Detection Control System (D-CS)

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Table of Contents

1 Detection-Control System (D-CS) User's Guide

The Detection-Control System (D-CS) concept was developed by the Texas Transportation Institute to improve the safety of high-speed, signalized intersections[1]. This system uses a unique detector configuration to monitor approaching vehicles and hold the green until they are safely clear of the intersection, as well as providing some priority for trucks.

This guide provides an overview of D-CS operation and identifies the settings necessary to provide for D-CS operation on a Cubic | Trafficware 2070, ATC or Commander controller.

1.1 Overview

D-CS is similar to a traditional advance detector system in that it uses information from detectors located upstream from the intersection to extend the green. However, it differs from the traditional advance detector system because it processes vehicle speed and length information to find the best time to terminate the major-road through phase. This time is based on a forecast of the number of vehicles that will be in the dilemma zone[2] in the immediate future as well as the number of minor movements waiting for service. D-CS re-evaluates this information continuously and updates it in real time.

D-CS uses a two-loop detector trap in each approach lane to obtain the necessary information about vehicles approaching the intersection. Each detector trap is located 700 to 1000 ft upstream of the intersection, as shown in figure below. The exact location is not critical. However, distances nearer 1000 ft are encouraged because they provide D-CS with a larger time horizon for evaluating future arrivals to the dilemma zone.

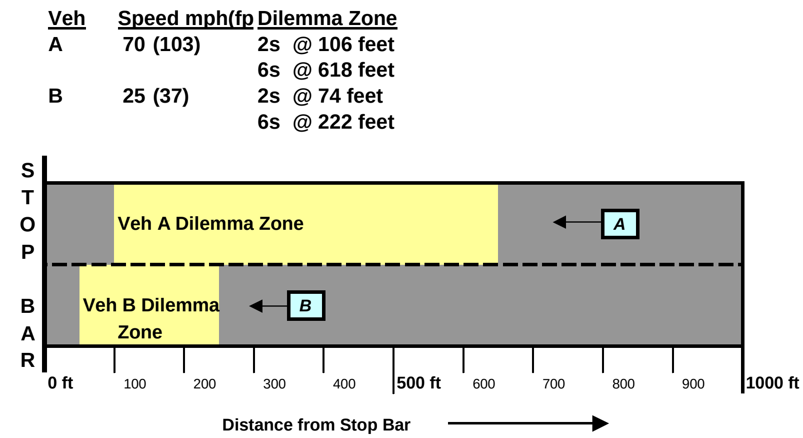
A key feature of D-CS is that it can predict, in real-time, when each vehicle will arrive to and depart from its dilemma zone on the intersection approach. This feature takes advantage of the fact that the dilemma zone boundaries are defined in terms of travel time to the stop line. D-CS measures each arriving vehicle's speed, forecasts its dilemma zone arrival and departure times, and holds the green phase when a vehicle is in its dilemma zone.

It is CRITICAL that the queue is cleared before D-CS starts operating. If the roadway does not have stop bar detection, the user must set up Min Green times long enough to assure that the vehicle queues will clear. If, the roadway does have a stop bar detector, then the user may need some extension time to keep natural gaps in the queue from making the software (controller) calculate that the queue has cleared. D-CS does not start working until it thinks the queue is cleared... and once it starts working, it will hold/terminate the phase at its will, so it is critical that the queue clearance be properly recognized.

When setting up a D-CS System, the user must consider limiting features that would render the software ineffective. As an example, users should avoid feeding any other detector inputs to this phase for the purpose of extending the phase, because it simply won't have any affect. Furthermore, users should not apply any special inhibits/holds/fore-offs/etc. when using D-CS.

[1] *Intelligent Detection-Control System for Rural Signalized Intersections*, Report FHWA/TX-03/4022-2, Texas Transportation Institute, August 2002. http://tti.tamu.edu/documents/4022-2.pdf

[2] The dilemma zone represents a length of roadway on the intersection approach within which the population of drivers are collectively indecisive as to whether to stop or continue when presented a yellow signal indication. The upstream edge of this zone is typically defined as being 5.5 s travel time from the stop line. The downstream edge of this zone is typically defined as being 2.5 s travel time from the stop line.



