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Development of the Capability-Enhanced PARAMICS Simulation Environment

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Development of the Capability-Enhanced PARAMICS Simulation Environment

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EXECUTIVE SUMMARY

This report summarizes research work conducted under TO4304 at the University of California, Irvine. Under this task order, the research team provided Caltrans with on-call direct support, technical guidance, and research related support. A series of Paramics plug-ins were developed and have been released to Caltrans. These plug-ins include actuated signal, multiple actuated signal timing plan, actuated signal coordination, detector data aggregator, ramp metering control, on-ramp queue override control, ALINEA ramp metering control, BOTTLENECK ramp metering control, SWARM Ramp metering control, and Freeway MOE. They complement the current Paramics simulation model and enhance its functionalities.

This report describes how we developed these plug-ins and the step-by-step procedure to use them. It can be used as user manuals.

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1. Actuated signal Control

1.1 Introduction

Generally, modes of traffic signal operation can be divided into three primary categories (USDOT, 1996): pre-timed, actuated and traffic responsive. PARAMICS can basically model the fixed-time signal control. Besides, PARAMICS also provides a plan/phase language (i.e. a kind of script language) to simulate some simple actuated signal control logic. However, in the field the widely used actuated signal controller uses the complex NEMA logic or type-170 logic. Our experiences found this script language is difficult to be used to model these types of complex control schemes and to replicate these schemes to multiple signalized intersections.

A plugin was developed in order to easily model actuated signal control within PARAMICS. This report discusses the logic of this plugin as well as its implementation.

1.2 Plugin implementation

1.2.1 Control logic

The layout of a typical actuated signal intersection is shown in Figure 1.1.

The control logic that is implemented in the plugin is for an eight-phase, dual-ring, concurrent controller actuated signal. The dual-ring, concurrent concept is illustrated briefly in Figure 1.2. Note that eight phases are shown, each of which accommodates one of the through or left turning movements. A "barrier" separates the north-south phases from the east-west phases. Any phase in the top group (Ring 1) may be displayed with any phase in the bottom group (Ring 2) on the same side of the barriers without introducing any traffic conflicts. For simplicity, the right turns are omitted and assumed to proceed with the through movements.

In the fully-actuated signal control, all phases at an intersection are actuated. Therefore the length of each phase, and consequently the cycle length, will vary with each cycle. Some phases may be skipped if there is no vehicle actuation. To simulate the real controller better, the order and sequence of phases can also be altered. The detailed description on how actuated signal works can be found in the textbook by McShane et al (1998).

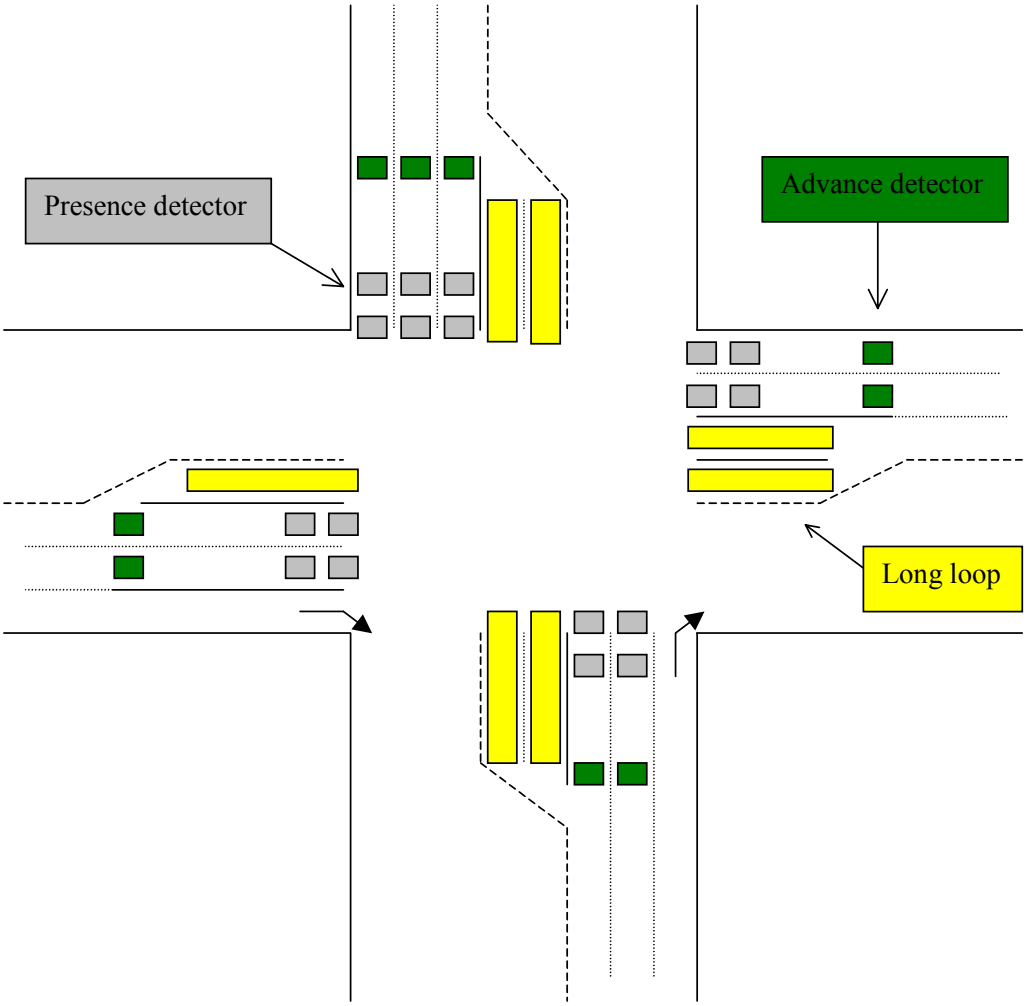


Figure 1.1 Typical Intersection Layout

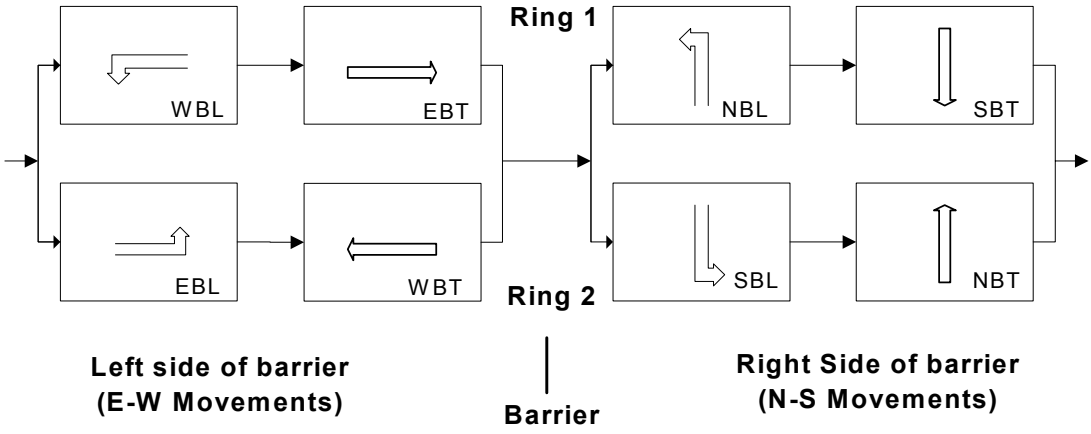


Figure 1.2 Dual-ring concurrent phasing scheme with assigned movements

1.2.2 Modeling vehicle detection

The vehicle detection is an important part of the actuated signal system. There are three groups of detectors in each approach for the typical intersection in the real world:

(1) Stopline detectors, located in the through lanes and very close to the stop line, for the presence detection of through vehicles. There may be 2-3 presence detectors for a lane that are typically about six feet by six feet in size;
(2) Advance loop detector, located at almost 150-300 feet from the stop bar, used to detect vehicles for the extension of the through movement phase; and
(3) Long loop detector for left turns, with the length of about 50-70 feet, for the presence detection of left turn vehicles. In some cases a set of individual detectors are used instead of a single long one.

For some intersections, there may be no advance detector at some approaches of an intersection. If presence detectors are only placed on the minor cross street, the signal has semi-actuated control.

To better simulate the functionality of detectors, ideally detectors should be modeled in PARAMICS according to the real-world configuration. However, in Build 3 of PARAMICS, detectors are not lane specific. A detector covers all lanes of a link and thus a PARAMICS detector represents a detector station. Therefore, we cannot model a separate long loop (for left turn use) in the actuated signal system. As a result, we use three small detectors instead of a long loop, as shown in Figure 1.3.

Three 2 m or 6.6 ft detectors are used to mimic one 50 ft long loop detector. These detectors model the stopline presence detectors as well as the left-turn detectors. The default length of detectors in PARAMICS is 2 meters, or 6.6 feet. The lengths of these detectors in PARAMICS do not match the common real-world length of six feet, but for the purposes of simulation this works fine.

As illustrated in Figure 1.4, we modeled 16 detectors for a typical intersection in PARAMICS and each detector covers all lanes of a link. For each approach, there are three detectors close to the stop line for through and left-turn vehicle presence detection, and one advance detector located at about 150-300 feet to the stop line for detecting vehicles for the extension of the through movement phase. For stopline detectors, all three of them employ the vehicle presence of left turn lanes; the two detectors close to the stop line are used for detecting the presence of through vehicles.

Due to improvements in the long loop detection in later versions of PARAMICS (later than Build V.3.0.7), we can use one long loop instead of three stopline loop detectors for vehicle presence. As a result, we only need to model 8 detectors for an intersection. That is to say, detectors 1, 5, 9 and 13 are long loops (with a typical length of 50 feet), and there is no need to code detectors 2, 3, 6, 7, 10, 11, 14, and 15. This is our recommended method to model detectors of an actuated signal intersection.

In version 4 of PARAMICS, detectors can be lane specific. This plugin does not support the use of this type of detector.

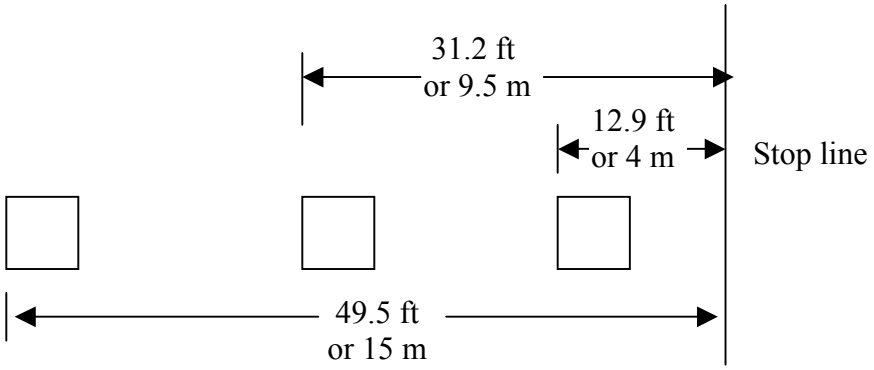


Figure 1.3 Modeling the left turn long loop detector

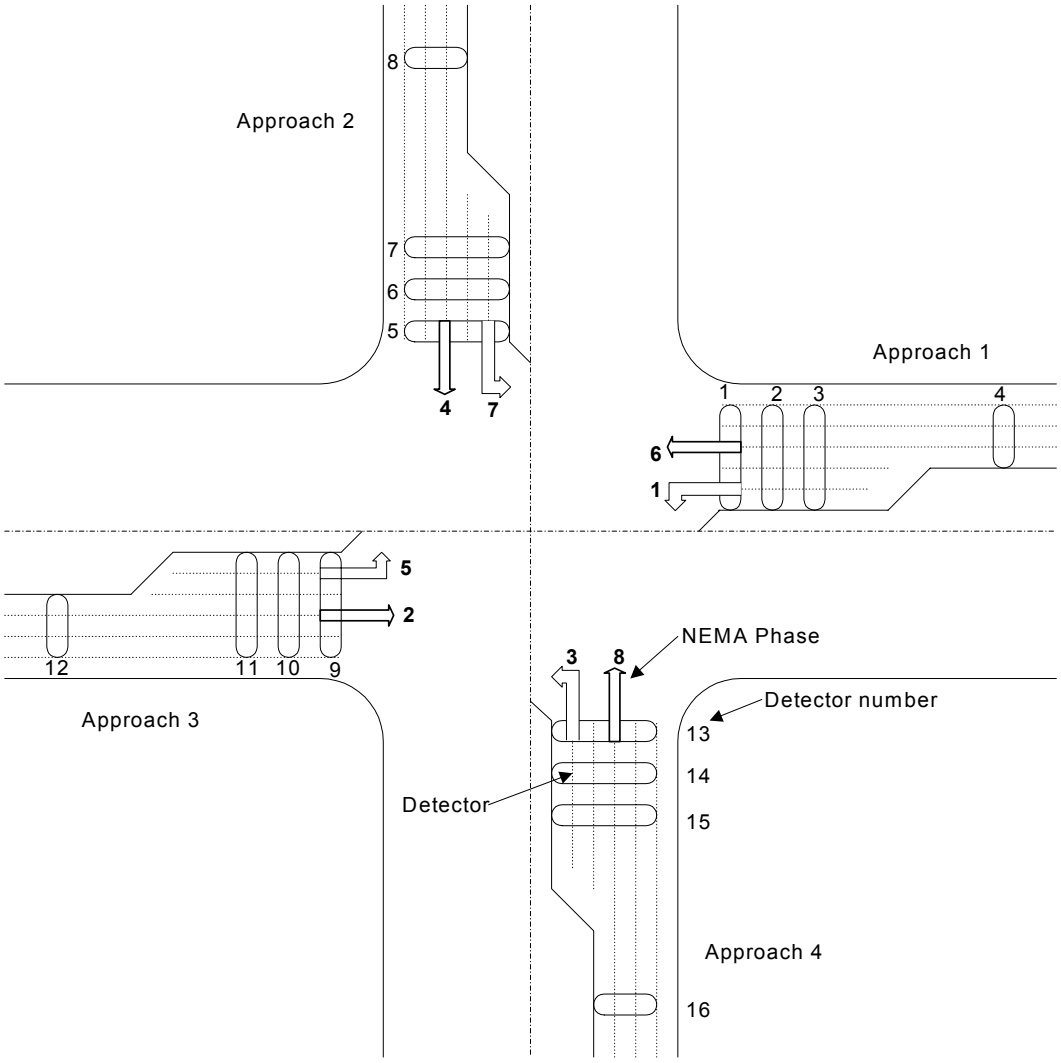


Figure 1.4 Typical Intersection Layout in PARAMICS with NEMA phases

1.2.3 Pseudo code

The pseudo code for the main control logic of this plugin is given as follows:

1. Initialize the actuated signal plugin, including signal data input, memory allocation, and initial signal phase set up.
2. At every time step of simulation, net_action is called:

```
For controller intersection = 1 : n {
  a. Inquiry the current signal information using signal_inquiry( ).
  b. If ( left green time == 0 ) {
                Amber and red time are counted.
                If ( amber and red time are reached )
                    Set the next signal phase parameters through signal_action( ).
        }
        else {
                vehicle presence detection (pp_presence_dection ( ) ).
                excute the current signal plan (pp_excute_plan ( ) )  {
                    If ( left green time < extension &&
                         vehicle presence for extension &&
                          expired green < ( maximal green – extension ) ) {
                              green  time increased by (extension – left green).
                        }
                    If ( left  green time <= time step )
                              Find the next phase by vehicle presence
                }
        }
}
```

1.3. Step-by-step user manual

1.3.1 Data preparation

The data input to this plugin is the signal timing plan, the geometry and detector information of actuated signal intersections.

If the purpose of simulation is to model a real-world network, the following information is required in order to make actuated signals:

(1) Signal Timing Chart obtained from the proper government agency
(2) Geometric layout of the intersection; the best source of this information is usually from as-built plans.

If the purpose of simulation is to evaluate an intersection design (or, test signal timing plans), you can obtain the signal timing from traffic signal software, such as SYNCHRO, based on historical traffic patterns.

1.3.2 Adding detectors and checking network coding

Based on the previous discussion, we can either code 16 detectors or 8 detectors to a four-legged actuated signal intersection. The exact set-back distance of the advance detector can found in the "Geometric layout of the intersection".

The following geometric information needs to be checked:

(1) Number of lanes for each approach;

(2) Lane use information at intersections (for example, at an approach of an intersection, which lanes are assigned to the left turn, through, or right turn movements). If the default lane configuration is not the same as that shown in the "Geometric layout of the intersection", the corresponding intersection needs to be re-coded via the PARMICS Modeller GUI (Node->Modify junction) or by editing the "junctions" file manually.

1.3.3 Preparation of worksheet

Running MODELLER, zoom in to the intersection. Fill out a worksheet that includes geometry and signal timing information of the intersection. The worksheet has been attached in APPENDIX 1 of this document.

The following is a list of necessary information in the worksheet:

(1) Write down the name of the intersection, i.e. Alton & ICD, and the signal ID that is shown in the first page of signal timing chart.

(2) Write down the two street names, the direction, and the PARAMICS designation of the junction node and the four adjacent nodes on four approaches.

(3) Find NEMA movement number 1, generally a left turn, from the Signal Timing Chart. Write down the turn arrow and the movement number 1. As a result, all NEMA movements / phases can be determined based on the definition of the standard NEMA phases / movements shown in figure 1. Write down all NEMA movements on the worksheet.

(4) Write down the approach number on the worksheet. The approach that the 1st NEMA movement locates is defined as approach 1 here. The counter-clockwise approaches around the junction are defined as approach 2, 3, 4.;

(5) Fill out the 3-5 rows (Initial green, Extension, Max green) of the table on the bottom of the worksheet. The ini_green corresponds to the "Initial"(green time) and the max_green corresponds to the "Max Green" in the Signal Timing Chart.

(6) Find out the recall movement from "Signal Timing Chart". Enter the two recall movement numbers into the first two columns of the "recall" row. If there is only one recall phase, put the second one as 0;

(7) Find out how many lanes correspond to each NEMA movement from "layout of the intersection" or PARAMICS environment. Fill them in the row of "lanes" in the worksheet. The first value in the row corresponds to the number of lanes for NEMA movement 1 and the second value corresponds to NEMA movement 2, etc. In many situations there are lanes that are shared by different movements. For example, one lane may allow both left turning and through vehicles to pass. In this case, the lane will count both as one through lane and as one half (0.5) of a left-turning lane.

(8) From the layout, find out how many right turn lanes for each approach (1 -> 4). Please refer to the definition at step 4 for the definition of approaches 1 to 4. Write down these numbers in the row of "Right-turn lanes". As in the case of lanes that allow both left and through movements, lanes that allow through and right-turn movements will count as one through lane and one half of a right-turning lane.

(9) The row of "detector 1' to "detector 4" should be filled with the name of detectors (the sequence is from stopline detectors to the advance detector, seen in figure 1) on "approach 1" to "approach 4". Please refer to the definition at step 4 for the definition of approaches 1 to 4. In some cases, one or more of the detectors for an approach does not need to be modeled. Each missing detector needs to be specified as "N/A" in the worksheet. In Paramics v3.0 build 6, it was necessary to place three separate detectors at the stopline to ensure proper detection. However, build 7 of Paramics 3.0 and all later versions only need one long detector. To allow reverse compatibility, it still might be desirable to place three separate detectors.

1.3.4 Preparation of "signal_control" file

The plugin requires a file titled "signal_control" to be in the PARAMICS network directory. An example of the "signal_control" file is shown in Figure 1.5.

The first line of this file specifies the number of actuated signals modeled in the network. The remainder of the file contains the signal timing information. The information in this file has a very similar format to that of the worksheet. There are two signals modeled in Figure 1.5. The first one uses 16 detectors and the second used 8 detectors.

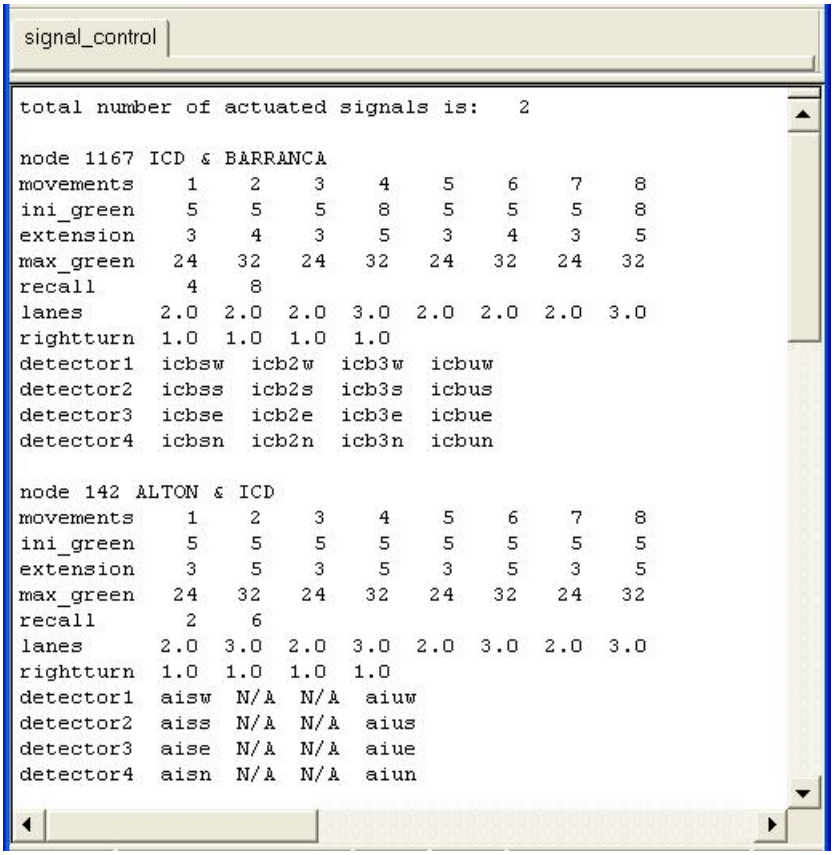


Figure 1.5 An example of signal_control file

1.3.5 Preparation of "priorities" information

The "priorities" file defines what movement can be allowed under each phase of an intersection. For pre-timed signal control, the priorities information can be edited through the PARAMICS GUI. However, for the actuated signal, the file "priorities" must be edited directly with a text editor.

We need to generate the "priorities" information of an actuated signalized intersection based on the worksheet we made on step 2, in which the node names of adjacent nodes of an intersection have been written down. Figure 1.6 is an example of the node designations for a four-legged intersection. "approach 1" is considered to be in the direction starting at node 7511 and heading towards the junction node 528z.

The "priorities" for a four-legged full-actuated intersection will have eight phases. As illustrated in Figure 1.7, "Phase 1" will correspond to the situation where the left-turning NEMA movements 1 and 5 will be given the green. "Phase 2" will account for the situation where movements 5 and 2 will be given the green, and "phase 3" will be for movements 1 and 6. "Phase 4" will be for the through movements 2 and 6. The last four phases will follow the pattern of the first four phases, starting with the left-turn movements 3 and 7.

