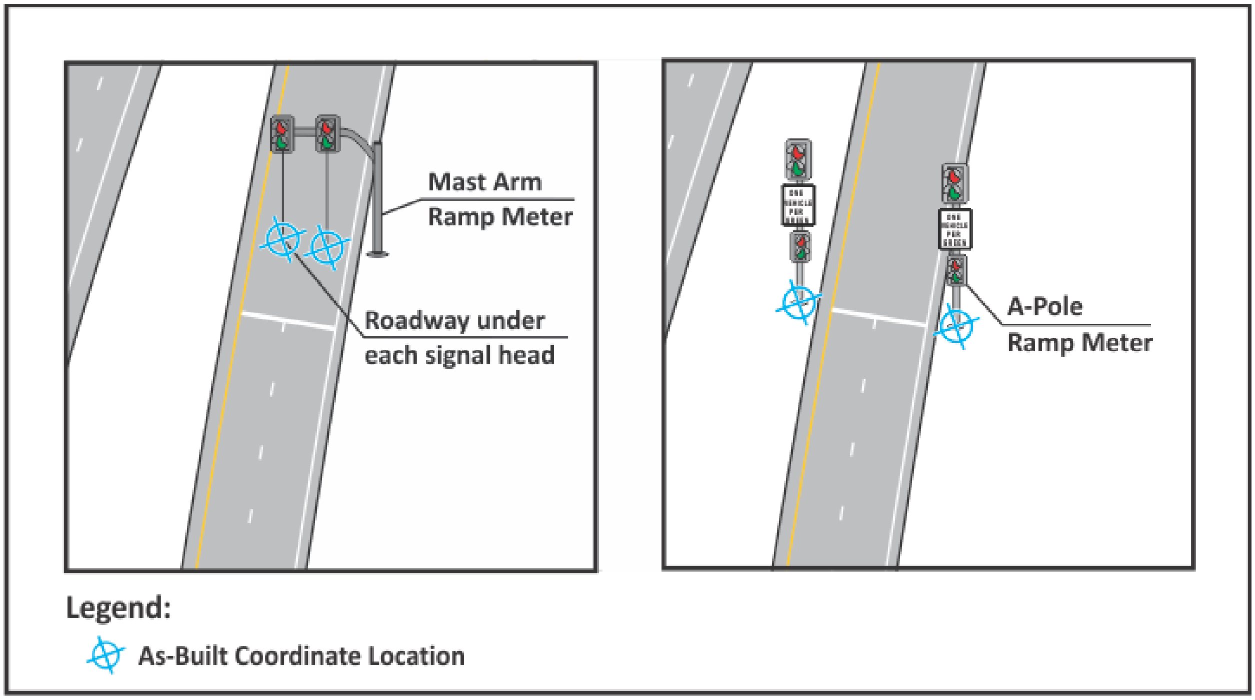
R10-6aR

4.8 Ramp Metering As-Built Specification

The designer shall include an as-built specification in the project specifications requiring the contractor to provide as-built coordinates of the following new and existing devices within the project limits:

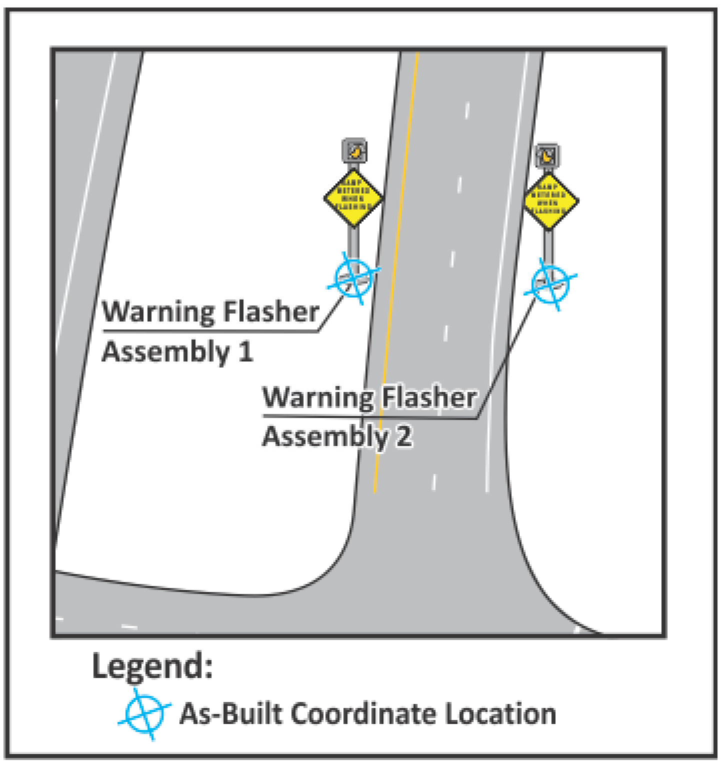
- Ramp meter signal assembly
- Warning flasher assembly
- Advance queue detector
- Controller cabinet

The contractor shall be required to record the latitude and longitude as-built coordinates. The designer shall provide fill-in placeholders on the plans for the contractor to record as-built coordinates. The contractor shall be required to collect the as-built coordinates using a GPS device with accuracy within 24 inches. The contractor shall provide the electronic files of the GPS survey to the ADOT Transportation Technology Group in both a raw (non-post-processed) file format and post-processed .shp file format compatible for import into GIS software. The following figures depict the location where as-built coordinates shall be collected.