Example # 1

To illustrate the implications of D-CS's dynamic dilemma-zone monitoring process, consider Example #1 as shown above. A vehicle traveling at 70 mph is at point A in the above example, and a vehicle traveling at 25 mph is at point B. Neither of these vehicles is in their respective dilemma zones, so D-CS could terminate the phase at this instant in time. In contrast, both vehicles are almost certainly in the zone protected by the traditional multiple advance detector system, and both vehicles would unnecessarily extend the phase. As a result, a D-CS-controlled phase could end at this point in time whereas the traditional system would continue to extend the green interval. This example uses an extreme speed differential to make its point. However, the concept applies to the full range of speeds and allows D-CS to consistently end the phase sooner than the traditional system. Over time, this capability ensures that D-CS will operate with less delay and catch fewer vehicles in the dilemma zone than the traditional advance detector system.

At the same time that D-CS is monitoring approaching vehicles, it is also searching for a time in the near future when the total number of drivers in their respective dilemma zone is at a minimum. This future time is defined as the "best time to terminate the phase." Other factors that are also considered when deciding the best time to terminate the phase include: (1) whether the vehicle is a large truck and (2) the delay to drivers waiting on the minor road.

When a vehicle places a call for service on a movement conflicting with a D-CS controlled phase, D-CS begins searching for the best time to terminate the phase. Initially, D-CS searches for a time when the dilemma zones in each lane are clear (i.e., unoccupied). This time period is called "Stage 1." If D-CS is unable to terminate the phase after the Stage 1 time has elapsed, it transitions to "Stage 2." During this stage, the search criteria are relaxed to allow one passenger car per lane to be in the dilemma zone upon phase termination, but no trucks. As in Stage 1, the presence of a truck in its dilemma zone during Stage 2 prevents the phase from being terminated. The Stage 2 operation is especially useful during higher flow rates when a search for a clear dilemma zone would frequently lead to max-out. Ending the phase with one car in the dilemma zone is reasonably safe from rear-end collisions and preferable to ending with no protection (i.e., at max-out)

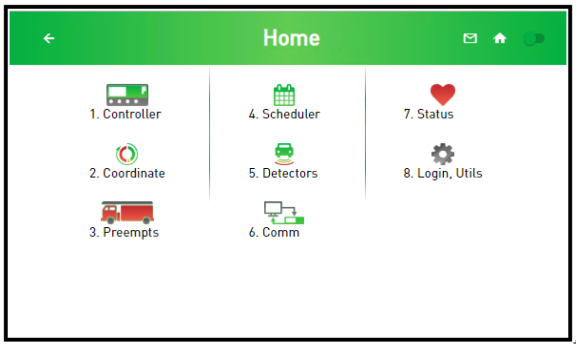
The real-time nature of D-CS operation allows it to dynamically accommodate changes in speed that occur at the intersection throughout the day, week, and year. Its performance is not compromised when traffic speeds change, as would be the case for traditional advance detection systems because their detectors are precisely located for a specified design speed.

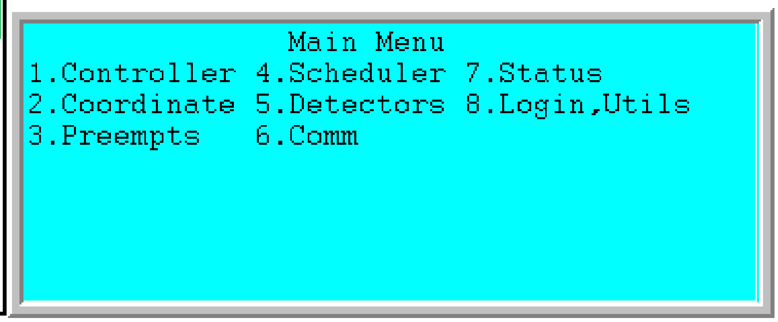
In short, D-CS is designed to dynamically identify the dilemma zone for *each* vehicle, in *real time*, and *predict* the best time to terminate the phase. This design allows D-CS to provide safe and efficient signal operation for the full range of intersection traffic volumes and speeds.