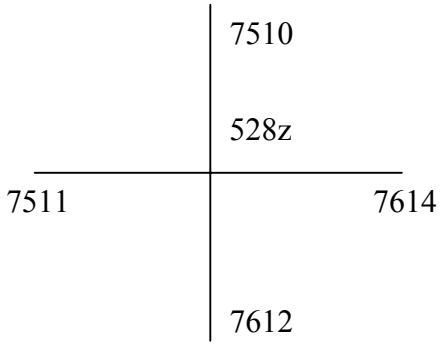


Figure 1.6 Intersection Layout

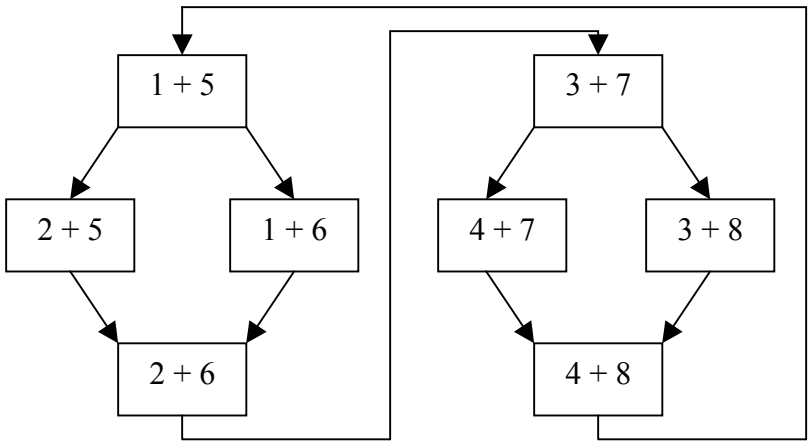


Figure 1.7 Eight phases of the four-legged full-actuated signal intersection

For the intersection in the previous figure, the definition of phases and actions (movements) in "priorities" file would be:

```
actions 528z
phase offset 0.00 sec
phase 1
        0.00
        max 100.00
red phase 0.00
fill
all barred except
from 7510 to 7511 minor
from 7511 to 7612 minor
from 7511 to 7510 major
from 7612 to 7614 minor
from 7614 to 7612 major
from 7614 to 7510 minor
```

phase 2
    0.00
    max 100.00
red phase 0.00
fill
all barred except
from 7510 to 7511 minor
from 7511 to 7612 minor
from 7511 to 7614 major
from 7511 to 7510 major
from 7612 to 7614 minor
from 7614 to 7510 minor
phase 3

…

phase 8
    0.00
    max 100.00
red phase 0.00
fill
all barred except
from 7510 to 7511 minor
from 7510 to 7612 major
from 7511 to 7612 minor
from 7612 to 7614 minor
from 7612 to 7510 major
from 7614 to 7510 minor

In this example, the movements of each phase are "major" while all right turns are "minor". We set the default signal time of each phase as 0 sec (This is the reason that we cannot edit these "actions" information through GUI). The plugin will assign a certain length of time to each phase based on the presence of vehicles.

Then, update the above priorities information of the corresponding signalized node in the "priorities" file of the network.

Please note that the network with modified "priorities" file must use together with this actuated signal plugin. Without this plugin, all movements of those actuated signal intersections are in red light.

1.3.6 Loading plugin

This plugin has two files:

actuated_signal.dll: Modeller Plugin

actuated_signal-p.dll: Processor Plugin

After the completion of the "signal_control" file and the update the "priorities" file, you can load the simulation network together with this plugin.

PARAMICS introduces a network specified method to load plugins. Each network has a "programming" file, which contains the plugins used together with the network. If you put this plugin in the PARAMICS root directory (where you can find other Quadstone's plugins, including HOV, Loop aggregator, Monitor, etc.), you do not need to specify the path of this plugin in the "programming" file:

actuated_signal.dll

If this plugin is stored to a directory other than the root directory of PARAMICS, the path of the loaded plugin needs to be specified:

\Program Files\ParamicsV4\uci_plugins\actuated_signal.dll

Note PARAMICS thinks this plugin is in Drive C only. If you put this plugin to Driver D or others, PARAMICS will not find the plugin. If you prefer to put this plugin to Driver D or others, you have to use the way of version 3 of PARAMICS to load plugins.

1.3.7 Error checking

After the network and the plugin are loaded in Modeller, you can start simulation. Via GUI, you will see that this plugin emulates the actuated signal control at specified intersections. This plugin can work if "signal_control" and "priorities" are prepared correctly. If there is any mistake in the "signal_control" file, the plugin will be disabled. The report window of PARAMICS will show whether this plugin works. This plugin generates a file named "Log-signal.txt" under the network directory, which can be used to check if the "signal_control" file has been understood by this plugin correctly.

The detector information in the "signal_control" file is connected with the "priorities" information of the signal intersection. The mismatch of them may cause the signal work abnormally. Two methods can be used to judge if the actuated signal control has the correct logic:

(1) Based on the observation from GUI (Node->Modify junction->Signal display), or
(2) Making a long time simulation run and then check if there are any serious congestion happened at actuated signal intersections. If an actuated signal control is not working correctly, all input files need to be double checked for any mistakes.

The correct use of this plugin depends on your knowledge of signal control. If necessary, please have a look at related chapters in the textbooks.

1.3.8 Exercises

In APPENDIX (Section 1.7), 1.7.2 and 1.7.3 show the "Signal Timing Chart" and "Geometric layout of the intersection ICD & BARRANCA". Based on Section 1.2.2, we filled in the worksheet, shown in 1.7.4. Based on this worksheet, the "signal_control" information is shown in Section 1.3.4. Its "priorities" information is shown in 1.7.5.

This plugin can be used to model more complex actuated signal control through proper configurations of the "priorities" and "signal_control" information. Users can learn more from one of our example Irvine networks, which includes 37 actuated signals.

1.4. Working with different phasing sequences

In dual-ring operation, full-actuated signal controllers are capable of a number of phase sequences between barriers. For each of the two major phase groups, there are three basic phase sequences:

1. Left-turn first
2. Lead-leg left-turns, and
3. Through movement first

The developed full-actuated signal plugin can work with all three sequences. We have described how to work with the "left-turn first" case in the previous section. This section will discuss how to make the plugin to work under the second and third phase sequences. Please refer to the example networks for further understanding this section.

1.4.1 Lead-leg left-turns

The layout of a typical intersection is as shown in Figure 1.8.

In the signal_control file, the two phases on the lead leg need to be put to the columns of movement 1 and movement 5. If we want to make link 14:10 as the lead leg, the phase sequence will be 2&5-> 1&5 -> 2&6 ->1&6[1], the corresponding signal_control file needs to be configure as follows.

Movements	2	1	3	4	5	6	7	8
ini_green	10	5	5	8	5	10	5	8
extension	4	3	3	5	3	4	3	5
max_green	32	24	24	32	24	32	24	32
recall	4	8						
lanes	2	2	2	3	2	2	2	3
rightturn	1	1	1	1				

[1] The real-world controller may not have the phase combination of 1 & 5. Our plugin cannot avoid having it. But its existence does not have any negative (but positive) influence on the operation of the control logic.

detector1	icbsw	N/A	N/A	icbuw
detector2	icbss	N/A	N/A	icbus
detector3	icbse	N/A	N/A	icbue
detector4	icbsn	N/A	N/A	icbun

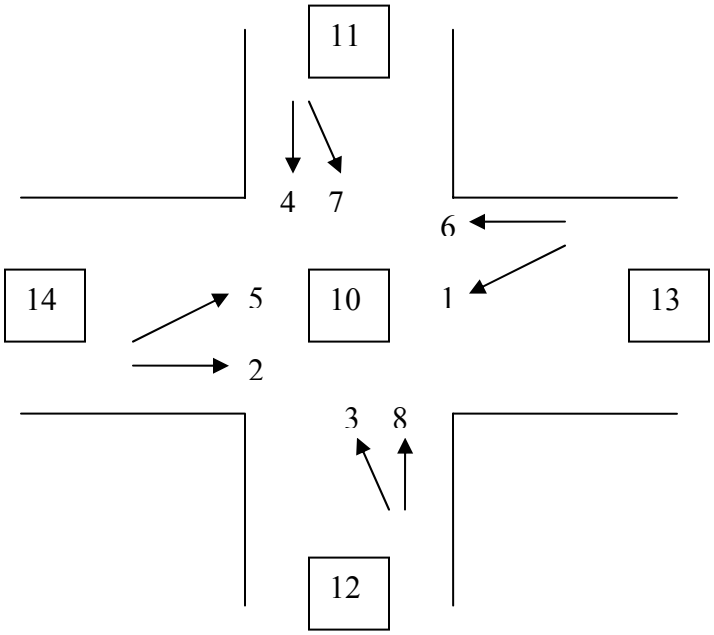


Figure 1.8 Phase layout of a signalized intersection

Based on phase sequences, 2&5 -> 1&5 -> 2&6 ->1&6, the priorities file needs to put 2&5 to phase 1, 1&5 to phase 2, 2&6 to phase 3 and 1& 6 to phase 4.

```
actions 10
phase offset 0.00 sec
phase 1
        0.00
        max 100.00
red phase 0.00
fill
all barred except
from 14 to 11 major
from 14 to 12 major
from 14 to 13 major
from 11 to 14 minor
from 13 to 11 minor
from 12 to 13 minor
phase 2
        0.00
        max 100.00
red phase 0.00
```

fill
all barred except
from 13 to 12 major
from 14 to 11 major
from 11 to 14 minor
from 13 to 11 minor
from 14 to 12 minor
from 12 to 13 minor
phase 3
    0.00
    max 100.00
red phase 0.00
fill
all barred except
from 13 to 14 major
from 13 to 11 major
from 14 to 13 major
from 14 to 12 major
from 11 to 14 minor
from 12 to 13 minor
phase 4
    0.00
    max 100.00
red phase 0.00
fill
all barred except
from 13 to 14 major
from 13 to 12 major
from 13 to 11 major
from 11 to 14 minor
from 14 to 12 minor
from 12 to 13 minor
phase 5
    0.00
    max 100.00
red phase 4.00
fill
all barred except
…

If we want link 13:10 as the lead leg, “signal_control” will be:

movements	1	2	3	4	6	5	7	8
ini_green	5	10	5	8	10	5	5	8
extension	3	4	3	5	4	3	3	5
max_green	24	32	24	32	32	24	24	32
recall	4	8						
lanes	2	2	2	3	2	2	2	3

rightturn	1	1	1	1
detector1	icbsw	N/A	N/A	icbuw
detector2	icbss	N/A	N/A	icbus
detector3	icbse	N/A	N/A	icbue
detector4	icbsn	N/A	N/A	icbun

The corresponding proiorities file will not be listed here. Users can easily figure out.

1.4.2 Through movement first

Based on the description of the last section, we can deduce that the phase 2 and 6 should be put to the location of the columns of movement 1 and movement 5.

As shown in the below figure, if we want phases 2 and 6 go first, the following phases will be 2&6 -> 1&6 -> 2&5 -> 1&5. The signal_control file should be:

movements	2	1	3	4	6	5	7	8
ini_green	10	5	5	8	10	5	5	8
extension	4	3	3	5	4	3	3	5
max_green	32	24	24	32	32	24	24	32
recall	4	8						
lanes	2	2	2	3	2	2	2	3
rightturn	1	1	1	1				
detector1	icbsw	N/A	N/A	icbuw				
detector2	icbss	N/A	N/A	icbus				
detector3	icbse	N/A	N/A	icbue				
detector4	icbsn	N/A	N/A	icbun				

For the “priorities” file, we can just put 2&6, 1&6, 2&5, and 1&5 to the phase 1, 2, 3 and 4, as shown below.

```
actions 10
phase offset 0.00 sec
phase 1
        0.00
        max 100.00
red phase 0.00
fill
all barred except
from 13 to 11 major
from 13 to 14 major
from 14 to 12 major
from 14 to 13 major
from 11 to 14 minor
from 12 to 13 minor
phase 2
```

0.00
max 100.00
red phase 0.00
fill
all barred except
from 13 to 11 major
from 13 to 14 major
from 13 to 12 major
from 11 to 14 minor
from 14 to 12 minor
from 12 to 13 minor
phase 3
0.00
max 100.00
red phase 0.00
fill
all barred except
from 14 to 11 major
from 14 to 12 major
from 14 to 13 major
from 11 to 14 minor
from 13 to 11 minor
from 12 to 13 minor
phase 4
0.00
max 100.00
red phase 0.00
fill
all barred except
from 13 to 12 major
from 14 to 11 major
from 11 to 14 minor
from 13 to 11 minor
from 14 to 12 minor
from 12 to 13 minor
phase 5
0.00
max 100.00
red phase 4.00
fill
all barred except
…

1.4.3 Split phases

Except the above-mentioned cases, users may need to make signals work under split phases. For example, there are only two possible phase combinations, 1&6 and 2&5, in the first phase group. Under this situation, the signal timing chart from the local transportation agency may provide phase information, which may not make this plugin work as expected.

1.4.3.1 2&5 first and 1&6 second

The "signal_control" file can be configured as:

movements	2	1	3	4	9	9	7	8
ini_green	10	5	5	8	0	0	5	8
extension	4	3	3	5	0	0	3	5
max_green	32	24	24	32	0	0	24	32
recall	4	8						
lanes	5	5	2	3	0	0	2	3
rightturn	0	1	0	1				
detector1	icbsw	N/A	N/A	icbuw				
detector2	icbss	N/A	N/A	icbus				
detector3	icbse	N/A	N/A	icbue				
detector4	icbsn	N/A	N/A	icbun				

There is no phase 5 and 6. Only phases 1 and 2 exist. Note that movement (i.e. phase) 1 includes all lanes of link 13:10 and phase 2 includes all lanes of link 14:10 no matter the lane is reserved for left turns or through movements. We can also configure the "signal_control" file in another way, i.e. without phases 1 and 2 but with phases 5 and 6, as shown below. The previous phase 1 goes to phase 6 and the previous phase 2 goes to phase 5.

movements	9	9	3	4	5	6	7	8
ini_green	0	0	5	8	10	5	5	8
extension	0	0	3	5	4	3	3	5
max_green	0	0	24	32	32	24	24	32
recall	4	8						
lanes	0	0	2	3	5	5	2	3
rightturn	0	1	0	1				
detector1	icbsw	N/A	N/A	icbuw				
detector2	icbss	N/A	N/A	icbus				
detector3	icbse	N/A	N/A	icbue				
detector4	icbsn	N/A	N/A	icbun				

For the "priorities" file, phase 1, 2 and 3 have the same allowed movements.

```
actions 10
phase offset 0.00 sec
phase 1
        0.00
```

max 100.00
red phase 0.00
fill
all barred except
from 14 to 11 major
from 14 to 12 major
from 14 to 13 major
from 11 to 14 minor
from 13 to 11 minor
from 12 to 13 minor
phase 2
0.00
max 100.00
red phase 0.00
fill
all barred except
from 14 to 11 major
from 14 to 12 major
from 14 to 13 major
from 11 to 14 minor
from 13 to 11 minor
from 12 to 13 minor
phase 3
0.00
max 100.00
red phase 0.00
fill
all barred except
from 14 to 11 major
from 14 to 12 major
from 14 to 13 major
from 11 to 14 minor
from 13 to 11 minor
from 12 to 13 minor
phase 4
0.00
max 100.00
red phase 0.00
fill
all barred except
from 13 to 14 major
from 13 to 12 major
from 13 to 11 major
from 11 to 14 minor
from 14 to 12 minor
from 12 to 13 minor

phase 5
0.00
max 100.00
red phase 0.00
fill
all barred except
…

1.4.3.2 1&6 first and 2&5 second

The "signal_control" file needs to be one of the following two:

movements	1	2	3	4	9	9	7	8
ini_green	5	10	5	8	0	0	5	8
extension	3	4	3	5	0	0	3	5
max_green	24	32	24	32	0	0	24	32
recall	4	8						
lanes	5	5	2	3	0	0	2	3
rightturn	0	1	0	1				
detector1	icbsw	N/A	N/A	icbuw				
detector2	icbss	N/A	N/A	icbus				
detector3	icbse	N/A	N/A	icbue				
detector4	icbsn	N/A	N/A	icbun				

movements	9	9	3	4	6	5	7	8
ini_green	0	0	5	8	5	10	5	8
extension	0	0	3	5	3	4	3	5
max_green	0	0	24	32	24	32	24	32
recall	4	8						
lanes	0	0	2	3	4	5	2	3
rightturn	0	1	0	1				
detector1	icbsw	N/A	N/A	icbuw				
detector2	icbss	N/A	N/A	icbus				
detector3	icbse	N/A	N/A	icbue				
detector4	icbsn	N/A	N/A	icbun				

The corresponding "priorities" file is:

actions 10
phase offset 0.00 sec
phase 1
0.00
max 100.00
red phase 0.00
fill
all barred except
from 13 to 14 major

from 13 to 12 major
from 13 to 11 major
from 11 to 14 minor
from 14 to 12 minor
from 12 to 13 minor
phase 2
    0.00
    max 100.00
red phase 0.00
fill
all barred except
from 13 to 14 major
from 13 to 12 major
from 13 to 11 major
from 11 to 14 minor
from 14 to 12 minor
from 12 to 13 minor
phase 3
    0.00
    max 100.00
red phase 0.00
fill
all barred except
from 13 to 14 major
from 13 to 12 major
from 13 to 11 major
from 11 to 14 minor
from 14 to 12 minor
from 12 to 13 minor
phase 4
    0.00
    max 100.00
red phase 0.00
fill
all barred except
from 14 to 11 major
from 14 to 12 major
from 14 to 13 major
from 11 to 14 minor
from 13 to 11 minor
from 12 to 13 minor
phase 5
    0.00
    max 100.00
red phase 0.00
fill

all barred except
…

1.5 PROGRAMMER capabilities

1.5.1 Interface functions

Interface functions have been provided by this plugin for external modules to acquire and change the default timing plan. This plugin provided a couple of interface functions for external plugin modules to acquire the current signal timing plan and set a new timing plan to a specific signal. An advanced signal control algorithm plugin can be further developed based on them. The prototypes of these interface functions are shown below.

Signal* uci_signal_get_parameters(char *nodeName);
Function: Querying the current signal timing plan of a specific actuated signal
Return Value: The current timing plan of an actuated signal.
Parameters: **nodeName** is the name of the signal node.
Signal is the structure of actuated signal data, whose definition is:

```
type Signal
{
        // intersection name and location
        char *node;
        char *controllerLocation;

        // signal parameters
        int movements[8];
        float maximumGreen[8];
        float minimumGreen[8];
        float extension[8];
        float storedRed[8];
        float phaseGreenTime[8];
        float movementGreenTime[8];

        // current phase information
        int currentPhase;
        int expiredTime;
        float redTimeLeft;
        Bool cycleEndFlag;
}
```

Void uci_signal_set_parameters(Signal *sig);
Function: Setting a new timing plan to a specific signal.
Return Value: None

Parameters: **sig** stores the new timing plan.

1.5.2 How to use interface functions in other plugins

These two interface functions can be called in other plugins. The following setting is required:

(1) In the workspace of your plugin that wants to use these interface functions, specify the library file "actuated_signal.lib" of the actuated signal plugin as an input object/library module. The path of "actuated_signal.lib" should be specified as well.

(2) Specify the prototype of the interface function at the beginning of your plugin as follows:

```
_declspec(dllimport) void uci_signal_set_parameters(Signal *sig);
_declspec(dllimport) Signal* uci_signal_get_parameters(char *nodeName);
```

1.6 Technical Supports

1.6.1 Limitations of this plugin

1) During our development on this full-actuated signal control plugin, we found that PARAMICS did not provide a plugin function for users to control the amber time (yellow light). Although yellow time can be set in the configuration file, it is a universal parameter for all the intersections and all the time. It is not convenient in the actuated signal case since some phases may be skipped (the amber time has to be skipped at the same time). In order to simulate the real world better, our developed plugins have to have a handle on the control of the amber time associated with each phase.

2) In PARAMICS, phase and movement are different. For the current actuated signal plugin implementation, each phase usually includes two major movements, and some minor movements. For instance, phase 1 may include dual left turn movements, and some right turn minor movements. PARAMICS runs through phase 1 to phase 8, some phases may be skipped depending on the vehicle presence. However, each movement has its own initial green and extension in the signal-timing sheet. Only one set of parameters could be used in each phase. Although a reasonable set of parameters is calculated and used during the simulation, and doing this does not hurt the simulation performance, the actual signal control cannot be fully simulated in this plugin. Ideally, we want each phase to include only one major movement, and two phases can be executed at the same time. Version 4 of PARAMICS provides users with this capability but we do not have time to implement this at the current time.

3) Only one timing plan for each intersection is supported by the current plugin. In order to support multiple signal plans, please use another plugin "multiple actuated signal plan" together with this plugin.

4) In version 3 of PARAMICS, vehicles may stop at stop lines because of routing problem (such as a through vehicle stopping on a left turn lane). Version 4 has bot this problem because it introduces the re-routing feature.

1.6.2 FAQ:

1. Grammar of input files

Unlike the parser system of PARAMICS, which allow flexible grammars and comments (i.e. ##), the format of the input file of this plugin is rigid and thus any problem in the file may cause the plugin not work well. Our recommendation for users is that the input file of the example network of this plugin is a good starting point to make your own input file in order to avoid editing problems.

2. Can a phase in priorities file have no movement information?
It is not good for a phase to have no movement information. Every phase corresponds to a combination of NEMA phases, if that phase is regarded to have vehicles and then a green signal will be given to that phase, which has no movement allowed. Then, the plugin may be locked to that phase. The solution is that you can repeat the movement information of a related phase. Please refer to Section 1.4.3.

1.6.3 Tools

In order to speed up the process of coding actuated signals, we also make two computer programs for the making of "signal_control" file and the "priorities" information. You can request these tools from California ATMS testbed.