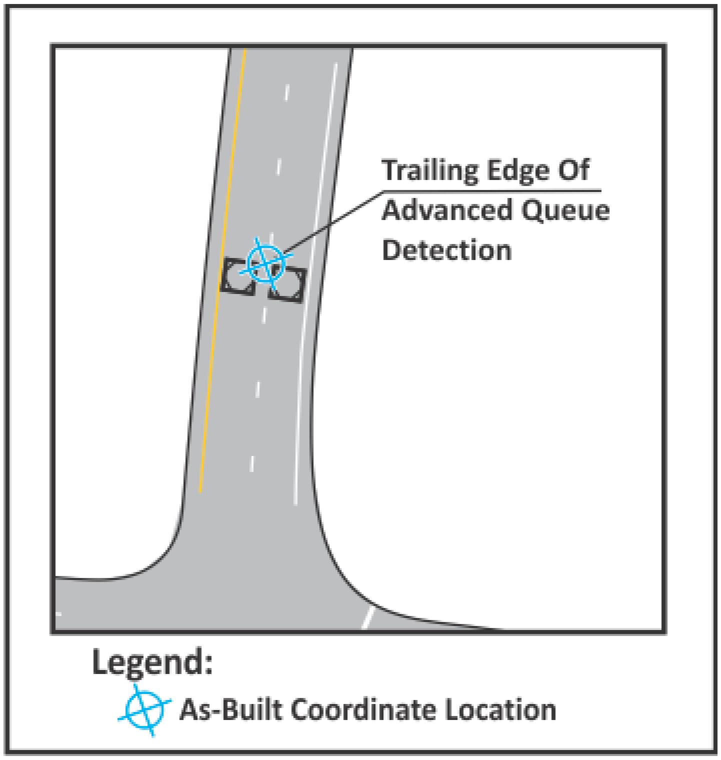
Source: United Civil Group, 2013

Figure 4.8a: Ramp Meter Signal Assembly GPS As-Built Coordinates



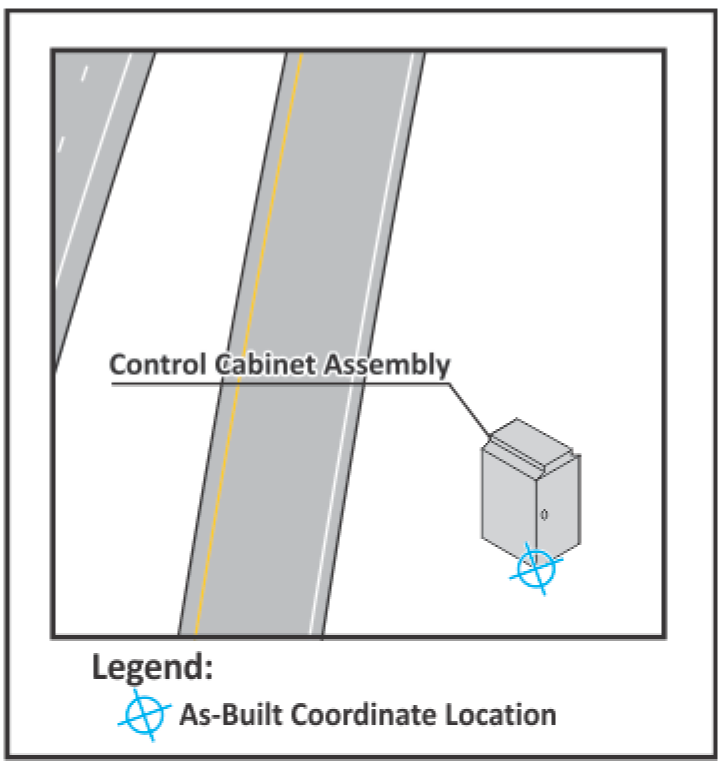
Source: United Civil Group, 2013

Figure 4.8b: Warning Flasher Assembly GPS As-Built Coordinates



Source: United Civil Group, 2013

Figure 4.8c: Advanced Queue Detector GPS As-Built Coordinates



Source: United Civil Group, 2013

Figure 4.8d: Control Cabinet Assembly GPS As-Built Coordinates