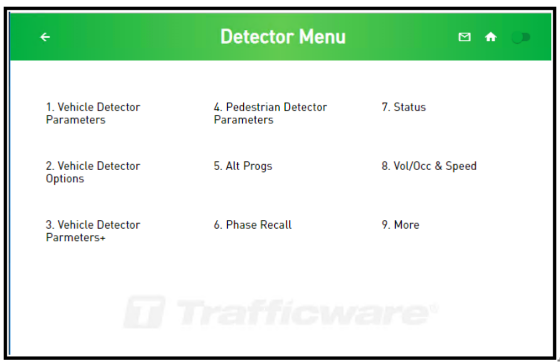
1.2 D-CS Input screens

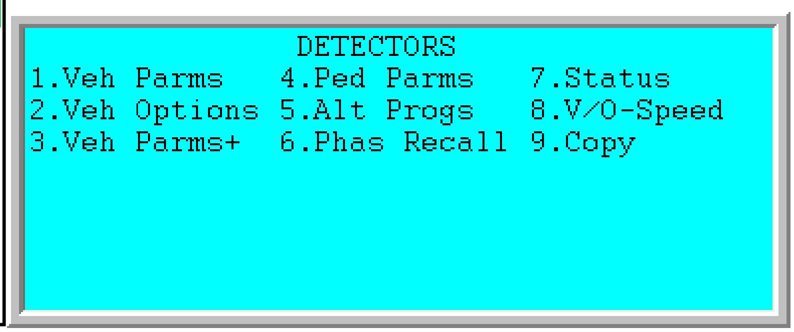
NOTE: For consistency with former NTCIP software platforms and operational feature descriptions, this manual will primarily display menu items using the Classic view screens. When appropriate, the Graphical view screens will also be displayed if the agency is using the Commander controller and V85/Scout software.

To access the screens that are used by D-CS, the user will access the detector submenu using MM→5→8 as shown below:









To set up the system, the user has to be concerned with programming both the Speed Detector Setup and the Lane Setup screens. Once programmed the user can monitor the D-CS operation via a Status screen.

All screens are discussed below.

```
            VOL/OCC & SPEED
1.Report Parms
2.Speed Detectors
3.Speed Thresholds
4.DCS Menu
```

This manual assumes that the user has assigned the detector parameters for each detector prior to setting up the speed detectors, via MM→5→1 (Veh. Params) and MM→5→2 (Veh. Options). Further note, that on the Veh Options screen the user may assign a D-CS phase number and various detector analysis parameters, as shown below. If the user decides to program these options, then if a detector fails, the phase can be set on Max Recall (i.e FailTime = 255 sec) or any value that the user wants the phase to be recalled thus “extending” the D-CS phase. Please refer to the Cubic | Trafficware NTCIP controller manual for further details.

Det#	Call	Switch	Delay	Extend	Queue >
1	1	0	0.0	0.0	0
2	2	0	0.0	0.0	0
3	2	0	0.0	0.0	0
4	0	0	0.0	0.0	0
5	6	0	0.0	0.0	0
6	6	0	0.0	0.0	0
7 +	0	0	0.0	0.0	0

< Det#	NoAct	MaxPres	ErrCnt	FailTime
1	0	0	0	2
2	0	45	75	255
3	0	45	75	255
4	0	0	0	2
5	0	45	75	255
6	0	0	0	255
7 +	0	0	0	2

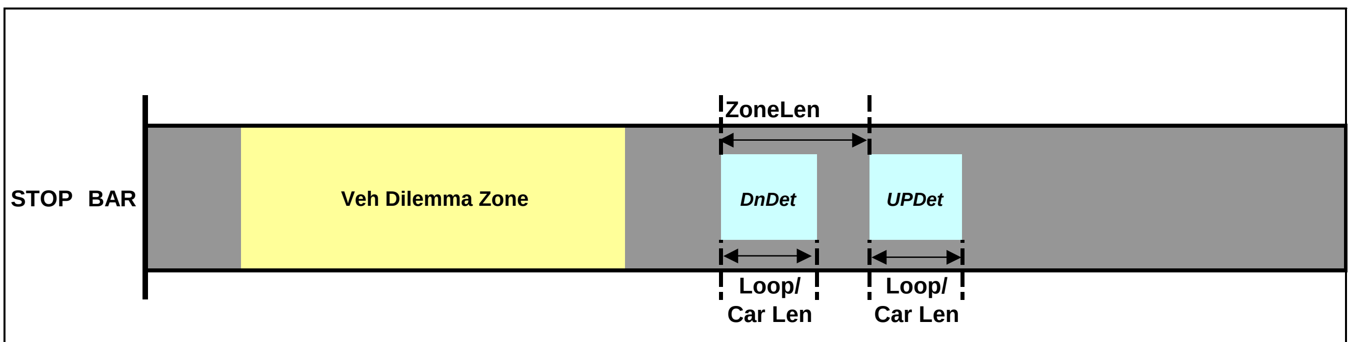
1.3 Speed Detectors

D-CS uses a pair of detectors in each lane in a speed trap configuration. Each speed trap is set up in the speed detector screen, accessed by **MM -> 5 (Detectors) -> 8 (V/O-Speed) -> 2 (Speed Detectors)**.