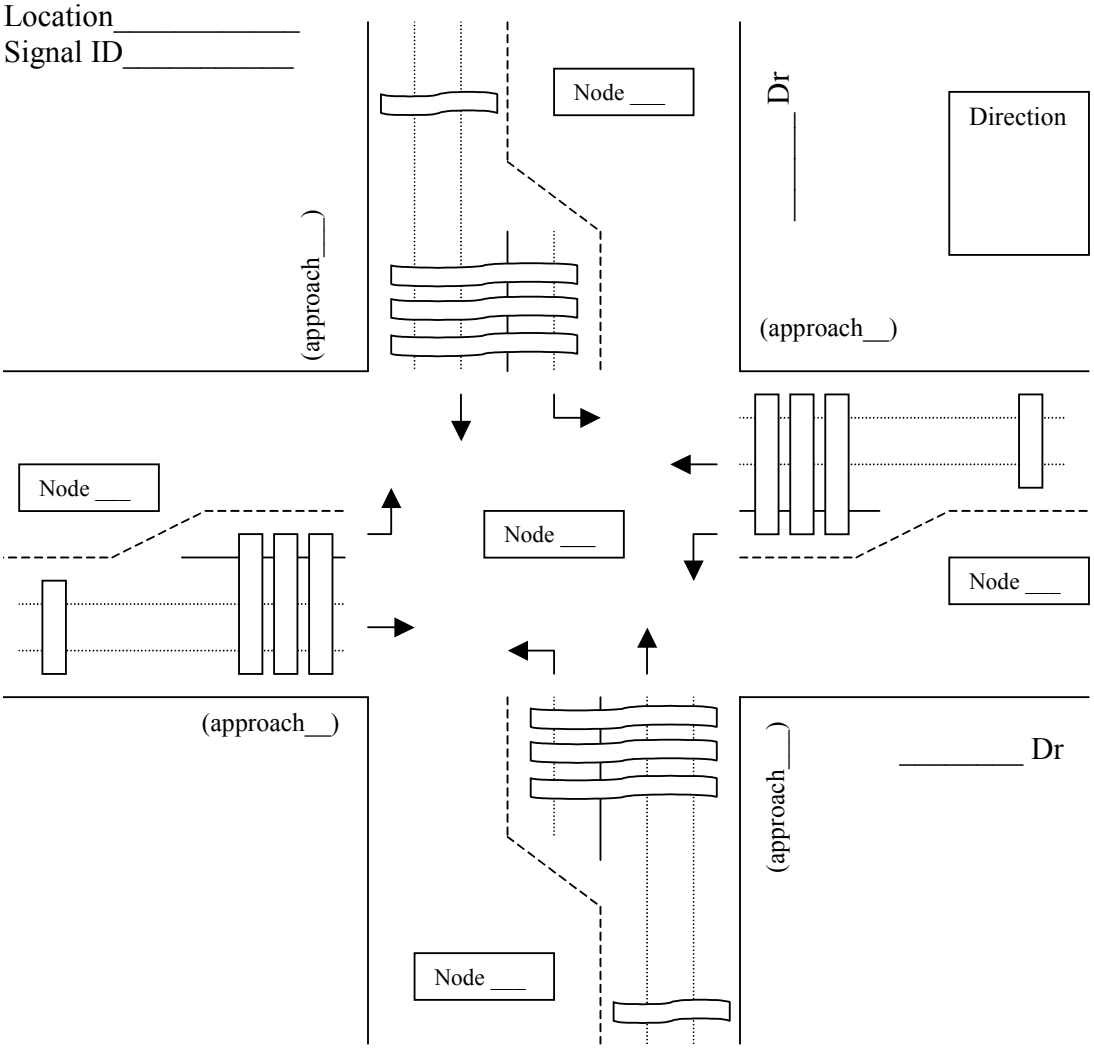
1.6.4 References

1. W.R. McShane, R.P. Roess and E.E. Prassas (1998). Traffic Engineering (Second Edition). Prentice-Hall.
2. Liu, X., Chu, L., and Recker, W. (2001) "*Paramics API Design Document for Actuated Signal, Signal Coordination and Ramp Control*", California PATH Working Paper, UCB-ITS-PWP-2001-11, University of California at Berkeley.
3. USDOT, Federal Highway Administration (1996) Traffic Control Systems Handbook.

1.7 APPENDIX

1.7.1 Worksheet

Location_____
Signal ID_____



Node								
Movement	1	2	3	4	5	6	7	8
Initial Green								
Extension								
Max Green								
Recall Phase								
Lanes								
Right-Turn lanes								
Detector 1								
Detector 2								
Detector 3								
Detector 4								

Signal Timing Chart For Controller Type: ***820 A*** *City Of Irvine - Traffic Operations* Page 1 of 4

LOCATION: IRVINE CENTER DR @ BARRANCA

Signal ID: 193 *Interconnect:*

ICU # 234 *Address #* 2 *MUX #* 59

Designed By: C. N. *Command Key:* VMS

Approved By: B. G. *Master Location:* ITRAC

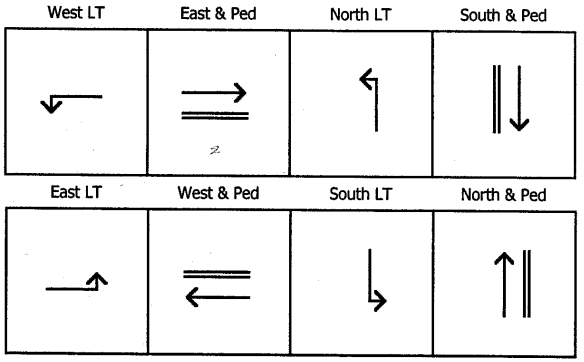
Installed By: STAR *Prom. Revision*

Timing Change: 4/30/92 **Supersedes:** 12/26/90 **Signal Turn On:** 12/5/90 **Turn On By:** A.T.

Phase	Vehicular Movement	Flash
1.	W/B Left Turn - Barranca	R
2.	E/B Thru - Barranca	R
3.	N/B Left Turn - Irvine Center Drive	R
4.	S/B Thru - Irvine Center Drive	R
5.	E/B Left Turn - Barranca	R
6.	W/B Thru - Barranca	R
7.	S/B Left Turn - Irvine Center Drive	R
8.	N/B Thru - Irvine Center Drive	R

Overlap	Vehicular Movement	Flash
1.		
2.		
3.		
4.		

SEQUENCES:



Notes and Comments:

1. Set time and cab flash monitor @ 120v, press MISC key. See BIKE TIMING on page 2, (Free Parameters)
2.
3.
4.
5.

Detection Amplifier Setup:

NB-ADV: 1.5 sec EXT. + _____ DEL. NB-THRU: _____ DEL. NB-LT: _____ DEL. NB-RT: _____ DEL.

SB-ADV: 1.5 sec EXT. + _____ DEL. SB-THRU: _____ DEL. SB-LT: _____ DEL. SB-RT: _____ DEL.

EB-ADV: 1.5 sec EXT. + _____ DEL. EB-THRU: _____ DEL. EB-LT: _____ DEL. EB-RT: _____ DEL.

WB-ADV: 1.5 sec EXT. + _____ DEL. WB-THRU: _____ DEL. WB-LT: _____ DEL. WB-RT: _____ DEL.

LOCATION: IRVINE CENTER DR @ BARRANCA

SIGNAL ID: 193 TIMING CHANGE : 1/19/00 SUPERSEDES: 5/24/99

SET UP

INTERSECTION PHASING	
Allowable Phases:	1 2 3 4 5 6 7 8
Flashing Walks:	
Exclusive Phases:	
Ped Phases:	- 2 - 4 - 6 - 8
Density Phases:	

START UP	
Start In:	RED
Start Up Time:	4.0
Start Up Phases:	- 2 - 4 - 6 - 8
Start Timing In:	Yellow
Start Veh Calls:	1 2 3 4 5 6 7 8
Start Ped Calls:	- 2 - 4 - 6 - 8

PHASE FEATURES	
Lag Phases:	
Non Actuated 1:	
Non Actuated 2:	
Cond Serv Phases:	
Red Rest Phases	
Flash Phases:	
Dual Entry Phases:	
Simultaneous Gap:	No
Min Yellow Time:	3.0
Red Revert Time:	5.0

LCD SETUP / SHAPE	
Xsect Shape:	QUAD
South Thru:	4
South Turn:	7
West Thru	6
West Turn:	1
North Thru	8
North Turn:	3
East Thru:	2
East Turn:	5
South Ped:	4
West Ped:	6
North Ped:	8
East Ped:	2

OVERLAPS	
1. Parent Phases:	
Timing Method:	
Overlap Type:	
Green Extension:	
Yellow Change:	
Red Clearance:	
2. Parent Phases:	
Timing Method:	
Overlap Type:	
Green Extension:	
Yellow Change:	
Red Clearance:	

OVERLAPS	
3. Parent Phases:	
Timing Method:	
Overlap Type:	
Green Extension:	
Yellow Change:	
Red Clearance:	
4. Parent Phases:	
Timing Method:	
Overlap Type:	
Green Extension:	
Yellow Change:	
Red Clearance:	

FREE PARAMS

PHASE TIMINGS								
PHASE	1	2	3	4	5	6	7	8
Ped Walk:		5		5		5		5
Ped Protect:		25		22		24		23
Add/Actuation:								
Initial:	5	5	5	8	5	5	5	8
Max Initial:								
Extension:	3	4	3	5	3	4	3	5
Min Extension:								
Before Reduce:								
Time to Reduce:								
Max Green:	24	32	24	32	24	32	24	32
Max II Green:	24	32	24	32	24	32	24	32
Yellow Change:	3	4	3	4	3	4	3	4
Red Clearance:	1	1	1	1	1	1	1	1
Bike Timing:		16		16		16		16

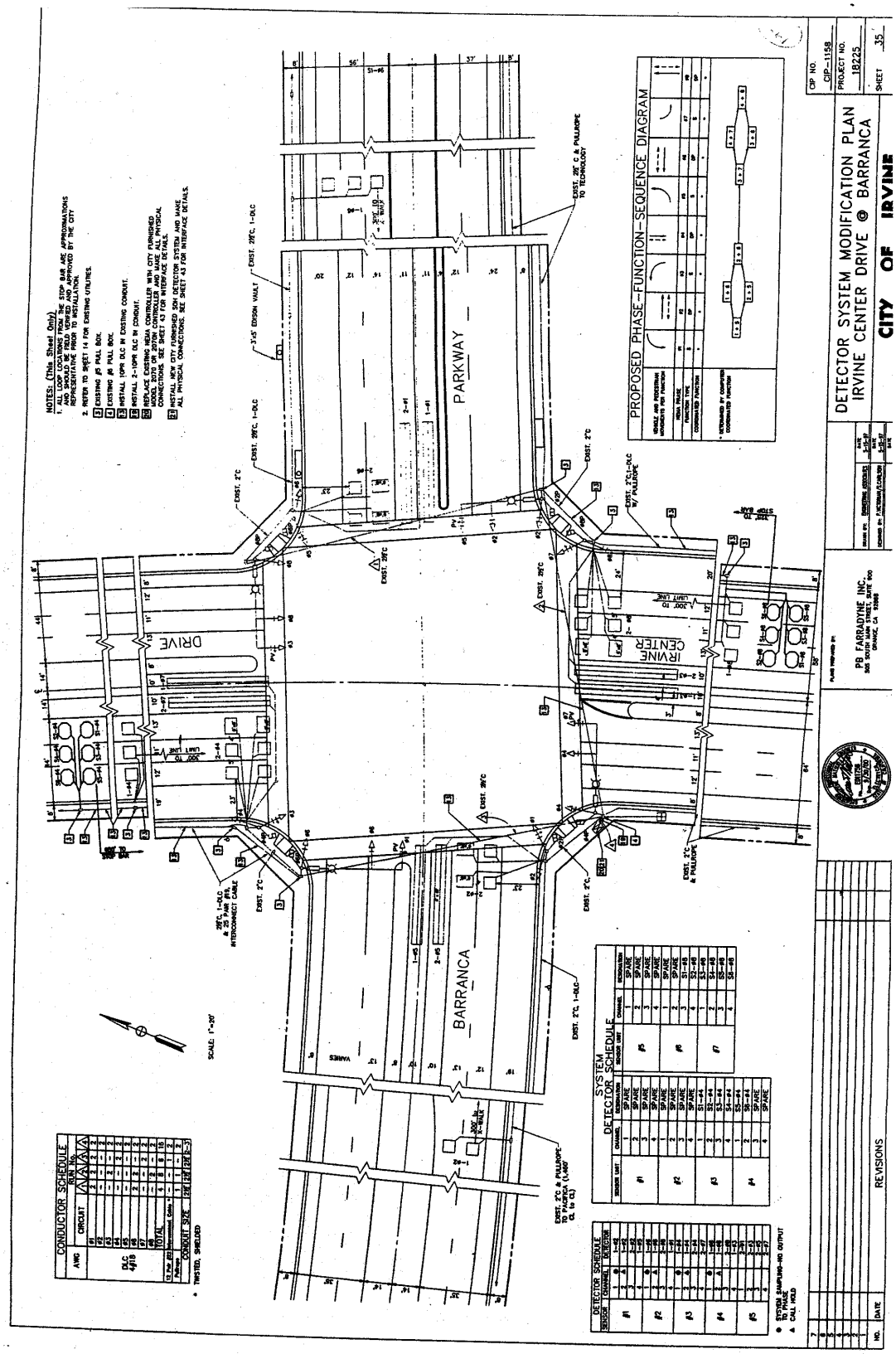
DETECTOR RECALLS	
Min Recall:	- - - 4 - - - 8
Max Recall:	
Ped Recall:	
Override Recall:	
Soft Recall:	- - - 4 - - - 8

PREEMPT KEY

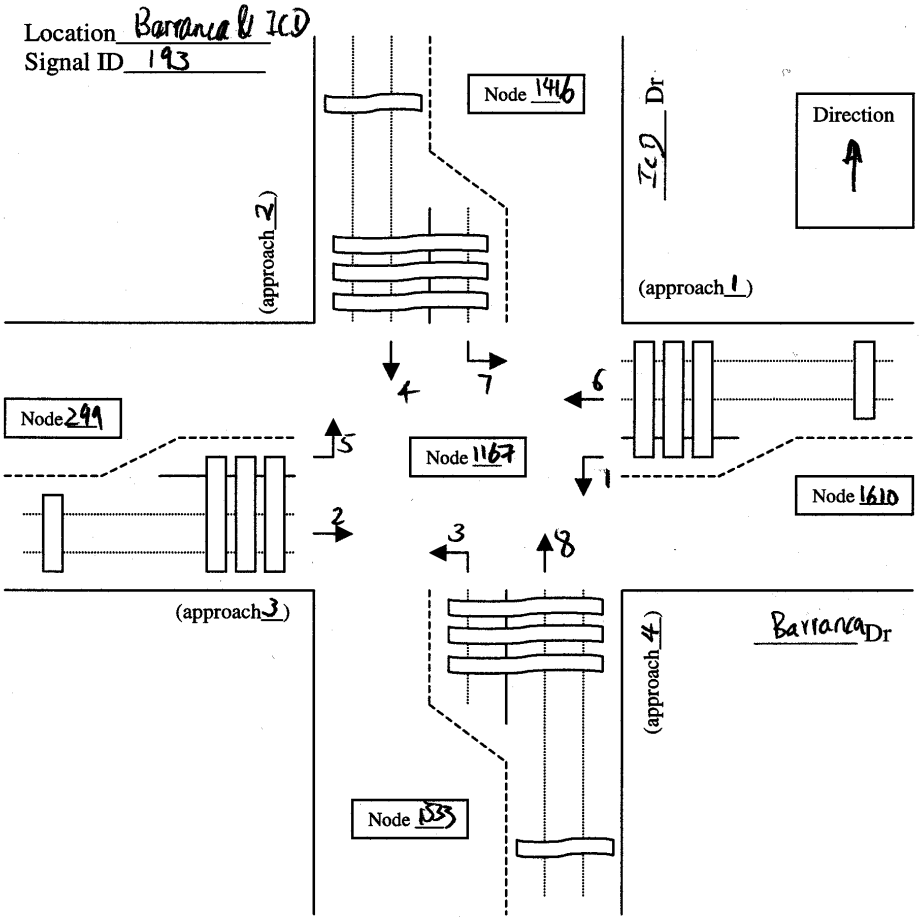
EMERGENCY VEHICLE PREEMPTS	
Delay Time:	
Hold Time:	
EVP Phases:	
EVP Min Time:	
Abort Min:	
Abort Walk:	
Abort FDW:	
Ret Veh Calls:	
Ret Ped Calls:	
Delay Output:	

RAILROAD PREEMPT	
Delay Time:	
Hold Time:	
Track Phases:	
Track 0 Grn Time:	
Preempt Phases:	
Intvl 5 In Flash:	
Intvl 5 Min Grn:	
Intvl 6 Yellow:	
Intvl 7 Red Time:	
Return Phases:	
Ret Veh Calls:	
Ret Ped Calls:	
Abort FDW:	
Preempt Enabled:	

1.7.3 Geometric layout of the intersection



1.7.4 Completed worksheet for the example intersection



Node	1167							
Movement	1	2	3	4	5	6	7	8
Initial Green	5	5	5	8	5	5	5	8
Extension	3	4	3	5	3	4	3	5
Max Green	24	32	24	32	24	32	24	32
Recall Phase	4	8						
Lanes	2	2	2	3	2	2	2	3
Right-Turn lanes	1		1		1		1	
Detector 1	icb5w		icb2w		icb3w		icbuw	
Detector 2	icb5s		icb2s		icb3s		icbus	
Detector 3	icb5e		icb2e		icb3e		icbue	
Detector 4	icb5n		icb2n		icb3n		icbun	

1.7.5 The priorities information for the example intersection

```
actions 1167
phase offset 0.00 sec
phase 1
        0.00
        max 100.00
red phase 0.00
fill
all barred except
from 1416 to 299 minor
from 1610 to 1416 minor
from 1610 to 1533 major
from 299 to 1416 major
from 299 to 1533 minor
from 1533 to 1610 minor
phase 2
        0.00
        max 100.00
red phase 0.00
fill
all barred except
from 1416 to 299 minor
from 1610 to 1416 minor
from 299 to 1416 major
from 299 to 1533 minor
from 299 to 1610 major
from 1533 to 1610 minor
phase 3
        0.00
        max 100.00
red phase 0.00
fill
all barred except
from 1416 to 299 minor
from 1610 to 1416 minor
from 1610 to 299 major
from 1610 to 1533 major
from 299 to 1533 minor
from 1533 to 1610 minor
phase 4
        0.00
        max 100.00
red phase 0.00
fill
```

all barred except
from 1416 to 299 minor
from 1610 to 1416 minor
from 1610 to 299 major
from 299 to 1533 minor
from 299 to 1610 major
from 1533 to 1610 minor
phase 5
    0.00
    max 100.00
red phase 0.00
fill
all barred except
from 1416 to 299 minor
from 1416 to 1610 major
from 1610 to 1416 minor
from 299 to 1533 minor
from 1533 to 299 major
from 1533 to 1610 minor
phase 6
    0.00
    max 100.00
red phase 0.00
fill
all barred except
from 1416 to 299 minor
from 1416 to 1533 major
from 1416 to 1610 major
from 1610 to 1416 minor
from 299 to 1533 minor
from 1533 to 1610 minor
phase 7
    0.00
    max 100.00
red phase 0.00
fill
all barred except
from 1416 to 299 minor
from 1610 to 1416 minor
from 299 to 1533 minor
from 1533 to 1416 major
from 1533 to 299 major
from 1533 to 1610 minor
phase 8
    0.00
    max 100.00

red phase 0.00
fill
all barred except
from 1416 to 299 minor
from 1416 to 1533 major
from 1610 to 1416 minor
from 299 to 1533 minor
from 1533 to 1416 major
from 1533 to 1610 minor

2. Multiple Actuated Signal Plan

2.1. Introduction

The actuated signal plug-in only supports one timing plan for each actuated signal. In order to allow multiple signal timing plans, this plug-in can be used.

2.2 Plug-in Implementation

This plug-in is developed based on actuated signal plug-in. The pseudo code for the main control logic of this plugin is given as follows:

1. Read the "multi_plan_signal_control" file and initialize the multiple actuated signal plugin.
2. At every time step of simulation:

```
For controller intersection = 1 : n
{
   If (time to switch timing plan)
   {
        Update signal timing plan using uci_signal_set_parameters().
   }
}
```

2.3 Step-by-step user manual

2.3.1 Preparation of "multi_plan_signal_control" file

In order to use this plug-in, the input file of the plug-in: "multi_plan_signal_control" needs to be prepared first. An example of this file is:

```
total number of actuated signals 2
total number of timing plans 2

plan 1 from 8:00:00  to 9:00:00

node 1167 ICD & BARRANCA
movements   1   2   3   4   5   6   7   8
ini_green   5   5   5   8   5   5   5   8
extension   3   4   3   5   3   4   3   5
max_green   24  32  24  32  24  32  24  32
```

node 142 ALTON & ICD
movements 1 2 3 4 5 6 7 8
ini_green 5 5 5 5 5 5 5 5
extension 3 5 3 5 3 5 3 5
max_green 24 32 24 32 24 32 24 32

plan 2 from 9:00:00 to 24:00:00

node 1167 ICD & BARRANCA
movements 1 2 3 4 5 6 7 8
ini_green 5 5 5 8 5 5 5 8
extension 3 4 3 5 3 4 3 5
max_green 20 28 20 28 20 28 20 28

node 142 ALTON & ICD
movements 1 2 3 4 5 6 7 8
ini_green 5 5 5 5 5 5 5 5
extension 3 5 3 5 3 5 3 5
max_green 20 28 20 28 20 28 20 28

The first two lines include some general information. “total number of actuated signals” represents the number of signals that have multiple timing plans. “total number of timing plans” is a global parameter. We assume that all signals have the same number of timing plans. The second part is about the timing plans. For each timing plan, users need to input movement, initial green, extension, and max_green information. The time period of the last timing plan needs to end at 24:00:00.

2.3.2 Load plugin

This plugin has two files:

multi_signal_plan.dll: Modeller Plugin
multi_signal_plan-p.dll: Processor Plugin

After the completion of the “multi_plan_signal_control” file, you can load the simulation network together with this plugin. Because this plugin is an functionality extension of another plugin: actuated signal control, both these two plugins should be specified in the “programming” file with the following sequence:

actuated_signal.dll
multi_signal_plan.dll

is developed based on the In order to support multiple signal plans, please use another plugin “multiple actuated signal plan” together with this plugin.

2.3.3 Error checking

If any mistakes occurred in the “multi_plan_signal_control” file, this plugin will be disabled. The report window of PARAMICS will show whether this plugin is working.

3. Actuated signal Coordination

3.1 Introduction

Coordination is a mode of signal operation designed to allow platoons of traffic to form and "progress" through several signals with minimum stops and delay. Where signals are closely spaced and traffic volumes are high, coordination of signals is necessary to avoid excessive delay and stops.

The actuated signal coordination API inherits most parts of full-actuated signal API, with additional force-off logic to maintain the background cycle length, and form green band for a particular phase (sync phase).

3.2 Plugin implementation

3.2.1 Control logic

To provide synchronization and maintain the background cycle length, all coordinated intersection have the same system clock reference point, which is usually the start point of signal coordination plan. For the fixed-time signal coordination plan, there is an offset, which is the difference between two green initiations of the sync phase for two adjacent intersections. However, for the traffic-actuated signal coordination, the sync phase of every coordinated intersection has fixed series of yield points, and the difference between yield points is the background cycle length. These yield points are also local clock reference points to other non-sync phases. The sync phase has minimal bandwidth, i.e. the sync phase has to start at the time of minimal bandwidth earlier than yield point. To do so, all other phases have to be cut at certain points, which are so-called force-off points. These force-off points are usually referenced to the local clock reference point. Figure 1 is the phase diagram of coordinated intersection.

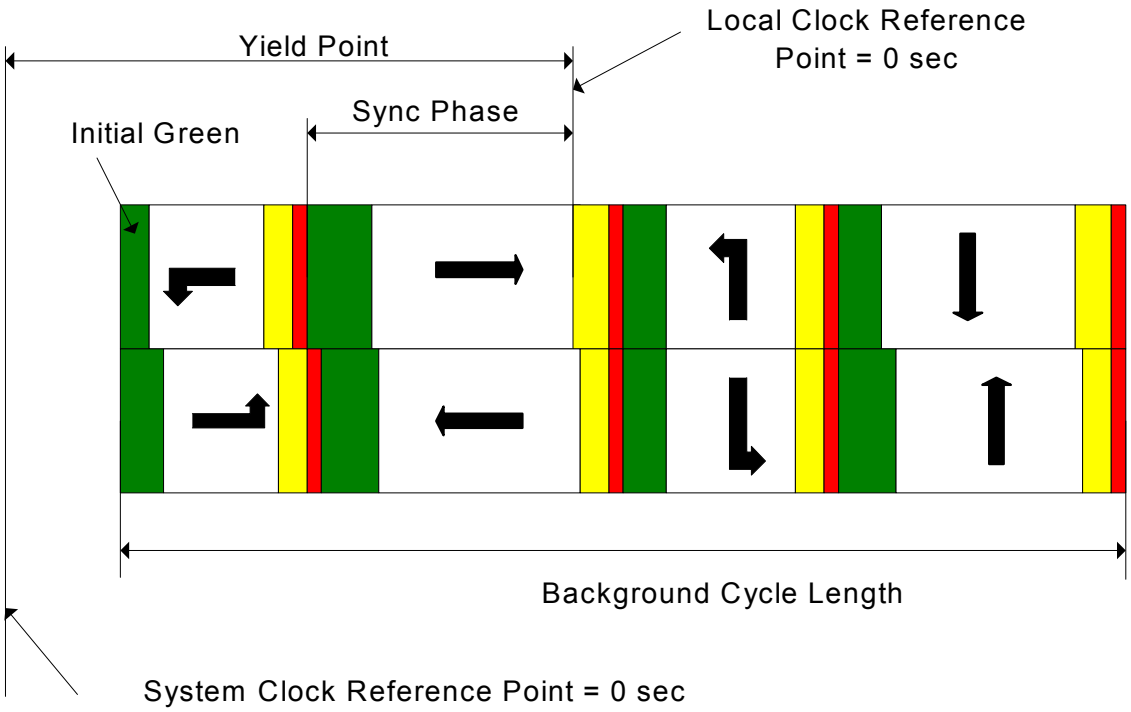


Figure 1. Actuated Signal Coordination

3.2.2 Control Logic and Pseudo Codes

In order to implement the above concept, the pseudo code for the main control logic is given in the following:

1. Actuated Signal API set up using api_setup( ), includes signal data input, memory allocation, and initial signal phase set up.
2. At every time step, net_action is called:

```
For controller intersection = 1 : n {
  a. Inquiry the current signal information using signal_inquiry( ).
  b. Vehicle presence detection (pp_presence_dection ( ) ).
  c. If (left green time > 0) {
       Check if this phase should be forced off (pp_force_off ( )).
       If (force-off )
          Find the next phase by vehicle presence.
       else {
            excute the current signal plan (pp_excute_plan ( ) )  {
          If ( left green time < extension &&
               vehicle presence for extension &&
               expired green < ( maximal green – extension ) ) {
                    green  time increased by (extension – left green).
               }
          If ( left  green time <= time step ) {
```

```
                                    Find the next phase by vehicle presence.
                            }
                        }
                    }
                }
                else {
                        Amber and red time are counted.
                        If ( amber and red time are reached )
                                Set the next signal phase parameters through signal_action( ).
                }
        }
```

3.3 Step-by-step user manual

3.3.1 Understanding actuated signal coordination

The implemented actuated signal coordination logic has some new concepts. The correct understanding of them is important for the use of the actuated signal coordination plugin. The following is a good description of these terms:

1. Background Cycle Length
To provide synchronization and maintain the background cycle length, all coordinated intersection have the same system clock reference point, which is usually the start point of signal coordination plan.

2. Yield Point

The sync phase of every coordinated intersection has fixed series of yield points, and the difference between yield points is the background cycle length.

3. Sync Phase

These yield points are also local clock reference points to other non-sync phases. The sync phase has minimal bandwidth, i.e. the sync phase has to start at the time of minimal bandwidth earlier than yield point.

4. Force Off

To do so, all other phases have to be cut at certain points, which are so-called force-off points. These force-off points are usually referenced to the local clock reference point.

3.3.2 Data requirement

As the actuated signal API, two files need to be prepared for the use of signal coordination API. One is the "priorities" file, provided by Paramics, to be used to identify the hierarchy of movements for all phases. The other is the so-called "signal_coordination_control" file, which contains all the signal timing information, intersection layout information, and coordination information.

The following is an example of the part of "signal_coordination_control" file for one intersection.

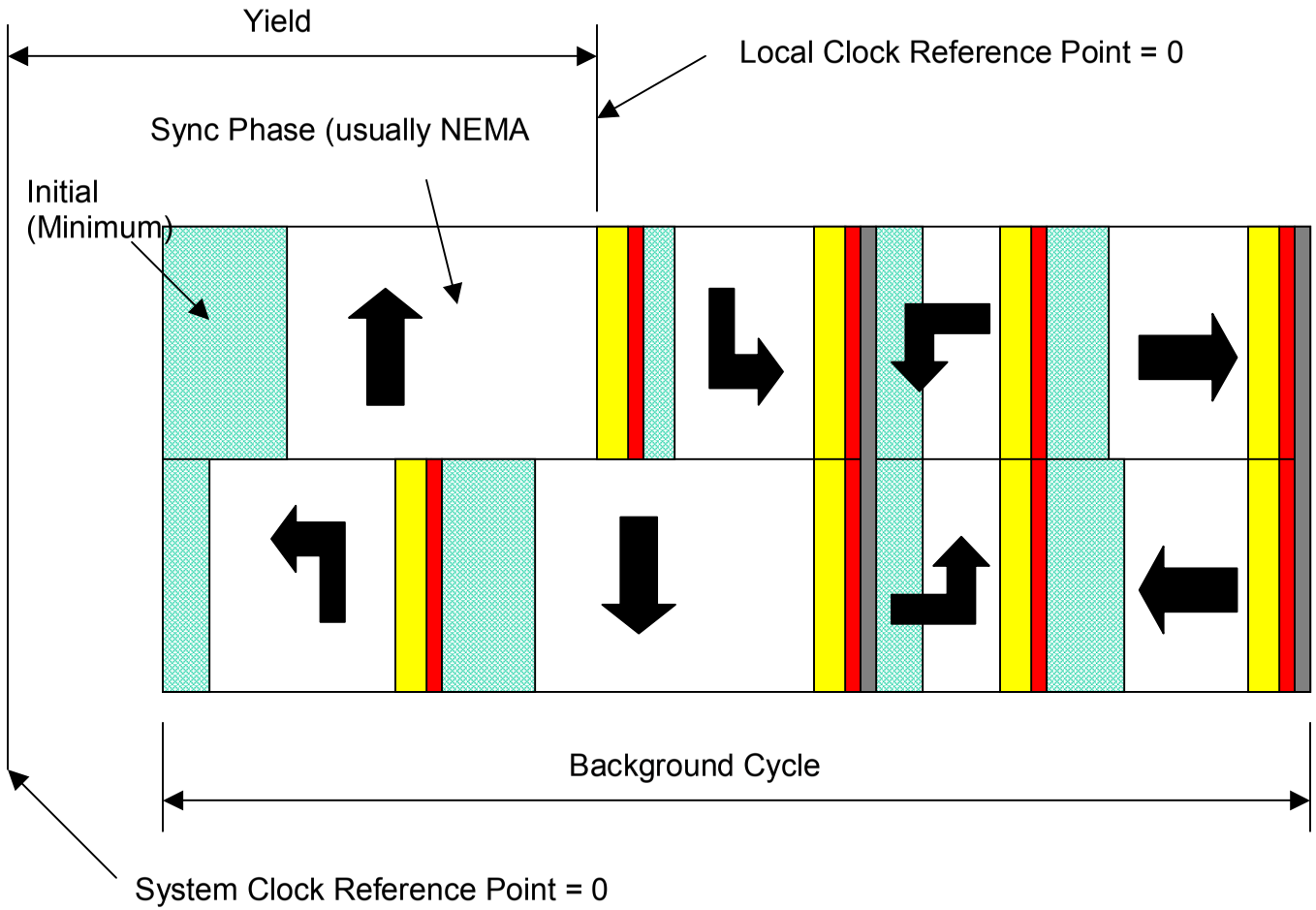
```
total number of actuated signals is:   4

node 6  ALTON & ICD
movements     1     2     3     4     5     6     7     8
ini_green     5     5     5     5     5     5     5     5
extension     3     5     3     5     3     5     3     5
max_green    24    60    24    32    24    32    24    32
recall        2     6
lanes         2     3     2     3     2     3     2     3
rightturn     1     1     1     1
detector1     aisw   ai2w  ai3w   aiuw
detector2     aiss   ai2s  ai3s   aius
detector3     aise   ai2e  ai3e   aiue
detector4     aisn   ai2n  ai3n   aiun
sync_phase    2     6
cycle_length 60
force_off    36    60    18    27    36    60    18    27
yield_point   5
system_clock  0
```

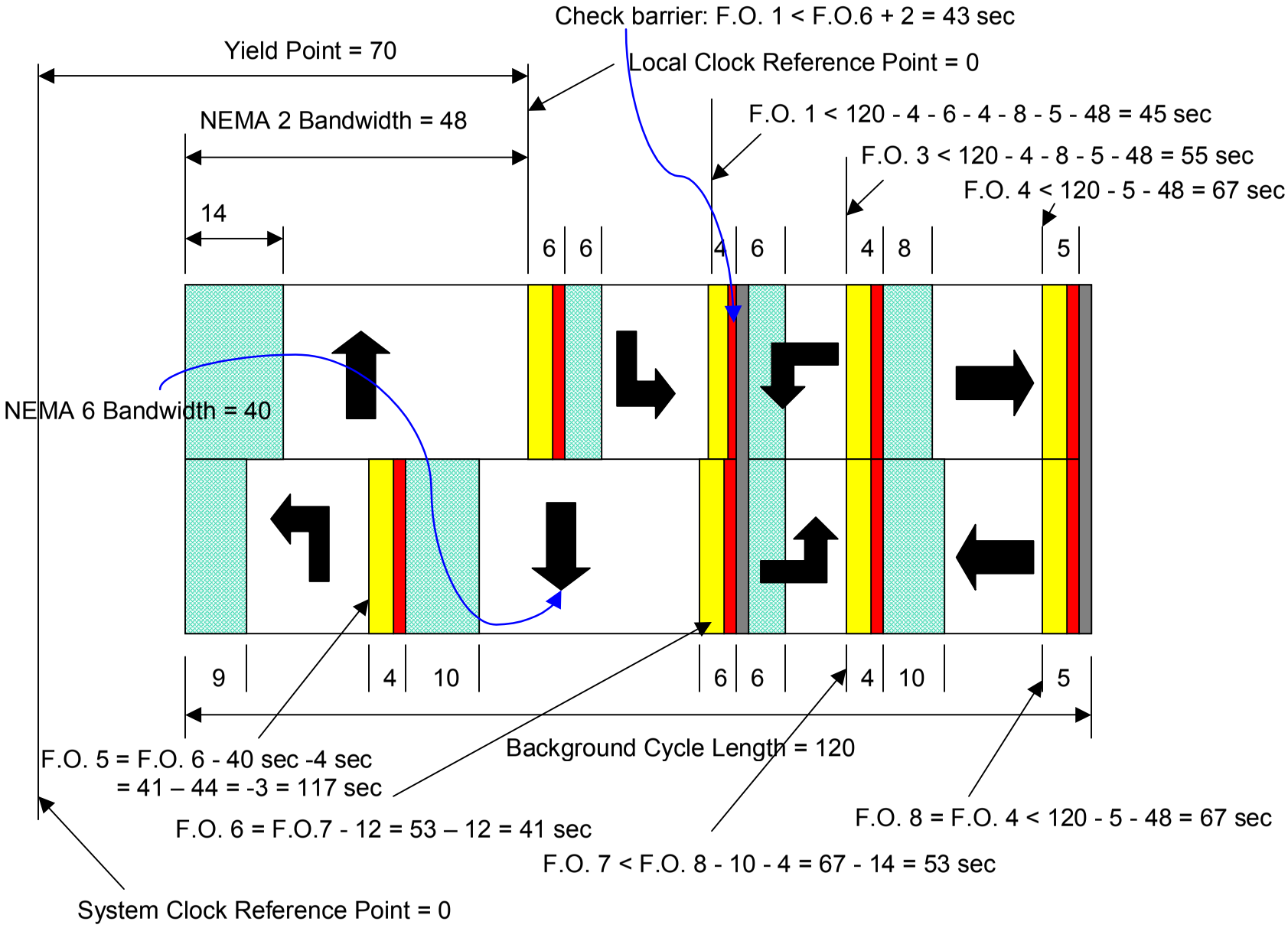
The data for signal coordination has been attached after the intersection layout data for each intersection. Besides to the yield point of the sync phase, all other phases have force-off points, referenced to the local clock reference point. Notice that the maximal green time of primary sync phase has to be the cycle length, since the green time of sync phase may occupy the entire cycle if there is no conflict traffic.

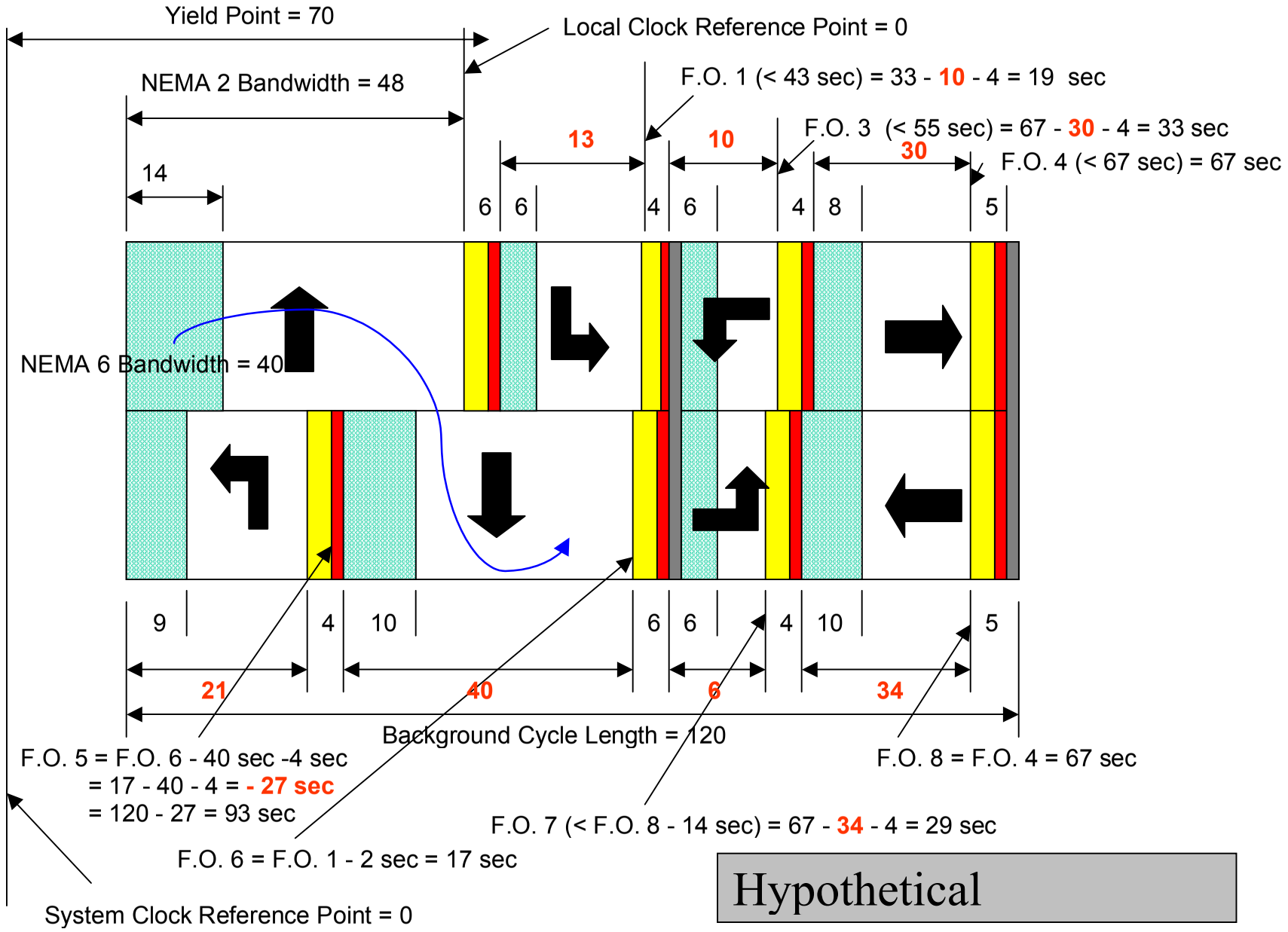
3.3.3 Example

Phase Interval Times

Interval	Phase							
	1	2	3	4	5	6	7	8
Walk								
Ped Clear								
Initial	6	14	6	8	9	10	6	10
Extension	2.0	3.0	3.0	2.0	2.0	3.0	3.0	2.0
Max Green	20	50	15	35	20	50	15	35
Yellow	3	5	3	4	3	5	3	4
Red	1	1	1	1	1	1	1	1
Permit	√	√	√	√	√	√	√	√
Max Recall								
Min Recall								
Ped Recall								
Lag Phase	√							


Yield
Local Clock Reference Point = 0
Sync Phase (usually NEMA
Initial
(Minimum)
Background Cycle
System Clock Reference Point = 0


Check barrier: F.O. 1 < F.O.6 + 2 = 43 sec
Yield Point = 70
Local Clock Reference Point = 0
NEMA 2 Bandwidth = 48
F.O. 1 < 120 - 4 - 6 - 4 - 8 - 5 - 48 = 45 sec
F.O. 3 < 120 - 4 - 8 - 5 - 48 = 55 sec
F.O. 4 < 120 - 5 - 48 = 67 sec
14
6
6
4
6
4
8
5
NEMA 6 Bandwidth = 40
9
4
10
6
6
4
10
5
Background Cycle Length = 120
F.O. 5 = F.O. 6 - 40 sec -4 sec
= 41 – 44 = -3 = 117 sec
F.O. 6 = F.O.7 - 12 = 53 – 12 = 41 sec
F.O. 7 < F.O. 8 - 10 - 4 = 67 - 14 = 53 sec
F.O. 8 = F.O. 4 < 120 - 5 - 48 = 67 sec
System Clock Reference Point = 0


Yield Point = 70
Local Clock Reference Point = 0
NEMA 2 Bandwidth = 48
F.O. 1 (< 43 sec) = 33 - 10 - 4 = 19 sec
F.O. 3 (< 55 sec) = 67 - 30 - 4 = 33 sec
F.O. 4 (< 67 sec) = 67 sec
13
10
30
14
6 6 4 6 4 8 5
NEMA 6 Bandwidth = 40
9 4 10 6 6 4 10 5
21 40 6 34
Background Cycle Length = 120
F.O. 5 = F.O. 6 - 40 sec -4 sec
= 17 - 40 - 4 = - 27 sec
= 120 - 27 = 93 sec
F.O. 8 = F.O. 4 = 67 sec
F.O. 7 (< F.O. 8 - 14 sec) = 67 - 34 - 4 = 29 sec
F.O. 6 = F.O. 1 - 2 sec = 17 sec
System Clock Reference Point = 0
Hypothetical

4. Detector Data Aggregator

4.1 Introduction

PARAMICS can output two types of loop detector data for analysis:

- Point loop data, including flow, speed, headway, occupancy, and acceleration of a vehicle, and
- Link loop data, including flow, average speed, density, lane use, and lane changing on a link.

Point data is gathered at every time step when an individual vehicle passes over the loop; link data analyses the traffic data over a link, where loops locate, at a user-defined time period. However, many Advanced Traffic Management and Information Systems (ATMIS) applications demand point traffic data, but in an aggregated manner over user-defined time intervals, e.g. *30* seconds.

The objective of this plugin is to emulate the outputs of real-world data collection from induction loops in PARAMICS. It is implemented through gathering point loop data at each time step of simulation and then aggregating at any time interval specified by users. The gathered data can be raw data or smoothed data in term of user's choice. Aggregated loop data (including volume, occupancy, and speed) can be output to text files, and can be also accessed by interface functions defined in this plugin[2].

Although Paramics has a loop data aggregation plugin coming with the package, we found it is not convenient for us to further develop some traffic control algorithms using APPI programming. Table 4.1 is a comparison of the loop data aggregator plugins of Quadstone and UCI.

Table 4.1 comparison of the loop data aggregator plugins of Quadstone and UCI

	Quadstone	ATMS testbed @ UCI
Measurements	flow, count, speed, gap, occupancy	count, occupancy, speed
Occupancy output	Time occupancy	Percent occupancy
Output files	A file only includes a lane's data, or the grouped data. Too many files will be opened.	Grouped data and lane-based data are in the same file for a detector
Restriction	There are restrictions on the total number of files to be opened in Paramics. Problems may occur when users want to collect aggregated data for many loop detectors.	No restriction on the number of files to be opened
Programming	Programmer users can use data in the	Full supports of advanced

[2] There is another MYSQL version of Loop Data Aggregator plugin. MYSQL database is used for storing aggregated loop data. All aggregated loop data since the beginning of simulation can be accessed through querying the database.

capability	output files through reading them. But, it is not convenient for on-line applications.	algorithm plug-ins developed by UCI

4.2 Plugin implementation

4.2.1 Aggregation method

In the real world, most detectors are loop detectors. A loop detector station generally has multiple loop detectors and each loop detector covers a lane. In PARAMICS, a detector can cover all lanes or just cover a lane. This plugin outputs aggregated detector data in term of a detector station. The aggregated data outputs include not only aggregated data of each lane but also the grouped data of the detector station.

In the real world, loop detectors are used to report volume and percent occupancy. In the simulation, besides volume and percent occupancy, speed can also be obtained from simulation because it is a basic element of simulation. As a result, this plugin will be used to aggregate traffic volume, percent occupancy and speed data.

The aggregated volume is defined as the number of vehicles passing the detector during last time interval. The aggregated speed is the average of speeds of passing vehicles during last time interval. If at the aggregation time, a vehicle is just on a loop, it is counted as a passed vehicle for aggregation.

Percent occupancy is defined as the percentage of time of a loop occupied by vehicles. However, the occupancy obtained from PARAMICS (via API function loop_occupancy()) is time occupancy, which is calculated based on vehicle length, loop detector length, and vehicle speed. Therefore, we need to convert from time occupancy to percent occupancy:

$$OCC = \sum_{i=1}^{N} OCC(i) \Big/ TT$$

where OCC(i) is the time occupancy of vehicle i; N is the total number of vehicles having passed the detector during last time interval; *TT* is the interval of aggregation. If at the aggregation time, a vehicle is just on a loop, the duration the vehicle is on the detector (this value can be obtained from simulation) is used for aggregation.