	UpDet	DnDet	ZoneLen	Loop/CarLen
1	2	3	20.0	6.0
2	5	6	20.0	6.0
3	8	9	25.0	6.0
4	11	12	25.0	6.0
5	0	0	0.0	0.0
6	0	0	0.0	0.0
+ 7	0	0	0.0	0.0
- 8	0	0	0.0	0.0
9	0	0	0.0	0.0
10	0	0	0.0	0.0
11	0	0	0.0	0.0
12	0	0	0.0	0.0
13	0	0	0.0	0.0
+14	0	0	0.0	0.0
15	0	0	0.0	0.0
16	0	0	0.0	0.0

Each row describes one speed trap. Speed traps 1, 2, 3, and 4 are defined in the figure above. An explanation of the values shown for each speed trap is provided in the following sections. Please refer to Example #2 below.

Note: D-CS can monitor one speed trap per lane and as many as eight lanes. So, the maximum number of speed traps is also eight. **Therefore for any D-CS system, program speed traps 1-8 only.**



Example # 2

UpDet

UpDet is the detector channel number for the upstream detector in a speed trap. Enter the appropriate detector number (1-64) for the lane that you want to monitor.

DnDet

DnDet is the detector channel number for the downstream detector in trap. Enter the appropriate detector number (1-64) for the lane that you want to monitor.

ZoneLen

ZoneLen is the distance from downstream end of UpDet to downstream end of DnDet in feet. The minimum ZoneLen is 20 ft, although a longer trap may be used if desired. Programmed values are 0.0 to 25.5 feet.

Loop/CarLen

Loop/CarLen is the size of the UpDet and DnDet detector loops, in feet. Programmed values are 0.0 to 25.5 feet.

IMPORTANT NOTE: For D-CS to function properly, both loops in each trap MUST be the same size.

1.4 Lane Setup

The lane setup is performed after the detector traps are assigned. The lane setup screen is accessed by **MM -> 5 (Detectors) -> 8 (V/O-Speed) -> 4 (DCS Menu) -> 1 (Lane Setup)** and is shown below

DCS Setup	Lane1	Lane2	Lane3	Lane4	>
Phase	2	6	4	8	
SpeedTrap	1	2	3	4	
TrapDistance	1000	1000	750	750	
DZArrival	6.0	6.0	6.0	6.0	
DZExit	2.0	2.0	2.0	2.0	
StagePercent	65	65	75	75	
MaxSpeed +	55	55	45	45	
MaxLength	50	50	25	25	

Lane1, Lane2, Lane3, … Lane8

Each lane controlled by D-CS has a detector trap assigned to it. Up to eight approach lanes can be monitored by D-CS.

Phase

The D-CS controlled phase associated with this lane. Phase 1-16 may be programmed.

SpeedTrap

SpeedTrap is the speed trap number assigned to this lane from the speed detector screen. Valid SpeedTrap values are 1-8.

TrapDistance

TrapDistance is the distance from the downstream end of the detector trap to the stop line of the intersection, in feet. The traps should be located between 700 ft and 1000 ft from the stop line. The maximum value that can be programmed is 1500 ft.

DZArrival

DZArrival is the travel time from the upstream end of the dilemma zone to the stop line, in seconds. **The DZArrival time can not be smaller than DZExit time!** Programming parameters vary from 0 to 9.0 seconds.

DZExit

DZExit is the travel time from the downstream end of the dilemma zone to the stop line, in seconds. **The DZExit time can not be larger than DZArrival time!** Programming parameters vary from 0 to 9.0 seconds.

StagePercent

The maximum green time is divided into two stages. Stage 1 occurs first, followed by Stage 2. The StagePercent is the percent of the maximum green time that is allocated to Stage 1. Phase termination during this stage requires that all dilemma zones are clear (i.e., no vehicles are in the dilemma zone). The balance of the maximum green time is allocated to Stage 2. During Stage 2, D-CS searches for a time when the number of vehicles in the dilemma zone is at a minimum. It terminates the phase when this minimum is reached.