Based on aggregated data of each lane, the grouped aggregated data (including grouped volume, occupancy and speed) of this detector station are also calculated. The grouped volume represents the total number of vehicles having passed the detector station (including several detectors, each lane has one detector) during last time interval, which can be expressed as

$$N_i(t) = \sum_{j=1}^{n} N_{i,j}(t)$$

where *i* is the index of the detector station; *j* is the loop index at detector station *i*; *n* is the total number of lanes, or loops at detector station *i*; $N_{i,j}(t)$ is the number of vehicles passing loop *j* of detector station *i* during time interval *(t-1, t)*.

The grouped occupancy represents the average percent occupancy of a detector station during last time interval, which can be expressed as

$$O_i(t) = (\frac{1}{n}\sum_{j=1}^{n}\sum_{k=1}^{N_{i,j}(t)}(TO_{i,j,k}(t)))/TT$$

where *i* is the index of the detector station; *j* is the loop index at detector station *i*; *n* is the total number of lanes, or loops at detector station *i*; *k* is the vehicle index; $N_{i,j}(t)$ is the number of vehicles passing loop *j* of detector station i during time interval *(t-1, t)*; $TO_{i,j,k}(t)$ is the time occupancy of vehicle *k* passing loop *j* at detector station *i* during time interval *(t-1, t)*.

The grouped speed represents the average speed of a detector station during last time interval, which can be expressed as

$$V_i(t) = \frac{1}{n}(\frac{1}{N_i(t)}\sum_{j=1}^{n}\sum_{k=1}^{N_{i,j}(t)}V_{i,j.k}(t))$$

where *i* is the index of the detector station; *j* is the loop index at detector station *i*; *n* is the total number of lanes, or loops at detector station *i*; *k* is the vehicle index; $N_{i,j}(t)$ is the number of vehicles passing loop *j* of detector station i during time interval *(t-1, t)*; $V_{i,j,k}(t)$ is the loop speed when vehicle k passes loop *j* at detector station *i* during time interval *(t-1, t)*.

4.2.2 Pseudo code

The control logic is given in the following pseudo codes:

1. Initialization of loop data aggregator plugin, including reading "*loop_control*" file, opening output files, memory allocation, and other initial settings;
2. At every time step, PARAMICS overload API function: "*vehicle_detector()*"when a vehicle traverses on or passes a loop. If a vehicle passed a detector, the occupancy and speed of the vehicle are accumulated. The following exceptional cases need to be handled in order to obtain the correct occupancy value:
   (1) Unexpected incorrect value of occupancy from simulation, which may happen when a loop is placed at a location near the start or the end of a link;
   (2) More than one vehicle are on a loop at the same time;

(3) One vehicle stays over a loop for more than certain time period, which may happen when an incident or congestion appears;
(4) One vehicle is just on a loop at the time of aggregation.

3. At every time step, PARAMICS overload API function: "*net_action()*".
   For *detector = 1:n*
   {
   If it is the time to calculate and report the aggregated data of a loop
   {
   Calculate count, average speed, and percent occupancy of a detector.
   Calculate grouped count, occupancy, and speed of all detectors at a detector station
   Output these data to output files and the interface function
   }
   }

4.3 Step-by-step user manual

4.3.1 Preparation of the "loop_control" file

"loop_control" is the input file of the loop data aggregator plugin. This file should be put to the same directory as any other network files. An example of *"loop_control"* file is shown as follows:

```
detector count          42
report cycle            30
activation time         06:00:00
deactivation time       10:00:00
gather smoothed data    no
output to files         yes

name 405n0.6ml
gather interval 00:00:30

name 405n0.93fr
gather interval 00:00:60
…
```

There are two parts in the file. The first part is the general information about data aggregation.

1. The first row of the file shows the number of detectors that are required to do the aggregation operation.

2. The second row specifies the polling / report cycle of data aggregation. The unit is seconds. This cycle is corresponding to the time interval of real-world loop data collection. A typical value of the "report cycle" is 30 seconds. Basically, this polling cycle is not related to aggregated data outputs. It is used for ATMS applications, such as adaptive ramp metering, that are based on aggregated loop data.

3. The next two rows specify the activation time and deactivation time of the loop data aggregation.

4. The fifth row specifies whether to gather smoothed loop data (including speed, occupancy). If "no", raw data will be gathered. There are two kinds of loop data that can be provided by PARAMICS at each time step, raw data or smoothed data. Smoothed refers to a value t_N^s at time-step N smoothed using the expression:

   $$t_N^s = (1-p)t_{N-1}^s + pt_N$$

   where t_N is the current value and p is the co-efficient of smoothing.

5. The sixth row specifies whether to output aggregated loop data to files. If say "yes", a file, generally named as *"XYZ.txt" ("XYZ"* is the name of the corresponding loop), will be generated for storing the aggregated volume, occupancy and speed data based on the gather interval specified in the second part of this control file.

The second part of the file contains the information of each loop detector, including the name of detector and the time interval that loop data are aggregated and reported to text files. There is a blank row between the information of any two loops. The name of a loop can be found in the "detectors" file, which is one of network files. The time interval to aggregate loop data can be different for different detectors.

4.3.2 Loading plugin

This plugin has two files:

loop_agg.dll: Modeller Plugin
loop_agg-p.dll: Processor Plugin

After the completion of the "loop_control" file, you can load the simulation network together with this plugin. Run simulation and then you will obtain the aggregated loop data outputs if you enable the option "output to files".

4.3.3 Text file outputs

If "output to files" is "yes", aggregated loop data will be output to text files. Each detector specified in the "loop_control" file has its own output file. These output files can be found in the subdirectory:

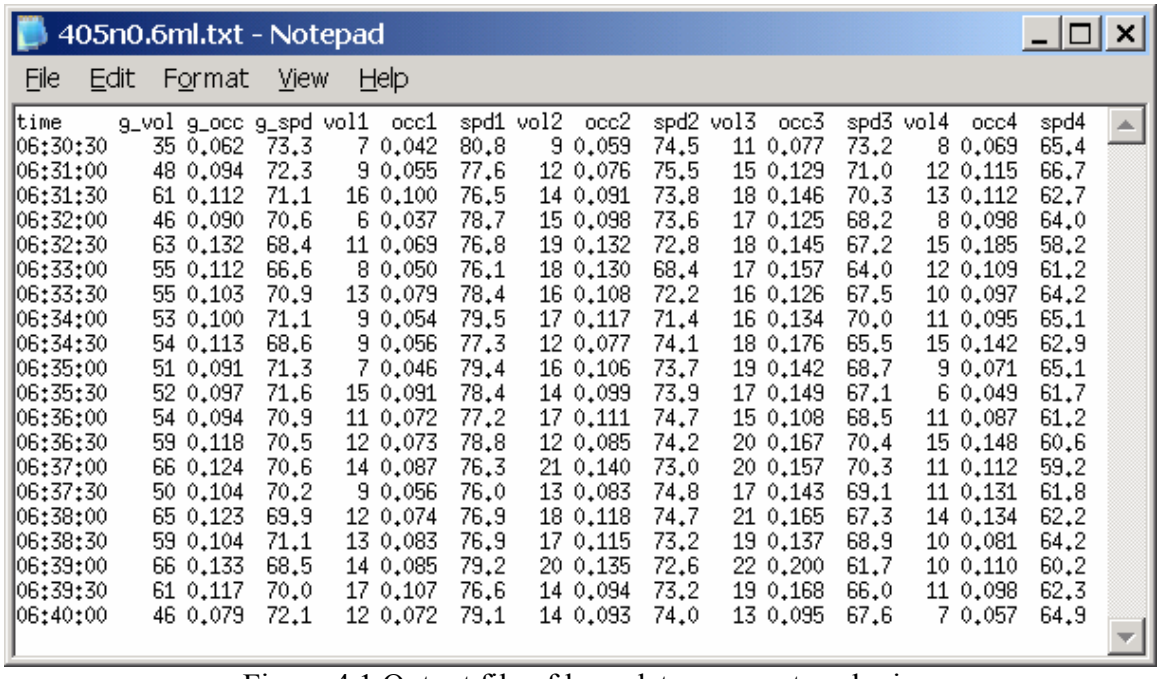
network/Log/run-xxx

where network is the name of the current working directory, and xxx is a three-digit sequence number.

During the simulation process, aggregated detector data are continuously calculated, and then immediately stored to the output text file. Each output file has several fields, whose definitions are shown as follows:

Time stamp, grouped volume, grouped occupancy, grouped speed, volume of lane 1, occupancy of lane 1, average speed of lane 1, volume of lane 2, occupancy of lane 2, average speed of lane 2, …, volume of lane n, occupancy of lane n, average speed of lane n

For right hand driving, lane *1* is the inside lane (the leftmost lane, it might be the HOV lane if applicable). Lane *n* is the outside lane (the rightmost lane). The unit of the speed output is miles per hour. The percent occupancy value is show in the format of "0.094", which represents the percent occupancy of 9.4%. Figure 4.1 shows an example of the output file.


405n0.6ml.txt - Notepad

File Edit Format View Help

time	g_vol	g_occ	g_spd	vol1	occ1	spd1	vol2	occ2	spd2	vol3	occ3	spd3	vol4	occ4	spd4
06:30:30	35	0.062	73.3	7	0.042	80.8	9	0.059	74.5	11	0.077	73.2	8	0.069	65.4
06:31:00	48	0.094	72.3	9	0.055	77.6	12	0.076	75.5	15	0.129	71.0	12	0.115	66.7
06:31:30	61	0.112	71.1	16	0.100	76.5	14	0.091	73.8	18	0.146	70.3	13	0.112	62.7
06:32:00	46	0.090	70.6	6	0.037	78.7	15	0.098	73.6	17	0.125	68.2	8	0.098	64.0
06:32:30	63	0.132	68.4	11	0.069	76.8	19	0.132	72.8	18	0.145	67.2	15	0.185	58.2
06:33:00	55	0.112	66.6	8	0.050	76.1	18	0.130	68.4	17	0.157	64.0	12	0.109	61.2
06:33:30	55	0.103	70.9	13	0.079	78.4	16	0.108	72.2	16	0.126	67.5	10	0.097	64.2
06:34:00	53	0.100	71.1	9	0.054	79.5	17	0.117	71.4	16	0.134	70.0	11	0.095	65.1
06:34:30	54	0.113	68.6	9	0.056	77.3	12	0.077	74.1	18	0.176	65.5	15	0.142	62.9
06:35:00	51	0.091	71.3	7	0.046	79.4	16	0.106	73.7	19	0.142	68.7	9	0.071	65.1
06:35:30	52	0.097	71.6	15	0.091	78.4	14	0.099	73.9	17	0.149	67.1	6	0.049	61.7
06:36:00	54	0.094	70.9	11	0.072	77.2	17	0.111	74.7	15	0.108	68.5	11	0.087	61.2
06:36:30	59	0.118	70.5	12	0.073	78.8	12	0.085	74.2	20	0.167	70.4	15	0.148	60.6
06:37:00	66	0.124	70.6	14	0.087	76.3	21	0.140	73.0	20	0.157	70.3	11	0.112	59.2
06:37:30	50	0.104	70.2	9	0.056	76.0	13	0.083	74.8	17	0.143	69.1	11	0.131	61.8
06:38:00	65	0.123	69.9	12	0.074	76.9	18	0.118	74.7	21	0.165	67.3	14	0.134	62.2
06:38:30	59	0.104	71.1	13	0.083	76.9	17	0.115	73.2	19	0.137	68.9	10	0.081	64.2
06:39:00	66	0.133	68.5	14	0.085	79.2	20	0.135	72.6	22	0.200	61.7	10	0.110	60.2
06:39:30	61	0.117	70.0	17	0.107	76.6	14	0.094	73.2	19	0.168	66.0	11	0.098	62.3
06:40:00	46	0.079	72.1	12	0.072	79.1	14	0.093	74.0	13	0.095	67.6	7	0.057	64.9

Figure 4.1 Output file of loop data aggregator plugin

4.3.4 Error checking

This plugin is easy to use if "loop_control" is prepared correctly. If any mistakes happened in the "loop_control" file, the plugin will be disabled. The report window of PARAMICS will show whether this plugin is working.

If the plugin is not working, you may need to check if there is any error in "loop_control". This plugin generates a file named "Log-loop.txt" under the network directory, which can be used to check if the "loop_control" file has been understood by this plugin correctly.

4.4. PROGRAMMER capabilities

4.4.1 Interface functions

This plugin provides three interface functions. The first one is used to obtain the current polling / report cycle of data aggregation, defined in the second row of "loop_control". If an ATMS application, such as an adaptive ramp metering control, is based on aggregated loop data, this interface can provide the polling cycle of aggregated loop data.

int uci_loop_agg_interval(void)
Return Value: The polling cycle of aggregated loop data.
Parameters: None

The second interface function is used to tell users if a loop detector has been specified in "loop_control" file for getting aggregated loop data.

Bool uci_loop_aggregation(char *name)
Return Value: If the name of a loop detector has been specified in "loop_control" file, return "TRUE". Otherwise, return "FALSE".
Parameters: Name of the loop detector.

The third interface function is used for querying the aggregated loop data of the latest time interval at a detector station. The aggregated loop data includes grouped volume, average occupancy and average speed, and lane-based volume, average occupancy and average speed.

LOOPAGG uci_loop_agg (int index)
Return Value: The aggregated detector data of a loop detector
Parameters: index: the network-wide index number for a loop detector
LOOPAGG is a structure that has the following definition:

```
typedef struct loopagg LOOPAGG;
struct loopagg
{
        int     index;
        float   time;
```

```
        int     g_vol;
        float   g_occ;
        float   g_spd;
        int     lane;
        int     *vol;
        float   *occ;
        float   *spd;
    };
```

where
index is the network-wide index for the detector;
time is the time stamp for the calculation of aggregation, decided by the gather interval of each loop;
g_vol is the total traffic volume passing all lanes of a detector station within last time interval;
g_occ is the average occupancy of all lanes of a detector station;
g_spd is the average speed of all vehicles passing all lanes of a detector station;
lane is the total number of lanes at the detector station;
**vol, *occ, *spd* are pointers for recording values of volume, occupancy and average speed of each lane of a detector station. Most items in this structure can be found in the output file of aggregated loop data, whose fields are defined in Table 2.

4.4.2 How to use interface functions in other plugins

The interface functions can be called by other plugins. The following setting is required:

(1) In the workspace of your plugin that wants to use the interface function, specify the library file "loop_agg.lib" of this plugin as an input object/library module. The path of "loop_agg.lib" should be specified as well.

(2) Make sure that loop aggregator plugin is specified before the plugin that will use the interface function in the *"plugin"* file (V3, located in "p*lugins\windows*" under the PARAMICS installed directory), or the "programming" file (V4, located at the network directory).

(3) Specify the prototypes of interface functions at the beginning of your plugin:

```
_declspec(dllimport) LOOPAGG uci_loop_agg(int index);
_declspec(dllimport) int uci_loop_agg_interval(void);
_declspec(dllimport) Bool uci_loop_aggregation(char *name);
```

5. Ramp metering control

5.1 Introduction

There have been a number of strategies to release vehicles into the mainline freeway traffic, each with different demands on sophistication of control and detectorization. Caltrans currently has three ramp metering systems, SATMS, SDRMS, and SJRMS. All of them use the 170 type controllers as hardware. SATMS, SDRMS, and SJRMS are names of their software algorithms installed in the 170 controller.

This plugin is designed to model pre-timed ramp metering control on n-cars-per-green basis (with n > 1) in PARAMICS. It also supports multiple timing plans and the use of ramp detectors for metering control. The data input of this plugin is a time-of-day ramp control plan and the detector information of each meter.

In addition, this plugin is designed to support the development of advanced ramp-metering algorithms, and integrated control strategies (ramp metering plus arterial signal control). A number of interface functions are provided by this plugin for external plugin modules to acquire the current metering rate and set a new metering rate to a specific ramp meter.

5.2 Plugin implementation

5.2.1 Real-world ramp metering system

The easiest ramp meter is based on fixed-time control. Some latest ramp metering design has included the check-in and check-out detector for a better control and the consideration of safety.

Caltrans has the following basic design of ramp metering system, as shown in Figure 5.1. Five types detectors can be possibly installed for a ramp meter, including on-ramp detector, demand detector, passage detector, queue detector, and ramp HOV detector. The on-ramp detector is used for counting total number of vehicles entering freeway from entrance ramps. The demand and passage detectors (i.e. corresponding to the check-in and check-out detectors) are used for the operation of on-ramp signals. The demand detector employs to initiate green and the passage detector employs to return the signal to red. The queue detector is located at the upstream end of the entrance ramp, used for detecting the excessive queue length in order to avoid interference with the arterial traffic. The ramp HOV detector is used for counting the number of carpool vehicles entering freeway from entrance ramps.

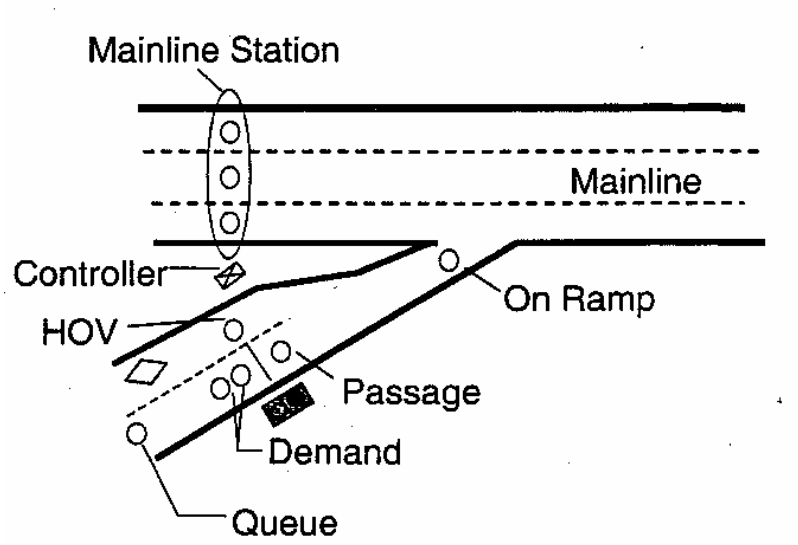


Figure 5.1 Typical ramp metering configuration in the real world

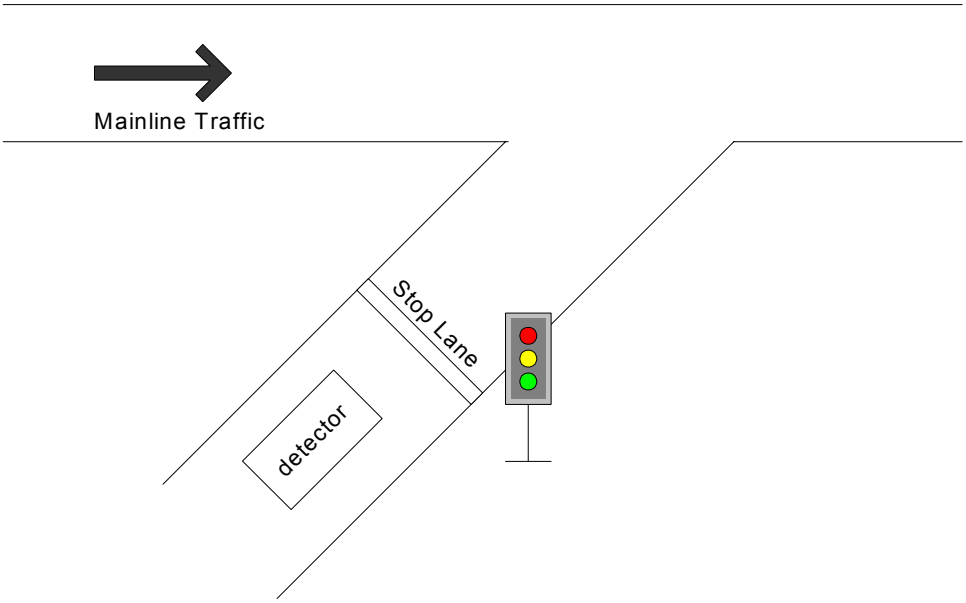


Figure 5.2 Typical ramp metering layout in Paramics

5.2.2 Modeling vehicle detection

This plugin is designed to implement the pre-timed metering control. The plugin can work with or without detectors. Due to a legacy issue[3], the plug-in only supports the use of check-in detector (or, demand detector) in the actuated ramp metering case. The simplified layout of ramp metering system is shown in Figure 5.2.

[3] The check-in and check-out logic of the real-world ramp metering system needs accurate detection of passing vehicles. However, in an older version of Paramics, detectors cannot be used to accurately detect traffic. This is the reason we did not use the check-out detector in the plug-in.

The length of the demand detector is based on the real-world design of ramp meter. Based on the design manual of Caltrans, District 11 typically uses 4 demand loops, Districts 3, 4, 6, 8 typically use 3 demand loops, Districts 7, 12 typically use 2 demand loops. As a result, the length of the demand detector is equal to the length that a demand detector can cover.

5.2.3 Control logic

The ramp signal generally provides two indications, green and red. Based on the time-of-day metering rate, the metering cycle can be calculated as:

$$cycle = 3600 / rate$$

If one-car-per-green is applied, we assume the green time a vehicle needs to pass the metering signal is 2 seconds. If two-car-per-green is applied, we assume the green time for two vehicles to pass the metering signal is 4 seconds. Then the length of red signal is:

$$red = cycle - green$$

If there is no demand detector or check-in detector, metering signal will show red and green based on the above red and green time. This guarantees that vehicles are released from ramp to the mainline freeway at a fixed ramp metering rate.

If there is a demand detector or check-in detector, every vehicle has to stop before the stop lane, waiting for the green signal. The detector for sensing the presence of a vehicle allows the signal to rest in red, avoiding potential confusion to a driver approaching the signal, due to the short greens. The following three principles are used for metering signal control:

(1) If the length of red signal is longer than "red" and the demand detector has detected the presence of a vehicle waiting, the green signal will be given with the length of "green".
(2) If the length of red signal is shorter than "red", green signal will not be given even there are waiting vehicles.
(3) If the length of red signal is longer than "red" and no vehicle is waiting, the metering signal keeps showing the red signal.

This plugin allows multiple metering plans. A metering rate is fixed within a specific time window. For another time window, another timing plan can apply.

As an illustration, suppose the ramp signal cycle length is 10 seconds from 4pm to 6pm. This is one vehicle every 10 seconds, so that a setting of a 2 sec of green followed by 8 sec of red could be used. The metering rate in this case is 360 vph.