MaxSpeed

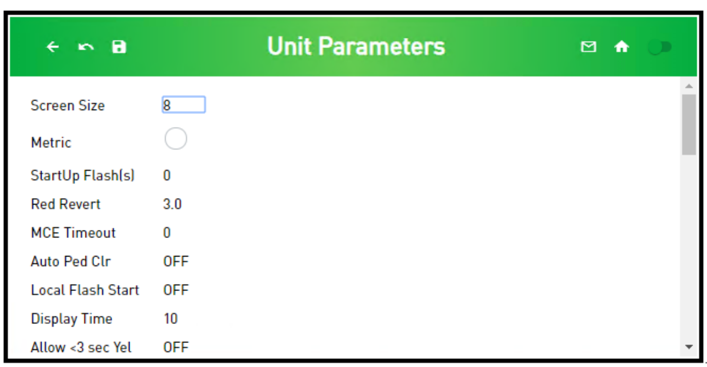
MaxSpeed is the maximum acceptable travel speed to be used by D-CS, in miles per hour. Speeds reported to D-CS that are higher than the maximum speed are considered to be an error and are set to the maximum speed.

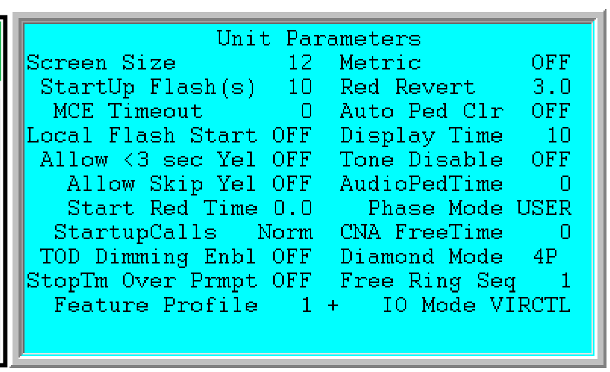
MaxLength

MaxLength is the maximum acceptable vehicle length for D-CS, in feet. Vehicle lengths reported to D-CS that are longer than the maximum length are considered to be an error and the maximum length is reported instead. Vehicle length can be programmed from 25 feet to 100 feet long.

1.5 Metric programming

DC-S now provides metric unit inputs via a simple selection on the Unit Parameters screen located at MM->1->2->1. Page down this screen and select the **Metric** parameter





Simply select “OFF” to edit and view all appropriate DCS entries in English units and “ON” to edit and display all appropriate DCS entries in Metric units.

2 D-CS Status Screens

There also is a D-CS status screen so a user can monitor D-CS operation in the field. This screen is accessed by **MM -> 5 (Detectors) -> 8 (V/O-Speed) -> 4 (DCS Menu) -> 7 (Status)**

	1	2	3	4	5	6	7	8>
PhaseOn	.	X	.	.	.	X	.	.
PhsCall	.	.	.	X	.	.	.	.
DCSActv	.	X	.	.	.	X	.	.
EGWUsed	0	0	0	0	0	0	0	0
Thrshold	0	0	0	0	0	0	0	0
Holding	.	.	.	.	.	.	.	.
QueClear	.	.	.	.	.	.	.	.

<	9	10	11	12	13	14	15	16
PhaseOn	.	.	.	.	.	.	.	.
PhsCall	.	.	.	.	.	.	.	.
DCSActv	.	.	.	.	.	.	.	.
EGWUsed	0	0	0	0	0	0	0	0
Thrshold	0	0	0	0	0	0	0	0
Holding	.	.	.	.	.	.	.	.
QueClear	.	.	.	.	.	.	.	.

UseSum	.	.	.	.	.	.	.	.
LookAhed	0	0	0	0	0	0	0	0
Error	0	0	0	0	0	0	0	0

UseSum	.	.	.	.	.	.	.	.
LookAhed	0	0	0	0	0	0	0	0
Error	0	0	0	0	0	0	0	0

Each column's entries have the data for one phase. The screen shots above indicate that phases 2 and 6 are the D-CS controlled phases.

PhaseOn

PhaseOn indicates if this phase is (X) or is not (.) currently active. A phase is "active" when it is timing the green, yellow, or all-red intervals. In the example, the active phases are phase 2 and phase 6.

PhsCall

PhsCall indicates if this phase has (X) or does not have (.) a call for service. In the example, phase 4 has a call for service.