5.2.4 Pseudo code

The control logic is given in the following pseudo codes:

```
(1) Read ramp_control file and initialize the plug-in
{
        Allocate memories for all pointers to be used.
        Store all necessary ramp information to global data structures.
        Check the existence of ramp nodes and correspondent detectors.
        Initialize the ramp signals based on the initial simulation time.
}
(2) At every time step of simulation, net_action is called:
        Get simulation time.
        For controlled ramp = 1 : n
        {
                Check the current running phase.
                Get green left time of the current running phase
                Find the correct ramp control plan according to the simulation time
                If (ramp cycle length changed due to entering another time period)
                {
                        Notify the operator
                        Recalculate the green times for the 2 phases                    15
                 }
                 If (controltype is always ON)
                        set next green time for “always ON”
                 Else if (controltype is always OFF)
                        set next green time for “always OFF”
                 Else
                 {
                        If (the running phase is 2 && green left time <= time step)
                                Set the next green time for phase 1
                        Else if (the running phase is 1)
                        {
                                If (no vehicle presence)
                                {
                                        If (the running time is less than RAMP_CYCLE)
                                              continue to increment green time for phase 1
                                        Else (the running time is equal to RAMP_CYCLE)
                                              set the next green time for phase 2
                                }
                                else
                                        Set the next green time for phase 2
                         }
                }
        }
```

5.3 Step-by-step user manual

In order to use this ramp metering plugin, two files need to be prepared:

(1) "priorities" file is a system file of PARAMICS, provided with the action and phase definition of a ramp signal.

(2) "ramp_control" file is the input of actuated ramp API including the ramp control information, such as ramp name, control type, cycle, effective time, etc.

5.3.1 Data preparation

The following documents are required in order to correctly use this plugin.

(1) Ramp meter design map, including the layout of detectors

(2) Entrance ramp control plans, obtained from the proper government agency

5.3.2 Adding demand detectors

The demand detector should be added to the PARAMICS network, which should be put just before the stop line based on the design map of the entrance ramp. The number of demand loops installed in the real world and the layout of these loops will decide the length of the demand detector in PARAMICS.

The ramp metering API can work with or without detectors. If with detectors, the plugin requires a demand detector, which should be specified by users in the "ramp_control" file, for the operation of on-ramp signal. If without detectors, users need to specify the demand detector of the on-ramp as N/A.

5.3.3 Adding on-ramp signal through editing "priorities" file

In order to let PARAMICS regard a node as a signalized node, users must add or edit the "priorities" information of the node. This can be realized through GUI or editing "priorities" file. The "priorities" file, a system file of PARAMICS, defines movements of each phase of a signalized intersection. We recommend the latter method.

There are two phases for each on-ramp signal. We define that phase 1 is the red signal to prohibit vehicles from entering the mainline freeway and phase 2 is the green signal to release the waiting vehicle into the freeway. An example of the "priorities" information fro an on-ramp signal is as follows:

```
actions 92
phase offset 0.00 sec
phase 1
        0.00
        max 30.00
```

```
red phase 0.00
fill
all barred except
phase 2
        0.00
        max 30.00
red phase 0.00
fill
all barred except
from 91 to 93 major
```

Where **fill** means no yellow will be shown. The initial phase lengths for both phases are set to 0. This plugin has set the maximum cycle of an on-ramp signal to 24 seconds. Currently in the above example, "**max 30.00**" means the maximum length of each phase is 30 seconds. This value should be larger than 24 seconds in order to make ramp meters controlled by this plugin.

5.3.4 Preparation of "ramp_control"

The "ramp_control" file includes the ramp control information, which is the input of this plugin. It should be located at the same directory as any other network files. An example of "ramp_control" is shown below.

```
total number of controlled entrance ramps is    7
control cycle of ramp metering                  30

on-ramp signal              33
name                        405N & ICD 1 @ 0.93
demand detector             405n0.93orb
number of control plans     2
from 6:0 to 9:0             METER_ON with 1 veh per 6 sec
from 15:0 to 19:0           METER_ON with 1 veh per 6 sec

on-ramp signal              36
name                        405~N & ICD 2 @ 1.11
demand detector             405n1.11orb
number of control plans     2
from 6:0 to 9:0             METER_ON with 1 veh per 12 sec
from 15:0 to 19:0           METER_ON with 1 veh per 7 sec
…
```

The first line defines the number of entrance ramps to be controlled by this plugin. The second line defines the control cycle of the ramp metering control.

The following is the necessary input information of each entrance ramp, which always begins from a blank line.

(1) **"*on-ramp signal*"** is the global node number of the on-ramp signal in the PARAMICS network.

(2) **"*name*"** is the description of the entrance ramp, such as its location.

(3) **"*demand detector*"** is the name of the demand detector of the entrance ramp. If there is no demand detector or the demand detector is not used for on-ramp signal operation, please specify as "N/A". If the specified detector can not be found in the "detectors" file, a warning message will be given and the entrance ramp will be operated without demand detector.

(4) ***"number of control plans"*** is the number of on-ramp signal control plans. The number will decide how many timing plans followed.

(5) The following are time-of-day timing plans. The possible format might be one of the following:

from **TIME1** to **TIME2**	METER_ON with **BB** veh per **CC** sec
from **TIME1** to **TIME2**	METER_OFF
from **TIME1** to **TIME2**	RAMP_CLOSURE

where **"TIME1"** is the starting time of a timing period and **"TIME2"** is the end time of a timing period. The format of **TIME1** and **TIME2** is HH:MM (only hour and minute is specified). The timing periods of any two timing plans should not overlap. "***BB***" is the type of metering operation, single-entry metering (**BB = 1**) or platoon metering (**BB = 2**). "***CC***" is the cycle of metering control. If the status is METER_ON**, BB** and **CC** should be specified. If there is no timing plan for a certain time period, it is regarded as METER_OFF.

5.3.5 Loading plugin

This plugin has two files:

ramp_controller.dll: Modeller Plugin
ramp_controller-p.dll: Processor Plugin

After the completion of the "ramp_control" file and the update the "priorities" file, you can load the simulation network together with this plugin.

5.3.6 Error checking

After the network and the plugin are loaded in Modeller, you can start simulation. Via GUI, you will see that this plugin emulates the metering control at specified on-ramps.

This plugin can work if "ramp_control" and "priorities" are prepared correctly. If any mistakes occurred in the "ramp_control" file, the plugin will be disabled. The report window of PARAMICS will show whether this plugin works.

If the metering control does not work or does not work as you expected, you may need to check if there is any error in the "ramp_control" file. This plugin generates a file named "Log-ramp.txt" under the network directory, which can be used for this purpose.

5.4 PROGRAMMER capabilities

5.4.1 Interface functions

There are three interface functions, used for querying current and time-of-day metering rate and setting a new metering rate. An advanced ramp-metering algorithm plugin can be developed based on them. Their prototypes are shown below.

RAMP *uci_ramp_get_parameters (char *rampnode)
Function: Querying the current metering plan of a specific ramp meter.
Return Value: The current metering plan of an on-ramp signal (may not be TOD plan).
Parameters: **rampnode** is the name of an on-ramp signal node.
RAMP is the structure of ramp control data, whose definition is:

```
typedef struct Ramp_data RAMP;
struct Ramp_data
{
// on-ramp signal node name and its location
char *node;
char *name;
// ramp control types and parameters
int type;
int cycle;
};
```

Where **controlType** is the status (or type) of the ramp metering control, which can be 0 (if RAMP_CLOSURE), 1 (if RAMP_ON with single-entry metering), 2 (if RAMP_ON with platoon metering) and 9 (if RAMP_OFF).

void uci_ramp_set_parameters (RAMP *ramp, Bool parameter)
Function: Setting a new metering rate to a specific ramp meter.
Return Value: None
Parameters: **ramp** stores the new metering control data of a specific on-ramp; **status** is a Boolean value. **parameter** = TRUE means to set a new metering rate based on an external algorithm; **parameter** = FALSE means to restore the default time-of-day timing plans.

float uci_ramp_get_tod_rate(char *rampnode)
Function: Querying the current time-of-day metering plan of a specific ramp meter.
Return Value: The current time-of-day metering plan of an on-ramp signal
TOD rate = 0: ramp_off
TOD rate = 1: metering_off
others: metering_rate
Parameters: **rampnode** is the name of an on-ramp signal node.

5.4.2 How to use interface functions in other plugins

These interface functions can be called in other plugins. The following setting is required:

(1) In the workspace of your plugin that wants to use these interface functions, specify the library file "ramp_controller.lib" of the actuated signal plugin as an input object/library module. The path of "ramp_controller.lib" should be specified as well.

(2) Specify the prototype of the interface function at the beginning of your plugin as follows:

```
_declspec(dllimport) void uci_ramp_set_parameters (RAMP *ramp, Bool parameter);
_declspec(dllimport) RAMP *uci_ramp_get_parameters (char *rampnode);
_declspec(dllimport) float uci_ramp_get_tod_rate(char *rampnode);
```

5.5 Technical Supports

5.5.1 Limitations of this plugin

The controllers in the real world have more capabilities than this plugin. For example, SATMS (one of Caltrans' ramp metering algorithm) contains local mainline responsive control (i.e. demand-capacity control) and time-of-day control (i.e. pre-timed control). However, this plugin only emulates pre-timed control.

In version 3 of PARAMICS, sometimes the presence detector does not work correctly, i.e. sometimes a vehicle cannot be detected though it is present on the detector. This case is very rare, however, this may cause severe problems in the simulation since all the following vehicles are blocked, and the signal may remain red all the time. To solve this problem, a green signal is given as long as the time of red signal is over RAMP_CYCLE.

The maximum number of timing plans is 256 for each entrance ramp signal. The length of green time for single-entry metering is 2.0 seconds and for platoon metering is 4.0 seconds, which are pre-set by the plugin.

No queue control is involved in this plugin. If a queue control is required, please use queue control plugin together with this plugin.

5.5.2 FAQ

1. PARAMICS can model ramp metering. Why do you develop this plugin?

PARAMICS can model fixed-time ramp metering with multiple timing plans. However, a ramp-metering controller, developed in PARAMICS API, is required for the support of development of adaptive ramp metering algorithms, which have more complicated control logics. The ramp-metering controller should provide interface functions that can be used for querying the old metering rate and setting a new metering rate based on the adaptive ramp metering algorithms. When the adaptive ramp-metering algorithm is not activated, the pre-timed metering will be the default control.

2. In "priorities" file, the two phases of ramp signal node has the input of "max 18.00", will this setting affect meters controlled by this plugin?

Please do not use a maximum lower than 26 seconds. The reason is described in Section 5.3.3. Our recommended value is "max 30.00".

3. How is this plugin used by advanced ramp metering algorithms?

This plugin is the ramp metering controller of any advanced ramp-metering algorithm (such as ALINEA or BOTTLENECK). This plugin provides current metering rate and sets a new metering rate based on the request of the advanced algorithm. If an advanced algorithm is associated with an entrance ramp, more detectors, such as the queue detector, HOV detector, on-ramp detector, might be required.

6. On-ramp queue override control

6.1 Introduction

The effect of ramp metering is that not all the vehicles can enter freeway from a meter and thus a waiting queue will be formed at the entrance ramp. If the queue exceeds a certain length, it will interfere with the adjacent street traffic. The queue override strategy is often used to solve this problem through the placement of a queue detector at the ramp entrance (usually, at the end of the entrance ramp).

An example of the queue override policy is that if the occupancy value of the queue detector exceeds a threshold (e.g. 50%), a high metering rate will be applied to the corresponding meter in order to release more vehicles to freeway.

This pluign is a complementary module of the ramp metering control plugin, which implements pre-timed metering control, but does not include any queue override strategy. The purpose of this plugin is to implement a typical queue override strategy that uses the queue detector. This plugin can be used together with the ramp metering control plugin. Also, this plugin can be used together with other advanced ramp metering control algorithms, such as ALINEA, which do not integrate a queue override strategy with them.

6.2 Plugin implementation

6.2.1 Development framework

Figure 6.1 illustrates the hierarchical development framework of advanced ramp-metering algorithm plugins in PARAMICS. The advanced ramp-metering algorithm plugin is built on top of two basic plugin modules, i.e., ramp metering controller and loop data aggregator. The on-ramp signals in the simulation network are controlled by the ramp metering plugin, through which metering rates can be queried and set by other plugin modules. The loop data aggregator emulates the real-world loop data collection, typically with a thirty-second polling interval, and broadcast the latest loop data to the dynamic memory. At each time increment, the advanced ramp-metering algorithm plugin can access the dynamic memory and obtains the required loop data through interface functions provided by the loop data aggregation plugin. Then the metering rate for the next control interval is calculated based on the advanced ramp-metering algorithm. The new metering rate is finally sent back to the ramp controller plugin for implementation.

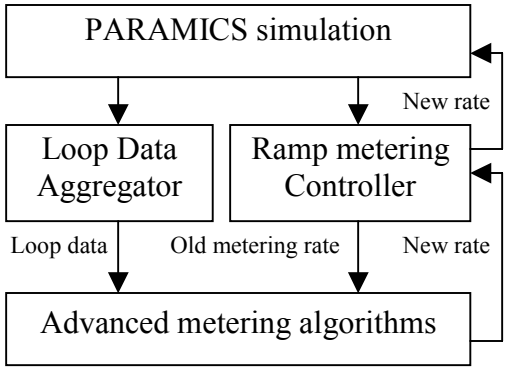


Figure 6.1 Hierarchical approach for the development of advanced metering algorithms

6.2.2 Control Logic

This plugin implements a queue override strategy depending on a queue detector placed on the entrance ramp. A typical location of the queue detector is located at the upstream end of the entrance ramp.

The control logic is as follows:

> If the percent occupancy of mainline detector is higher than the pre-specified "override occupancy threshold", an override control plan will be applied to the corresponding meter in order to avoid interference with the arterial traffic.

The override control plan can be a specified metering rate (such as maximum metering rate), or all green.

6.3 Step-by-step user manual

6.3.1 Adding queue detector

The queue override strategy implemented in this plugin is based on a queue detector, which is generally located at the end of the entrance ramp in the real world. The ramp meter design manual of Caltrans has the following descriptions of the location of queue detectors: "One loop per entrance ramp lane should be installed for queue detection near the connection of the surface street".

This location of queue detector can be modified in order to improve the control performance. A study shows that when the queue detector is located at 75% of the physical ramp length of the on-ramp, the performance of queue control is better than the cases when the queue detector is located at 100% and 62.5% length of the on-ramp (Hasan, M., 1999).

6.3.2 Preparation of the "queue_control" file

The "queue_control" file includes the queuing control information, which is the input of this plugin. The file should be located at the same directory as any other network files. An example of "queue_control" is shown below.

```
total number of queuing-controlled on-ramps is      7
checking control file                       yes
control cycle                               30
algorithm activation time                   06:00:00
algorithm deactivation time                 09:00:00
report queuing condition                    yes

on-ramp signal                  33
queue detector                  405n0.93orspill
override occupancy threshold    0.5
override control plan           METER_ON with 1 veh per 5 sec

…

on-ramp signal                  36
queue detector                  405n1.11orspill
override occupancy threshold    0.5
override control plan           METER_OFF
```

There are two parts in this "queue_control" file. The first part is the basic information of this plugin.

1. The first line defines the number of entrance ramps to be controlled by this API.

2. The option of "checking control file" is used for checking if there are any mistakes in the control file. If "yes", this API will print out the information obtained from "queue_control" file during the starting process of simulation.

3. The third line defines the control cycle of the ramp metering control. Basically, this control cycle is the loop data aggregation cycle, typically 30 seconds. If the queue detector detects the excessive queue length on entrance ramp, the metering rate controlled by the queuing strategy will be effective for the time length equal to this control cycle.

4. During the time period between "algorithm activation time" and "algorithm deactivation time", the ramp-metering algorithm is activated.

5. If "report queuing condition" is "yes", the metering rates of queuing control condition of all controlled ramps will be output (every update cycle) to a file named "rampQueue.txt". This file can be found in the sub-directory "Log" under the network directory.

The second part of the "queue_control" file is the input information of each entrance ramp, which always begins from a blank line.

1. "*on-ramp signal*" is the global node number of the on-ramp signal in the road network.

2. "*queue detector*" is the name of the queue detector for the entrance ramp. If there is no queue detector or no queuing strategy is involved in ramp metering, please specify as "N/A". If the specified detector can not be found in the "detectors" file, a warning message will be shown and the entrance ramp will be operated without any queuing strategy (even a strategy has been input in the "queue_control" file).

3. "override occupancy threshold" is required to be specified if the queue detector has been specified earlier in the file. If the percent occupancy of the queue detector station (if there is more than one queue detector at this location, the maximal percent occupancy of this location will be used) exceeds this threshold, the queuing strategy will be applied to avoid interference with the traffic on the surface street. If there is no queue detector, nothing needs to be filled in this line.

4. "override control plan" is actually the timing plan to handle the excessive queue length, which is required to be specified if the queue detector has been specified earlier in the file. The format is one of the following

METER_ON with ***BB*** veh per ***CC*** sec
METER_OFF
RAMP_CLOSURE

   where "***BB***" is the type of metering operation, single-entry metering (**BB = 1**) or platoon metering (**BB = 2**). "***CC***" is the cycle of metering control. If the status is METER_ON**, BB** and **C**C must be specified. If the queue detector is specified but the override control plan timing plan of the corresponding queuing strategy is not specified, "METER_OFF" is applied. If there is no queue detector, nothing needs to be filled in this line;

6.3.3 Loading plugin

This plugin has two files:

queue_controller.dll: Modeller Plugin
queue_controller-p.dll: Processor Plugin

This plugin needs the support of loop data aggregator plugin and ramp metering plugin.

They should be specified earlier than this plugin in the “plugins” or “programming” file, i.e.:

loop_agg.dll
ramp_controller.dll
queue_controller.dll

In order to load and run this plugin correctly, please satisfy the following requirements:

(1) The queue detectors in the “queue_control” file should be specified in “loop_control” file.

(2) The “report cycle” in the “loop_control” file should be the same as the control cycle specified in the “queue_control” file.

6.3.4 Output file

If “report queuing condition” in the “queue_control” file is specified as “yes”, the queuing information of all controlled ramps will be output (every update cycle) to a file named “moe-rampQueue.txt”. It can be found in the subdirectory:

network/Log/run-xxx

where network is the name of the current working directory, and xxx is a three-digit sequence number.

For each on-ramp, queuing condition of last control cycle will be output. If the queuing control is enabled due to a long queue (spillback) on an entrance ramp, the output value is 1. Otherwise, it is 0. At the end of this file, a summary of the percentage of time that the queue override strategy is activated is provided. An example of this file is shown in Figure 6.2.

6.3.5 Error checking

If there is any mistake in the “queue_control” file or the input files of the two supporting plugins, i.e. loop data aggregator and ramp metering control, this plugin will be disabled. The report window of PARAMICS will show whether this plugin is working.

Through enabling the option: “checking control file” in the “queue_control” file, you can check if there is any error in the “queue_control” file.

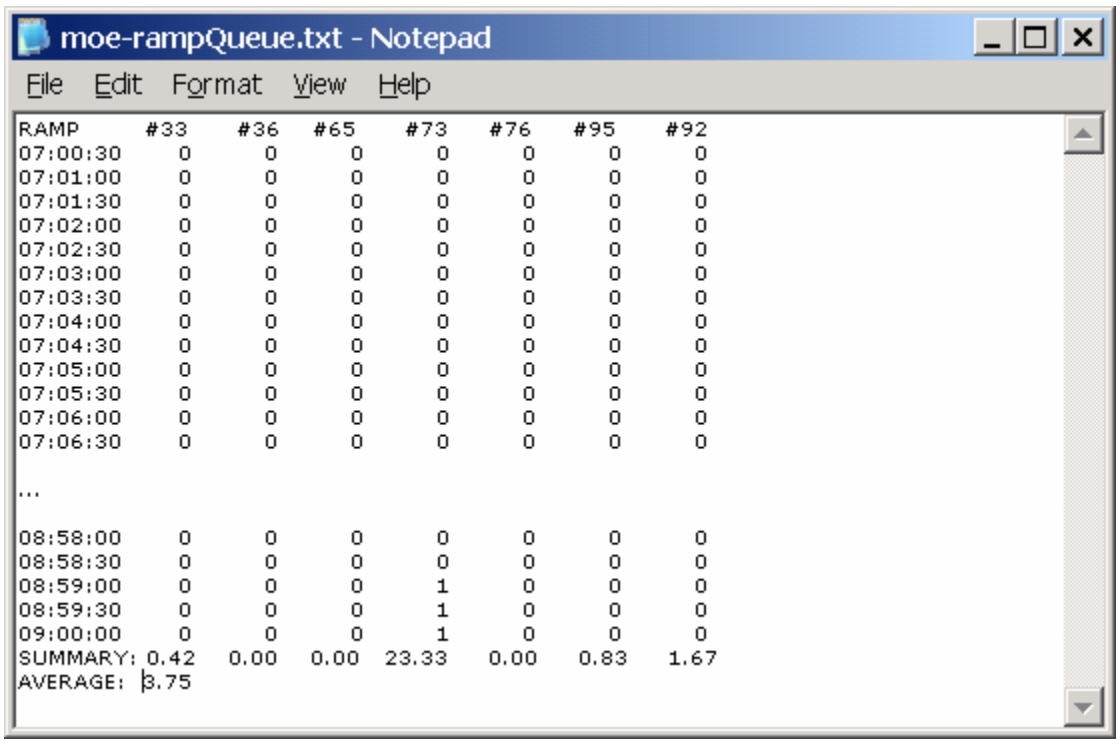


Figure 6.2 Example of the "moe-rampQueue.txt" file

6.4 Technical supports: References

1. Hasan, M. (1999) *Evaluation of ramp Control Algorithms using a Microscopic Simulation Laboratory, Mitsim*, Master thesis, Massachusetts Institute of Technology.

7. ALINEA ramp metering control

7.1. Introduction

The ALINEA algorithm, proposed by Papageorgiou et al, is a local feedback ramp metering policy. The algorithm attempts to maximize the mainline throughput by maintaining a desired occupancy on the downstream mainline freeway.

As shown in Figure 7.1, two detector stations are required for the implementation of the ALINEA algorithm. The first loop detector is located on the mainline freeway, immediately downstream of the entrance ramp, where the congestion caused by the excessive traffic flow originated from the ramp entrance can be detected. The second loop station is on the downstream end of the entrance ramp, and used for counting the on-ramp volume.