DCSActv

DCSActv indicates if D-CS is (X) or is not (.) active for this phase. D-CS is "active" when it is searching for a safe time to terminate the phase. D-CS can only be active for two of the eight phases at any one time, and only when those two phases are green. In the example, D-CS is active on phases 2 and 6.

EGWUsed

EGWUsed is the sum of the lengths of all the vehicles currently in the dilemma zone for a given phase, or the sum of the lengths of all vehicles in any phase's dilemma zone if the phases must terminate together. This value is used to compare against the Threshold in order to determine whether or not the phase can terminate. If the EGWUsed is less than or equal to the threshold, and there is not a safer time in the future to terminate, then the phase will immediately terminate.

Consider for example that EGWUsed is calculated as 24 feet and Thrshold is programmed as of 24 feet. A threshold of 24 feet indicates that no single vehicle will occupy more than 24 feet, unless it is a truck; therefore anything 24 feet or longer is either more than one car (which inhibits termination) or a truck (which also inhibits termination). Because EGWUsed is equal to the threshold, and there is not a safer time in the future to terminate, then the phase will immediately terminate.

Thrshold

Threshold is the maximum sum of vehicles length allowable in the dilemma zone to permit a phase to terminate

Thrshold can have two different states for an active D-CS phase:

- When D-CS is in Stage 1, Thrshold is zero.
- When D-CS is in Stage 2, Thrshold is 24 feet.

There are three ways to terminate a D-CS controlled phase: in Stage 1, in Stage 2, or by max out. EGWUsed and Thrshold can be used together to determine how each D-CS controlled phase ended. To terminate a phase in Stage 1 or Stage 2, the EGWUsed value must be less than or equal to Thrshold. In Stage 1, D-CS requires that all dilemma zones must be clear before the phase is allowed to terminate. For this reason, Thrshold is set to zero during Stage 1 and the EGWUsed must equal zero in each lane before the phase can be terminated.

In Stage 2, D-CS relaxes the requirement that all dilemma zones must be clear to terminate the phase. In this stage, a phase can be terminated when there is no more than one *passenger car* in the dilemma zone. To provide truck priority, D-CS maintains the requirement in Stage 2 that all dilemma zones be clear of trucks (defined as vehicles with a length of 25 ft or more). For this reason, **Thrshold is set to 24 during Stage 2 and the EGWUsed must be less than 24 in each lane before the phase can be terminated.**

When the maximum green limit is reached, the phase is terminated (i.e., maxes out), regardless of the Thrshold or EGWUsed values.

Holding

Indicates whether D-CS is (X) or is not (.) holding the phase in its green interval. This variable will show both indications while an active D-CS controlled phase is timing, depending on whether or not there are vehicles in the dilemma zone. It will show (.) when the phase terminates.

QueClear

Indicates whether or not D-CS has determined that the stopped queue has cleared. D-CS will not terminate a phase until the stopped queue is cleared. D-CS checks one of two different conditions to determine if the queue has cleared. These two conditions are: (1) gap out of a presence detector near the stop line, or (2) the end of minimum green, whichever occurs *later*. If presence detection is not provided near the stop line, the end of minimum green is used exclusively to make this determination.

Use Sum

Indicates if the phase is using an EGW SUM (“X”) or the EGW (“.”) for its own lane. Remember that EGWUsed is the sum of the lengths of all the vehicles currently in the dilemma zone for a given phase, or the sum of the lengths of all vehicles in any phase's dilemma zone if the phases must terminate together. This value is used to compare against the Threshold in order to determine whether or not the phase can terminate.

Look Ahead

Indicates the amount of time that the DC-S algorithm is looking ahead.

Error

This parameter outputs error codes that explain why the particular DCS lane may not be working

0 = No errors

1 = Missing data (arrival time, max length, max speed, trap distance, trap ID)

2 = DZ exit time larger than DZ arrival time

3 = Look ahead time invalid (trap length, max length, max speed, arrival time are not using valid values)

3 Recommended D-CS Settings

D-CS has relatively few input settings. However, some key settings are interrelated, and their values must be adjusted in combination to optimize D-CS operation. The key D-CS settings are:

- Dilemma zone boundaries (DZArrival and DZExit),
- Maximum green,
- Stage 1 percentage, and
- Minimum green.

Recommendations for each of these settings is discussed below.

Dilemma Zone Boundaries (DZArrival and DZExit)

Research studies have shown that the dilemma zone begins at 5.5 s of travel time from the stop line and ends at 2.5 s travel time from the stop line. The physical location of the dilemma zone can be easily identified when the vehicle travels at a constant speed. D-CS makes this assumption when it determines the location of each vehicle's dilemma zone. This determination is made soon after the vehicle crosses the detector trap. If fact, studies have shown that most drivers maintain a relatively constant speed on the intersection approach so the assumption is reasonable. However, drivers may occasionally alter their speed on the intersection approach after crossing the detector trap. To allow for this situation, it is recommended that 0.5 s be added to the dilemma zone arrival time and that 0.5 s be subtracted from the dilemma zone exit time. Therefore, the recommended value for DZArrival is 6.0 s, and the recommended value for DZExit is 2.0 s.

Maximum Green

The maximum green setting for D-CS should be somewhat longer than the typical maximum green setting used at an isolated intersection with conventional detection and control. D-CS requires this longer maximum green duration to find the safest time to terminate the phase and provide adequate truck priority. However, D-CS is highly efficient at finding safe termination times and rarely extends the green interval to is maximum limit. Research studies have shown that delay is lower with D-CS operation than with conventional detection and control.

The recommended maximum green setting for D-CS is equal to the sum of the Stage 1 and Stage 2 durations. Stage 1 should be as long as the typical maximum green setting, which may range from 35 s to 60 s, depending on the location. Stage 1 should always be longer than the longest queue clearance time to maximize the safety benefits of D-CS. The recommended Stage 2 duration is about 20 s. Hence, the maximum green setting should range from 55 s to 80 s, with larger values in this range preferred for the reasons mentioned in the previous paragraph.

Stage 1 Percentage

The Stage 1 percentage is ratio of Stage 1 duration divided by the length of the maximum green duration, expressed as a percentage. As noted previously, Stage 1 should range from 35 s to 60 s and the maximum green duration should range from 55 s to 80 s. Therefore, the Stage 1 percentage should range from 65 to 75 percent, but it should not be less than 60 percent.

Minimum Green

D-CS operation is very sensitive to the length of the minimum green for the phases it controls. There are two reasons for this sensitivity. First, D-CS does not control the intersection until after queue clearance, or the end of minimum green, whichever occurs *later*. D-CS uses the stop line detectors to determine if the queue has cleared. However, a slow-starting vehicle may create a gap in the queue large enough to gap out the detector even though the queue has not cleared. This situation can result in premature phase termination by D-CS.

Second, the D-CS algorithm assumes that the distance from the detector trap to the stop line is clear of vehicles at the start of the green interval. It has no knowledge of vehicle presence on the intersection approach at the start of this interval and cannot extend the green interval for them. Thus, the minimum green duration must be sufficiently long to allow any moving vehicle that is between the detector trap and the stop line at the start of the green interval to reach the inside edge of the dilemma zone before the minimum green expires. If this opportunity is not available, D-CS may terminate the phase prior to this vehicle being served.

To avoid these two situations, the minimum green duration should be at least 15 s for phases with approach speed limits of 55 mph and higher. The minimum green duration should be at least 17 s for phases with approach speed limits of 45 or 50 mph. Larger minimum green times may be used, although a minimum green time greater than or equal to the Stage 1 duration is not recommended.

If presence detection is not available in the vicinity of the stop line, then the minimum green must be long enough to allow the stopped queue to adequately clear. Otherwise, D-CS may end the phase before the stopped queue clears. If D-CS ends a phase before the queue clears, and no presence detection is available, it is likely that subsequent phases may also end before the queue clears. This pattern will persist until the queue is able to clear within the minimum green. This situation is undesirable and should be avoided if possible, either with a long minimum green or the addition of presence detection near the stop line.

If volume density operation is being used, the 15 s (or 17 s) recommended minimum green for D-CS operation must be supplied even if no actuations occur during the yellow and red intervals.

3.1 Summary

The table below shows the recommended values for the D-CS settings described in this section. The recommended values for the minimum green duration are the minimum recommended values for reliable D-CS operation.

Setting	**Recommended Value**
DZArrival	6.0 s
DZExit	2.0 s
Maximum green duration	55 s to 80 s (larger values will improve D-CS performance)
Stage 1 percentage	65 to 75 percent preferred, but not less than 60 percent
Minimum green duration	Minimum of 15 s for approach speed limits of 55 mph or higher Minimum of 17 s for approach speed limits of 45 mph or 50 mph Larger values may be needed if presence detection is not available near the stop line.

4 Index