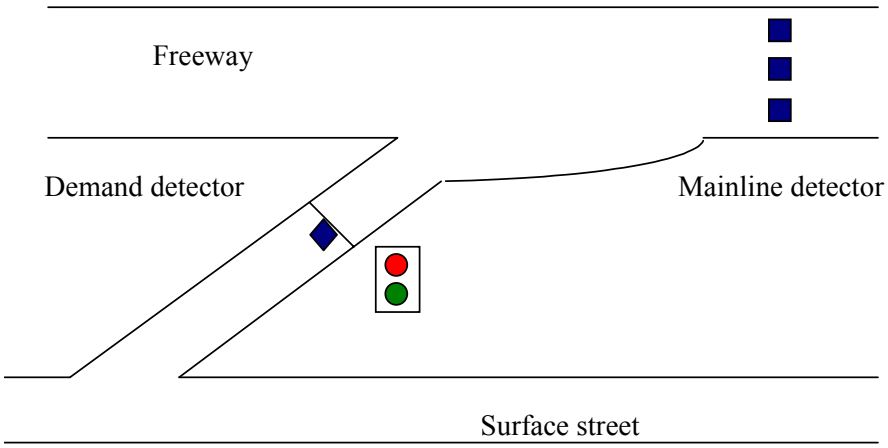


Figure 7.1 Detector layout for the implementation of the ALINEA algorithm

For an on-ramp under ALINEA control, its metering rate during time interval (t, t+ Δt) is calculated as:

$$r(t) = \tilde{r}(t - \Delta t) + K_R \bullet (O^* - O(t - \Delta t))$$

where Δt is the update cycle of ramp metering implementation; $\tilde{r}(t - \Delta t)$ is the measured metering rate of the time interval of (t –Δt, t); O(t–Δt) is the measured occupancy of time interval (t –Δt, t) at the downstream detector station; K_R is a regulator parameter, used for adjusting the constant disturbances of the feedback control; O* is the desired occupancy at the downstream detector station. The value of O* is typically set equal to or slightly less than the critical occupancy, or occupancy at capacity, which can be found in the volume-occupancy relationship.

7.2 Plugin implementation

Figure 6.1 illustrates the hierarchical development framework of advanced ramp-metering algorithm plugins in PARAMICS. We implement the ALINEA algorithm plugin with the following pseudo codes:

1. Communicating with ramp metering API and loop data aggregator API in order to obtain related up-to-date traffic information and historical metering rates.
2. Calculating the next metering rate based on formula 1.
3. Metering rate restriction
   An on-ramp volume restriction, which requires the implemented metering rate to be limited within some pre-defined maximum and minimum values, is also included in this API.
4. HOV adjustment
   The ideal ramp-metering algorithm should control all vehicles entering freeway from entrance ramps. If there is a HOV preferential lane on the entrance ramps, the HOV traffic volume can either be considered or not considered in the calculation of future metering rate.
5. Sending its computed metering rate to the ramp metering API for implementation.

7.3 Step-by-step user manual

7.3.1 Adding detectors

ALINEA needs two detector stations. The first one is located on the mainline freeway, immediately downstream of the entrance ramp, where the congestion caused by the excessive traffic flow originated from the ramp entrance can be detected.

The second one is located on the downstream end of the entrance ramp, and used for counting the on-ramp volume. You can use the demand detector (i.e. check-in detector), which is installed to the network for the vehicle presence in the ramp metering plugin.

If you want to implement ALINEA with a queue override strategy, you may need to add a queue detector. Please see the document of on-ramp queue control plugin for how to use that plugin and how to add a queue detector.

7.3.2 Preparation of the “alinea_control” file

The “alinea_control” file includes all necessary information required by this ALINEA plugin. Some of inputs should be calibrated based on the modeled network before implementation. An example of the file is as follows:

```
total number of alinea controlled ramps is   7
checking control file                yes
metering rate update interval        30
algorithm activation time            06:00:00
algorithm deactivation time          09:00:00
report metering rate                 yes

ramp                         33
mainline detector            405n0.93ml-ds
on-ramp detector             405n0.93orb
HOV                          0
control type                 1
desired occupancy            0.13
regulator                    70.0
rate restriction             300 1200

…

ramp                         95
mainline detector            405n5.55ml-ds
on-ramp detector             405n5.55orb
HOV                          1
control type                 1
desired occupancy            0.20
regulator                    70.0
rate restriction             240 900

ramp                         92
mainline detector            405n5.74ml-ds
on-ramp detector             405n5.74orb
HOV                          0
control type                 1
desired occupancy            0.20
regulator                    70.0
rate restriction             400 1500
```

“metering rate update cycle” is the time interval of metering rate calculation.

The option of “checking control file” is used for checking if there are any mistakes in the control file. If “yes”, this API will print out the information obtained from “alinea_control” file.

If “report metering rate” is yes, the metering rates of ALINEA controlled ramps will be output (every update cycle) to a file named “ALINEA-rampRate.txt” under the “Log” directory.

During the time period between “algorithm activation time” and “algorithm deactivation time”, the ramp-metering algorithm is activated.

The second part of “alinea_control” is about each ALINEA-controller ramps. “mainline detector” generally corresponds to the detector placed on the downstream of an on-ramp. It can be specified as an upstream detector but the performance of this algorithm may be deteriorated.

“on-ramp detector” generally corresponds to the demand detector shown in Figure 2. The purpose of this detector is to count the total vehicles entering freeway from an on-ramp. If the specified on-ramp detector cannot be found in the “detectors” file, this API will not work.

On the row of “HOV” (number of HOV lane at the location of on-ramp detector), if the HOV lane is modeled as a separated link or there is no HOV lane, please write down 0 on this row. If there is at least one HOV lane on the in-ramp, and the HOV and SOV lanes are modeled on the same on-ramp link, there are two conditions, HOV bypass and HOV metering. If “HOV” is specified as one (or more than one), vehicles entering freeway from the HOV lane are un-metered and the calculation of the future metering rate will not consider HOV vehicles. This is the HOV bypass situation, whose example is the first ramp shown in the above example. If “HOV” is specified as 0, this is the HOV metering situation. Vehicles entering freeway from HOV lanes will be considered in the calculation of the future metering rate. The example of this case is the second ramp shown in the above example.

“control type” means one-car-per-green or multiple-car-per-green. There are three possible values, 1, 2, 3. This information will be used for calculating the correct metering cycle under a certain control type.

“desired occupancy” and “regulator” are two parameters. “desired occupancy” has the format like “0.20”, but it represents 20%.

“rate restriction” include a minimum rate and a maximum rate, which are actually the two boundaries that metering rate can vary. Its unit is vehicle per hour.

7.3.3 Loading plugin

This plugin has two files:

alinea.dll: Modeller Plugin
alinea-p.dll: Processor Plugin

The ALINEA plugin depends on other two plugins, ramp metering control and loop data aggregator. These two plugins should be specified earlier than this plugin in the “plugins” or “programming” file, i.e.:

loop_agg.dll
ramp_controller.dll
alinea.dll

If you want to implement ALINEA with a queue override strategy, you will need to add on-ramp queue control plugin to the "plugins" or "programming" file with the following sequence in order to give the on-ramp queue control strategy higher priority than ALINEA:

loop_agg.dll
ramp_controller.dll
queue_control.dll
alinea.dll

In addition, in order to correctly load and run this plugin, please satisfy the following requirements:

(1) For ramp metering control plugin: on-ramp signals controlled by the ALINEA algorithm should be specified in the "ramp_control" file. For example, the correspondent on-ramp signal 33 needs to be specified in the "ramp_control" file:

on-ramp signal	33
name	405N & ICD 1 @ 0.93
demand detector	405n0.93orb
number of control plans	2
from 6:0 to 9:0	METER_ON with 1 veh per 6 sec
from 15:0 to 19:0	METER_ON with 1 veh per 6 sec

(2) For the loop data aggregator plugin: all loops involved in the "alinea_control" file should be specified in the "loop_control" file for aggregated data collection. In addition, the "report cycle" in the "loop_control" file should be the same as the "metering rate update interval" specified in the second row of "alinea_control" file. For example, all relevant loops of ramp 33 needs to be specified in the "loop_control" file:

detector count	42
report cycle	**30**
activation time	06:00:00
deactivation time	10:00:00
gather smoothed data	no
output to files	yes

…

name 405n0.93ml
gather interval 00:00:30

name 405n0.93orb
gather interval 00:00:30
…

7.3.4 Output file

If "report metering rate" in the "alinea_control" file is specified as "yes", the applied metering rate of all ALINEA controlled on-ramps will be output (every update cycle) to a file named "moe-ALINEA.txt". The file can be found in the subdirectory:

network/Log/run-xxx

where network is the name of the current working directory, and xxx is a three-digit sequence number.

7.3.5 Error checking

If there is any mistake in the "alinea_control" file or the input files of the two supporting plugins, i.e. loop data aggregator and ramp metering control, this plugin will be disabled. The report window of PARAMICS will show whether this plugin works.

Through enabling the option: "checking control file" in the "alinea_control" file, you can check if there is any error in the "alinea_control" file.

7.4 Technical Supports

7.4.1 Calibration of ALINEA algorithm

In order to maximize the performance of ALINEA metering control, parameters of the ALINEA algorithm need to be calibrated and optimized. Basically, ALINEA has four parameters to be calibrated, including the location of the downstream detector station, the desired occupancy of the downstream detector station, the update cycle of metering rate, and a constant regulator parameter K_R.

The following is a summary of currently applied parameter values:

(1) The desired occupancy can be equal to or around the occupancy value at capacity, which can be also found in the volume-occupancy diagram. Various values ranging from 0.18 to 0.31 have been found in previous applications.

(2) The regulator K_R, used for adjusting the constant disturbances of the feedback control, is found to perform well in the real-life experiment when it is set to 70. Simulation results are considered to be insensitive for a wide range of values.

(3) The downstream detector should be placed at a location where the congestion caused by the excessive traffic flow originated from the ramp entrance can be detected. In reported implementations, this site is located between 40 m and 500 m downstream of the on-ramp nose.

(4) The update cycle of ramp-metering rate is also variable with the range from 40 seconds to 5 minutes. In theory, if the value is small, the location of the downstream detector station should be close to the entrance ramp. Otherwise, there is a risk of congestion built-up in the interior of the stretch from the ramp nose to the downstream detector.

These calibrated parameters of ALINEA can be obtained based on reported practices (such as the regulator) and your own network (such as the desired occupancy). The recommended values are shown in Table 7.1. Since the current loop aggregation cycle is 30 seconds, the update cycle is set to 30 seconds in order to quickly feedback the variation of mainline traffic to the ramp control.

Table 7.1 Calibrated parameters for the ALINEA algorithm

Calibrated parameters	Calibrated values
Location of downstream detector station	60 m
Desired occupancy	18%
Update cycle of the metering rate	30 seconds
Regulation parameter K_R	70 veh / hour

7.4.2 References

1. Papageorgiou, M., Hadj Salem, H., and Blosseville, J. M. (1991). "ALINEA: A Local Feedback Control Law for On-Ramp Metering." *Transp. Res. Rec*. 1320, 58-64.

2. Papageorgiou, M., Hadj-Salem, and H., Middelham, F. (1997). "ALINEA Local Ramp Metering: Summary of field Results." *Transp. Res. Rec*. 1603, 90-98.

8. BOTTLENECK ramp metering control

The BOTTLENECK algorithm has been applied in Seattle, Washington for several years (Jacobsen, *et al*., 1989). This plugin is to implement the BOTTLENECK ramp-metering algorithm in PARAMICS.

8.1 Introduction

The BOTTLENECK algorithm has three components: a local algorithm computing local-level metering rates based on local conditions, a coordination algorithm computing system-level metering rates based on system capacity constraints, and adjustment to the metering rates based on local ramp conditions.

The local metering algorithm employed by the BOTTLENECK algorithm is occupancy control. The metering rate for the occupancy control is selected from a predetermined, finite set of discrete metering rates, on the basis of occupancy levels upstream of the given metered ramp. Historical data collected from the given detector station are used to approximate volume-occupancy relationships, which will be used to calculate the predetermined set of metering rates.

The coordination algorithm is the unique aspect of BOTTLENECK. The freeway segment under control is divided into several sections, each of which is defined by the stretch of freeway between two adjacent mainline loop stations. A section is identifies as a bottleneck if it satisfies two conditions, i.e. capacity condition and vehicle storage condition. The capacity condition can be described as:

$$O_{down}(i,t) \geq O_{threshold}(i) \tag{3}$$

where $O_{down}(i, t)$ is the average occupancy of the downstream detector station of section i over the past one-minute period $(t-1, t)$; $O_{threshold}(i)$ is a pre-defined loop station occupancy threshold when it is operating near capacity. The vehicle storage condition can be formulated as:

$$Q_{reduction}(i,t) = (Q_{up}(i,t) + Q_{on}(i,t)) - (Q_{off}(i,t) + Q_{down}(i,t)) \geq 0 \tag{4}$$

where $Q_{reduction}(i, t)$ is the number of vehicles stored in section i during the past minute. $Q_{up}(i, t)$ and $Q_{down}(i, t)$ are the volume entering section i across the upstream detector station and the volume exiting section i across the downstream detector station during the past minute, respectively; $Q_{on}(i, t)$ is the total volume entering section i from on-ramps during the past minute; $Q_{off}(i, t)$ is the total volume exiting section i to off-ramps during the past minute.

The number of vehicles stored in the bottleneck section $Q_{reduction}(i, t)$ should be reduced. Each section needs to define an area of influence that consists of a number of upstream

on-ramps for the volume reduction. The amount of volume reduction from an on-ramp is determined by a weighting factor, pre-defined according to how far it is to the downstream detector station of the bottleneck section and the historical demand pattern from the on-ramp. If on-ramp *j* involves in the volume reduction of any bottleneck section, its system-level metering rate is calculated as:

$$r(j,t) = Q_{on}(j,t-1) - \overset{n}{MAX}_{i=1}(Q_{reduction}(i,t) \bullet ((WF_j)_i / \sum_j (WF_j)_i)) \quad (5)$$

where $\overset{n}{MAX}_{i=1}$ is defined as the operator of selecting the maximum volume reduction if the on-ramp is located within more than one section's area of influence. $Q_{on}(j, t-1)$ is the entrance volume from on-ramp *j* during the past minute; $(WF_j)_i$ is the weighting factor of on-ramp *j* within the area of influence for section *i*; $Q_{reduction}(i,t) \bullet ((WF_j)_i / \sum_j (WF_j)_i)$ is the volume reduction of on-ramp *j* because of section *i*.

The more restrictive of the local rate and the system rate will be selected for further adjustments, including queue adjustment, ramp volume adjustment and advanced queue override. The queue adjustment and advanced queue override are used for preventing traffic spillback onto arterials. Ramp volume adjustment copes with the condition that more vehicles have entered the freeway compared to the number of vehicles assumed to enter, which may be caused by HOV traffic or HOV lane violators. The metering rate to be finally implemented should be within the range of the pre-specified minimum and maximum metering rates.

8.2 Plugin implementation

Figure 6.1 illustrates the hierarchical development framework of advanced ramp-metering algorithm plugins in PARAMICS. In the framework, the advanced ramp-metering algorithm plugin is built on top of two basic plugin modules, i.e., ramp metering controller and loop data aggregator.

The control logic of the BOTTLENECK algorithm plugin is implemented as the following pseudo codes:

1. Communicating with ramp metering API and loop data aggregator API in order to obtain up-to-date traffic information and historical metering rates.
2. Calculating and then checking if the two conditions are met. If they are met, the system metering rate and local metering rate are calculated and the most restrictive one is selected for further adjustment. Otherwise, the local metering rate is selected for further adjustment.
3. Metering rate restriction
4. Checking if the queuing strategy needs to be activated.
5. HOV adjustment
6. Sending its computed metering rate to the ramp metering API for implementation.

8.3 Step-by-step user manual

8.3.1 Adding detectors

BOTTLENECK needs to put mainline detectors at the spacing of 0.5 to 1.0 mile to the target freeway in order to capture the traffic congestion dynamics. As a result, the freeway segment under control is divided into several sections, each of which is defined by the stretch of freeway between two adjacent mainline detector stations.

8.3.2 Preparation of "bottleneck_control" file

The "bottleneck_control" file includes all necessary information required by the BOTTLENECK API. Some of inputs should be calibrated based on the modeled network before implementation. An example of the file is as follows:

```
total number of bottleneck controlled sections is 13
checking control file                       no
update cycle of metering rate               30
time period to accumulate detector data     60
algorithm activation time                   07:00:00
algorithm deactivation time                 09:00:00
report metering rate                        yes
local algorithm                             ALINEA

section                     1
upstream loop               405n0.93ml
downstream loop             405n1.11ml
number of influenced ramps  1
ramps                       33
reduction factors           1.0
number of onramps           1
onramp loops                405n0.93ora
number of offramps          0
offramp loops
number of unmetered ramps   0
unmetered ramp loops
desired downstream occupancy        0.20

…

section                     13
upstream loop               405n5.74ml
downstream loop             405n6.21ml
```

```
number of influenced ramps   2
ramps                        95 92
reduction factors            0.37 0.63
number of onramps            1
onramp loops                 405n5.74ora
number of offramps           0
offramp loops
number of unmetered ramps    0
unmetered ramp loops
desired downstream occupancy         0.20

total number of entrance ramps is 7

ramp                         33
mainline detector            405n0.93ml
queue detector               405n0.93orspill
on-ramp detector             405n0.93orb
HOV                          0
control type                 1
rate restriction             240 900
desired occupancy            0.20
regulator                    70.0
metering level
occupancy threshold
metering cycle
…
```

There are three parts of this control file. The first part is the basic information of the BOTTLEENECK algorithm.

The option of "checking control file" is used for checking if there are any mistakes in the control file. If "yes", this API will print out the information obtained from "bottleneck_control" file when this API is loaded.

"update cycle of metering rate" is the time interval of metering rate calculation.

The option "time period to accumulate detector data" determines if more than one observation of loop data will be used for metering rate calculation. For example, if "time period to accumulate detector data" is 60 and "metering rate update cycle" is 30, the loop data at time interval t-1 and t-2 will be accumulated first and then used for calculating the metering rate at time t. The value of "time period to accumulate detector data" must be integer times of the value of "metering rate update cycle".

During the time period between "algorithm activation time" and "algorithm deactivation time", the ramp-metering algorithm is functional.

If “report metering rate” is yes, the metering information of all BOTTLENECK controlled ramps will be output (every update cycle) to a file named “BOTTLENECK-rampRate.txt”.

The current applied “local algorithm” should be also specified. The local algorithms can be either OCCUPANCY_CONTROL or ALINEA (Therefore, ALINEA algorithm has been integrated in this API).

The second part is the section information. “upstream loop” and “downstream loop” are the names of upstream and downstream loop detectors.

“number of influenced ramps” is the number of on-ramps in the area of influence of this section. “ramps” is the node name of influenced on-ramps. If there is more than one on-ramp, please use a space between any two on-ramp names.

“reduction factors” is the correspondent reduction factors of on-ramps specified in the last row. “number of onramps” is the number of on-ramp in the section. If there is more than one on-ramp in the section, their names should be specified in the row of “onramp loops”. If there is no on-ramp in the section, please leave blank nothing in the row of “onramp loops”.

“number of offramps” is the number of off-ramps in the section. If there is more than one off-ramp in the section, their names should be specified in the row of “offramp loops”. Otherwise, leave blank nothing. “number of unmetered ramps” is the number of un-metered on-ramps in the section. If there is more than one un-metered on-ramp in the section, their names should be specified in the row of “unmetered ramp loops”. Otherwise, leave blank.

“desired downstream occupancy” is the occupancy threshold of the downstream loop detector station.

The third part of the file is the entrance ramp part. If a queue detector is specified, the queuing strategy is involved in BOTTLENECK (queuing strategy is required by BOTTLENECK). If there is no queue detector or no queuing strategy involved in ramp metering, please specify as “N/A”. If the specified detector cannot be found in the “detectors” file, a warning message will be given and the entrance ramp will be operated without any queue strategy.

If ALINEA is specified as the local algorithm in the first part of the file, please fill in the rows of “desired occupancy” and “regulator” and leave rows of “metering level”, “occupancy threshold” and “metering cycle” blank. If CCUPANCY_CONTROL is the local algorithm, please fill in the rows of “metering level”, “occupancy threshold” and “metering cycle” and leave rows of “desired occupancy” and “regulator” blank.

The following is an example of the use of OCCUPANCY_CONTROL as the local algorithm. The example of the use of ALINEA_CONTROL as the local algorithm is shown in last example.

…

local algorithm	OCCUPANCY_CONTROL

…

total number of entrance ramps is 7

ramp	33
mainline detector	405n0.93ml
queue detector	405n0.93orspill
on-ramp detector	405n0.93orb
HOV	0
control type	1
rate restriction	240 900
desired occupancy	
regulator	
metering level	6
occupancy threshold	0.15 0.17 0.20 0.25 0.40
metering cycle	4.0 5.0 7.0 9.0 12.0 15.0

…

8.3.3 Loading plugin

This plugin has two files:

bottleneck.dll: Modeller Plugin
bottleneck-p.dll: Processor Plugin

The BOTTLENCK plugin depends on other two plugins, ramp metering control and loop data aggregator. These two plugins should be specified earlier than this plugin in the "plugins" or "programming" file, i.e.:

loop_agg.dll
ramp_controller.dll
bottleneck_controller.dll

If you want to implement BOTTLENCK with another queue override strategy, which can be implemented by the on-ramp queue control plugin, you will need to leave the "queue detector" line in the "bottleneck_control" file blank (which disables the internal queue

override strategy of BOTTLENCK). Then you will need to add on-ramp queue control plugin to the "plugins" or "programming" file with the following sequence in order to give the on-ramp queue control strategy higher priority than BOTTLENCK.

loop_agg.dll
ramp_controller.dll
queue_control.dll
bottleneck_controller.dll

In addition, in order to correctly load and run this plugin, please satisfy the following requirements:

(1) For ramp metering control plugin: on-ramp signals controlled by the BOTTLENCK algorithm should be specified in the "ramp_control" file. For example, the correspondent on-ramp signal 33 needs to be specified in the "ramp_control" file:

on-ramp signal	33
name	405N & ICD 1 @ 0.93
demand detector	405n0.93orb
number of control plans	2
from 6:0 to 9:0	METER_ON with 1 veh per 6 sec
from 15:0 to 19:0	METER_ON with 1 veh per 6 sec

(2) For the loop data aggregator plugin: all loops involved in the "bottleneck_control" file should be specified in the "loop_control" file for aggregated data collection. In addition, the "report cycle" in the "loop_control" file should be the same as the "metering rate update interval" specified in the second row of "bottleneck_control" file. For example, all relevant loops of ramp 33 needs to be specified in the "loop_control" file:

detector count	42
report cycle	**30**
activation time	06:00:00
deactivation time	10:00:00
gather smoothed data	no
output to files	yes

…

name 405n0.93ml
gather interval 00:00:30

name 405n0.93orb
gather interval 00:00:30
…

8.3.4 Output file

If "report metering rate" in the "bottleneck_control" file is specified as "yes", the metering information of all BOTTLENECK controlled ramps will be output (every update cycle) to a file named "moe-BOTTLENECK.txt". It can be found in the subdirectory:

network/Log/run-xxx

where network is the name of the current working directory, and xxx is a three-digit sequence number.

8.3.5 Error checking

If there is any mistake in the "bottleneck_control" file or the input files of the two supporting plugins, i.e. loop data aggregator and ramp metering control, this plugin will be disabled. The report window of PARAMICS will show whether this plugin works.

Through enabling the option: "checking control file" in the "bottleneck_control" file, you can check if there is any error in the "bottleneck_control" file.

8.4 Technical Supports

8.4.1 Calibration of BOTTLENECK algorithm

Basically, the calibration of the BOTTLENECK algorithm involves five aspects:

(1) Calibration of local algorithm. If ALINEA is used, its calibration requirements have been described in Section 6; if occupancy control is used, its calibration involves the analysis the allowed traffic flow from on-ramps and mainline occupancy based on a plot of historical volume-occupancy data collected at its correspondent mainline loop detector station;

(2) Defining each section in the study network, basically the stretch of freeway between two adjacent mainline loop detector stations. The typical spacing of two adjacent loop detector stations is ½ to 1 mile;

(3) Calibrating the threshold occupancy of the downstream detector station of each section based on the volume-occupancy diagram at the downstream loop detector station of each section. The typical threshold occupancy is the occupancy at capacity;

(4) Defining the area of influence of each section (including several upstream on-ramps that are responsible for the volume reduction), according to how far it is to the downstream detector station and the historical demand level of the on-ramp. A typical definition is that entrance ramps in the area of influence should be within a maximum distance of two miles to the location of the downstream detector of the section;

(5) Defining the weighting factor of each on-ramp in the area of influence of each section, based on historical demands pattern.

8.4.2 References

Jacobsen, L., Henry, K., and Mahyar, O. (1989). "Real-Time Metering Algorithm for Centralized Control." *Transp. Res. Rec*., 1232, 17-26.

9. SWARM Ramp metering control

The purpose of this plugin is to allow users to implement the System Wide Adaptive Ramp Metering System (SWARM) of Caltrans in the PARAMICS simulation environment. This plugin is developed based on source codes of SWARM, obtained from Caltrans.

9.1 Introduction

SWARM is a coordinated traffic responsive ramp metering operation strategy, which is developed as a component of the Advanced Transportation Management System (ATMS) at Traffic Management Center (TMC) by National Engineering Technologies' (NET) System. It has drawn wide interests because of the introduction of traffic flow forecasting in the algorithm. The initial field tests were attempted in the Field Operational Test (FOT) of an integrated corridor-level adaptive control system from fall 1994 through spring 1999 in the City of Irvine, California. The system is currently tested in the I-210 freeway within the Los Angeles transportation network.

The SWARM algorithm actually consists of two independent algorithms, SWARM 1 and SWARM 2. SWARM 1 is a forecasting and system-wide apportioning algorithm using a forecasting methodology. SWARM 2 includes two local traffic-responsive ramp metering algorithms, SWARM 2a and SWARM 2b. We provide a brief description of these three algorithms below. Details about them can be found in the listed references.

9.1.1 SWARM 1

SWARM 1 forecasts the traffic state at predetermined problem points (bottlenecks), and adjusts metering rates based on forecasts. It treats the freeway network as sections. Each section is defined as the two adjacent detectors that have reliable data outputs. The operation of SWARM 1 is based on traffic density, with the goal of maintaining real-time density below a pre-determined saturation density for each section of freeway. The linear regression and a Kalman filtering process are applied to pass detector data to forecast a density trend at each detector location for each control interval.

The time into the future to forecast is a tunable parameter named *Tcrit*. Once the forecast density trend is obtained, it can be combined with *Tcrit* to calculate the excess density (the portion above the saturation density in the following Figure 1). Excess density is used to calculate the target density for the next metering cycle:

*Target Density = (Current Density) - (1/Tcrit) * (Excess Density)*

Then the volume reduction at each detector is:

*Volume Reduction = (Local Density - Target Density) **

(Number of lanes) (Distance to next Station)*

These volume reduction values are then distributed to upstream ramps within the defined area of influence for each site using pre-defined weighting factors at each ramp based on ramp demand, queue storage capacity, etc. The most restrictive volume reduction is then utilized at each ramp location.

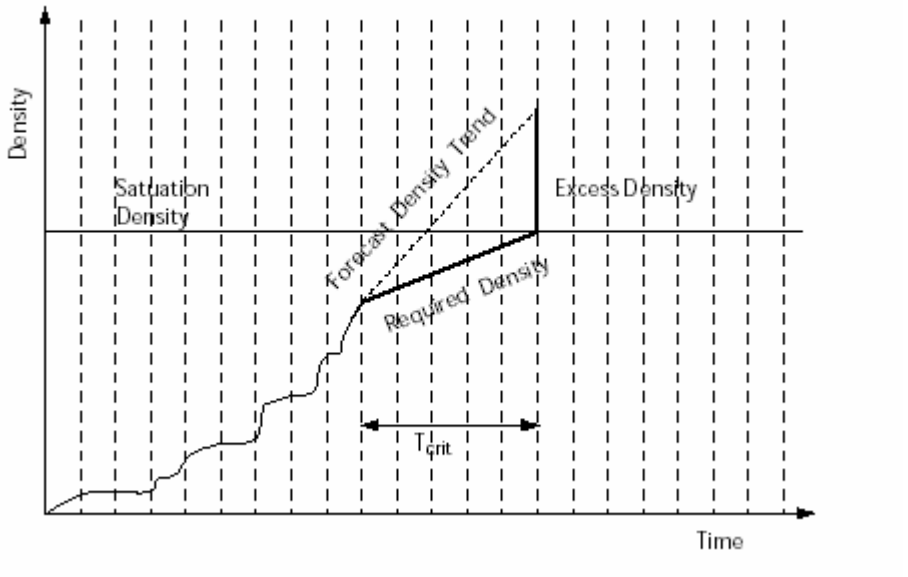


Figure 9.1 SWARM forecasting

9.1.2 SWARM 2

SWARM 2a uses a density function to compute local metering rates based on headway theory. Theoretically, it attempts to maintain headway at the detector station upstream of metered ramp by optimizing density to maintain maximum flow.

SWARM 2b introduces a concept of storage zone, which starts from the mainline upstream VDS to the next downstream mainline VDS. The number of vehicles storing within this storage zone will be calculated. Then, SWARM 2b computes metering rates to maintain demand such that LOS D as along as possible. If there are on-ramps and off-ramps between the two VDSs, detectors are required to be placed at on-ramps and off-ramps for counting traffic volumes. This algorithm depends on accurate loop detector data.

9.2 Plugin implementation

Based on the algorithm logic of SWARM and the hierarchical development framework for advaced ramp metering algorithms shown in Figure 6.2, we developed the SWARM plugin with the following pseudo codes:

```
Loop data polling time (i.e. the time to update metering rate)?
{
        Calculate loop station statistics
        {
                For mainline VDS
                {
                        Get aggregated loop data from the loop aggregator plugin
                        Calculate normalized station density / occupancy, speed
                        Calculate the average vehicle length
                }
                For ramp VDS
                        Get aggregated loop data from loop aggregator plugin
        }
        Query the current time-of-day metering rate from ramp metering plugin
        Query the current default rate control
        Query the current minimum rate control
        Check the status of loop detector station at known bottlenecks
        {
                If bad, search for a good upstream loop detector station to replace it
        }
        Calculate / update saturation density
        {
                For each mainline VDS
                {
                        Collect enough VDS data in one day
                        If (enough VDS data = SAMPLE_SIZE_SAT_DENSITY)
                                Calculate the saturation density for the VDS
                }
        }
        SWARM 2a
        {
                For each on-ramp
                (Starting from the furthest downstream ramp on the freeway)
                {
                        Calculate station speed at upstream loop station (ft/sec)
                        Calculate time headway from upstream loop to downstream loop
                        Calculate the speed reduction per mile
                        Calculate the desired metering rate
                        Minimum rate control
                        Maximum rate control
                        Rate smoothing
                        Startup/shutdown strategy
                }
        }
        SWARM 2b
```

```
{
        For each on ramp on freeway
        (Starting from the furthest downstream ramp on the freeway)
        {
                Calculate estimated storage in the storage zone based on density
                values of upstream and downstream loop stations
                Calculate volume change of the storage zone
                Calculate cumulative storage
                Calculate storage within a zone
                Calculate critical storage
                Calculate maximum available capacity
                Calculate desired available capacity
                Calculate metering rate for this ramp
                Minimum rate control
                Maximum rate control
                Rate smoothing
                Startup/shutdown strategy
}
Kalman Filtering
{
        For each bottleneck ramp
        {
                Update observations
                Time update
                Measurement update
                Forecast the density ahead of time (FORECAST_LEAD_TIME).
        }
}
Determine local_max as the upper limit of calculation of SWARM_1 rate
(Based on the metering mode, such as SWARM_2A_2B)
Traffic apportionment ()
{
        If (excess volume at a bottleneck)
                Assign desired reduced traffic to related meters
        Calculate metering rate for related meters
        Minimum rate control
        Maximum rate control
        Rate smoothing
        Startup/shutdown strategy
}
Check SWARM's start_up_strategy
Find the metering rate based on SWARM's metering mode
Queue control is required?
Implement new metering rate to meters through ramp metering plugin
}
```

9.3 Step-by-step user manual

The SWARM plugin has three input files:

(1) "swarm_global", containing global parameters of SWARM.
(2) "vds_control", containing information of network, detector stations, and bottlenecks.
(3) "swarm_control", containing the initial setup of SWARM to the target network.

Unlike the parser system of PARAMICS, which allows flexible grammars, the formats of these input files are rigid and thus any problem may cause that the SWARM plugin cannot be loaded. As a result, we hope users can use the example input files we provide with this plugin as the starting point to make your own input files for avoiding editing problems.

In order to correctly use this plugin in a target network, the "infrastructure layout" of the target freeway network needs to be obtained from the proper government agency, such as Caltrans. The "infrastructure layout" includes the number of lanes and locations of loop detector stations. This layout is also the basic information required for network coding in PARAMICS. An example of this "infrastructure layout" can be found in APPENDIX 1.

9.3.1 Adding detectors

1. Real world ramp metering system

The configuration of a typical ramp metering system in California is shown in Figure 9.2.

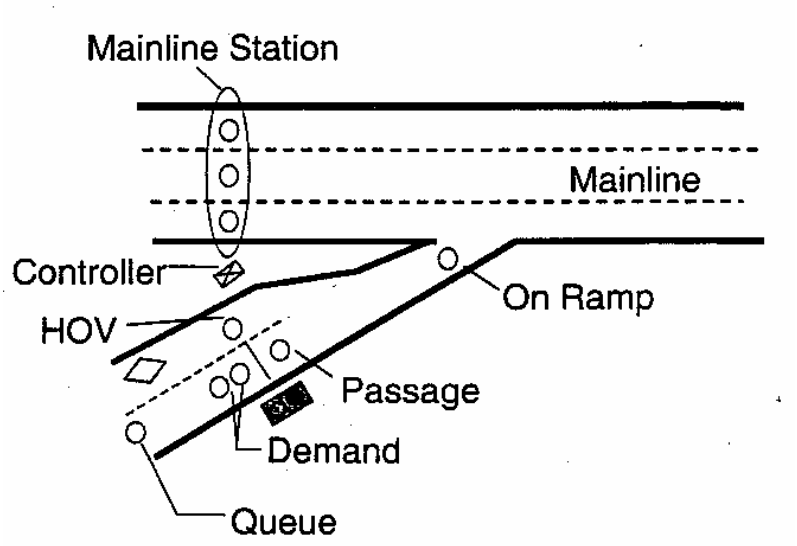


Figure 9.2 Typical ramp metering configuration

Five types detectors can be possibly installed for a ramp meter, including on-ramp detector, demand detector, passage detector, queue detector, and ramp HOV detector. The on-ramp detector is used for counting total number of vehicles entering freeway from entrance ramps. The demand and passage detectors (i.e. corresponding to the check-in and check-out detectors) are used for the operation of on-ramp signals. The demand detector employs to initiate green and the passage detector employs to return the signal to red. The queue detector is located at the upstream end of the entrance ramp, used for detecting the excessive queue length in order to avoid interference with the arterial traffic. The ramp HOV detector is used for counting the number of carpool vehicles entering freeway from entrance ramps.

Caltrans currently has three ramp metering systems, SATMS, SDRMS, and SJRMS / TOS. All of them use the 170 type controllers as hardware. SATMS, SDRMS, and SJRMS / TOS are names of their software algorithms installed in the 170 controllers.

The SWARM algorithm is designed for the ramp metering system of SATMS, used in District 7 and 12. The local controller and its ramp metering software of SATMS support centralized metering control, i.e. the application of the requested metering rate from TMC.

2 Detectors required for this plugin

The demand detector has been used in the ramp metering control plugin, which is a supporting module of the SWARM plugin. The ramp metering control plugin acts like the local controller in the real world.

In order to make this plugin work, three additional detectors or detector stations are required to be put to the simulation network. They are the on-ramp detector, queue detector, and the mainline (detector) station, shown in Figure 9.2.

If your simulated network in the real world does not have the required detector configuration for the SWARM control, please add demand detector, on-ramp detector, mainline detector, and queue detector to the simulation network based on Figure 9.2 in order to correctly use this plugin.

9.3.2 Preparation of “swarm_global”

SWARM has several global parameters. They are defined in the “swarm_global” file. Totally, there are 27 parameters.

The first part of this file is about loop data acquisition. Please see Section 2.6 of reference 1 for more detailed description. The value shown on the leftmost side of each line is actually the recommended value.

```
25.0 "Ave_veh_length for the right lane (10.0 - 30.0)" range 10.0 to 30.0 precision 1
22.0 "Ave_veh_length for the 2nd right lane (10.0 - 30.0)" range 10.0 to 30.0 precision 1
18.0 "Ave_veh_length for other ML and HOV lanes (10.0 - 30.0)" range 10.0 to 30.0 precision 1
```

9.0 "Absolute maximum effective loop length (6.0 - 10.0)" range 6.0 to 10.0 precision 1
9 "Volume threshold to compute a new effective loop length (4 - 14)" range 4 to 14 precision 0
3.0 "Absolute minimum effective loop length (2.0 - 6.0)" range 2.0 to 6.0 precision 1
55 "Speed threshold to compute a new effective loop length (50 - 90)" range 50 to 90 precision 0
0.02 "Smoothing factor for the effective loop length (0.0 - 1.0)" range 0.0 to 1.0 precision 2
65.0 "Free speed (55.0 - 85.0)" range 55.0 to 85.0 precision 1

The second part includes parameters used for the calculation of the saturation density for each loop station.

2200 "Maximum hourly lane volume (1800 - 2500)" range 1800 to 2500 precision 0
200 "Sample size required to compute saturation density (6 - 1200)" range 6 to 1200 precision 0
0.05 "Smoothing factor for saturation density computation (0.0 - 1.0)" range 0.0 to 1.0 precision 2

The third part includes parameters of Kalman filtering used in the SWARM 1 algorithm.

1 "Max number of VDSs to search if bottleneck VDS is failed (1 - 4)" range 1 to 4 precision 0
30 "Number of previous time intervals used for the forecast (2 - 60)" range 2 to 60 precision 0
6 "Number of points used to estimate slope for Kalman filter (2 - 9)" range 2 to 9 precision 0
30 "Number of time intervals into the future to forecast (1 - 60)" range 1 to 60 precision 0
0.04 "Variation in the accuracy of the density measurements (0.02 - 0.5)" range 0.02 to 0.5 precision 2
1.0 "Variance representing the inaccuracy of the model (0.5 - 10)" range 0.5 to 10 precision 1

The fourth part includes parameters of apportionment algorithm used in the SWARM 1 algorithm.

1.0 "Fraction of excess traffic to propagate within a section (0.0 - 1.0)" range 0.0 to 1.0 precision 1
0.85 "Fraction of excess traffic to propagate between sections (0.0 - 1.0)" range 0.0 to 1.0 precision 1

The fifth part includes parameters of the SWARM 2a algorithm.

1.0 "Target speed reduction (0.1 - 20.0)" range 0.1 to 20.0 precision 1

The sixth part includes parameters of the SWARM 2b algorithm.

0.1 "Smoothing factor for the final storage computation (0.0 - 1.0)" range 0.0 to 1.0 precision 2
0.85 "Fraction of saturation density equivalent to LOS D (0.0 - 1.0)" range 0.0 to 1.0 precision 2

The seventh part includes parameters of Phase 2 failure management, used to decide if the detector data at a detector station can be used in SWARM.

0.66 "Fraction of good lanes required for station statistics (0.0 - 1.0)" range 0.0 to 1.0 precision 2

The eighth part includes parameters of the startup and shutdown strategy.

6 "Start metering counter (1 - 20)" range 1 to 20 precision 0
20 "Stop metering counter (1 - 30)" range 1 to 30 precision 0

The parameter in the last part is not a parameter of the real-world SWARM, but a parameter of the SWARM in the simulation world.

```
1    "Using speed estimation (0) or PARAMICS speed(1) (0 - 1)" range 0 to 1 precision 0
```

These parameters are universal parameters used in SWARM. If you want to know more about the functionality of any a parameter in SWARM, please find related information from the references listed at the end of this document.

9.3.3 Preparation of "vds_control"

"vds_control" includes the information of loop detector stations in the simulation network. The format of this file is:

```
number of freeways    1
polling cycle         30

number of mainline detectors 9
405n5.74ml    405    N    N    5.74    5    45    yes
405n5.55ml    405    N    N    5.55    4    45    no
…
number of off-ramp detectors 5
405n5.55fr    405    N    N    5.55
…
```

There are three parts in "vds_control". The first part includes the general information, i.e. the number of freeways and the loop detector aggregation cycle, i.e., "polling cycle". "polling cycle" should be the same as "report cycle" in the "loop_control" file, and "metering rate update interval" in the "swarm_control" file.

The format for mainline detectors is

Freeway ID, direction, pri-direction, loop name, post-mile, number of lanes, saturation density, whether this loop station is a bottleneck

The format for off-ramp detectors is:

Freeway ID, direction, pri-direction, loop name, post-mile

The VDSs listed in the "vds_control" file are ordered by freeway id, direction, from downstream to upstream. "direction" can be one of N, S, W, and E. "pri-direction" refers to the direction of post-mile, and thus can also be one of N, S, W, and E. For example, if the post-mile at downstream is higher than that at upstream, "pri-direction" is the same as

"direction". "saturation density" refers to the density of the loop detector station at capacity. It can be a value between 40-45. The SWARM plugin provides capabilities to calculate the saturation density of mainline detector station based on simulation results and report to an output file named "Log-sat_density". Since the network model may not be calibrated well, the saturation density calculated based on real world loop data might not be the same as that calculated based on simulation.

9.3.4 Preparation of "swarm_control"

This file includes the design of the SWARM algorithm to the target network.

```
total number of SWARM controlled ramps is   8
metering rate update interval          30
report metering rate                   yes

ramp                        92
freeway                     405
direction                   N
postmile                    5.74
mainline detector           405n5.74ml
upstream ramp               95  N/A  N/A  N/A
apportionment factor        1.0  0.0  0.0  0.0
onramp detector             405n5.74orb
queue detector              405n5.74orspill
HOV                         0
metering mode               SWARM_1
minimum rate control        ABS_MIN
default rate control        ABS_MAX
swarm startup strategy      RUN_SWARM_DURING_TOD_ONLY
rate restriction            6 30
…
```

The unit of the metering rate in "swarm_control" is veh/minute. The on-ramps (such as "92") listed in "swarm_control" are ordered by freeway id, direction, from downstream to upstream. The furthest downstream ramp on a freeway is input first.

"mainline detector" is the corresponding mainline detector of a "ramp". "postmile" can be obtained from Caltrans, which is a basic input of SWARM. In general, a ramp's postmile is the same as the postmile of the corresponding mainline detector of the ramp. "upstream ramp" and "apportionment factor" are used for metering rate apportionment, the second part of the SWARM 1 algorithm.

"metering mode" can be one of has the following: DISABLED_MODE, SWARM_1, SWARM_2A, SWARM_2B, SWARM_1_2B, SWARM_2A_2B, SWARM_1_2A, SWARM_1_2A_2B, LOCAL_TOD, and LOCAL_LMR.

All ramps should be included in “swarm_control”. If it is a freeway-to-freeway or unmetered ramp, the metering mode can be set as DISABLED_MODE.

“minimum rate control” is one of the following two: “TOD_TABLE_MIN”, “ABS_MIN”.

“default rate control” is one of “TOD_TABLE_DEFAULT” and “ABS_MAX”.

“swarm startup strategy” is one of “RUN_SWARM_ANYTIME” and “RUN_SWARM_DURING_TOD_ONLY”.

9.3.5 Loading plugin

The plugin files includes two files:

swarm.dll: Modeller Plugin
swarm-p.dll: Processor Plugin

The SWARM plugin depends on other two plugins, ramp metering control and loop data aggregator. These two plugins should be specified earlier than this plugin in the “plugins” or “programming” file, i.e.:

```
loop_agg.dll
ramp_controller.dll
swarm.dll
```

If you want to implement SWARM with a queue override strategy, you will need to disable the queue override strategy in the SWARM plugin through specifying queue detector as “N/A” in “swarm_control”. Then you need to add on-ramp queue control plugin to the “plugins” or “programming” file with the following sequence:

```
loop_agg.dll
ramp_controller.dll
queue_control.dll
swarm.dll
```

In addition, in order to correctly load and run this plugin, please satisfy the following requirements:

(1) For ramp metering plugin: on-ramp signals controlled by the SWARM algorithm should be specified in “ramp_control”. For example, if the on-ramp signal 33 is under SWARM control, on-ramp signal 33 also needs to be specified in “ramp_control” as the following format:

on-ramp signal	33
name	405N & ICD 1 @ 0.93
demand detector	405n0.93orb
number of control plans	2
from 6:0 to 9:0	METER_ON with 1 veh per 6 sec
from 15:0 to 19:0	METER_ON with 1 veh per 6 sec

If an on-ramp signal is specified in "swarm_control" but not in "ramp_control", this on-ramp signal will be regarded as a "METER_OFF" meter.

(2) For the loop data aggregator plugin: all detectors used by SWARM should be specified in "loop_control" for the aggregated data collection. In addition, the "metering rate update interval" specified in the second row of "swarm_control" must be the same as the "report cycle" in "loop_control".

9.3.6 Output files

Each simulation run will generate two output files, "Log_meteringRate" and "Log-sat_density". They can be found in the subdirectory:

network/Log/run-xxx

where network is the name of the current working directory, and xxx is a three-digit sequence number. The contents of these files are dynamically saved. Users can check the progress and condition of the SWARM control during the simulation process.

1. "Log_meteringRate"

"Log_meteringRate", used to record the metering rates of all on-ramps during operation with the interval of "metering rate update interval" defined in "swarm_control". For example,

RAMP#	92	95	76	73	65	56	36	33
07:25:30	1 0	1 0	6 0	3 0	3 0	1 0	1 0	1 0
07:26:00	1 0	1 0	5 0	3 0	3 0	1 0	1 0	1 0
07:26:30	1 0	1 0	6 0	4 0	3 0	1 0	1 0	1 0
07:27:00	1 0	1 0	7 0	5 0	3 0	1 0	1 0	1 0
07:27:30	1 0	1 0	6 0	4 0	3 0	1 0	1 0	1 0
07:28:00	1 0	1 0	15 1	3 0	3 0	1 0	1 0	1 0
07:28:30	1 0	1 0	15 1	3 0	3 0	1 0	1 0	1 0
07:29:00	1 0	1 0	15 1	3 0	3 0	1 0	1 0	1 0
07:29:30	1 0	1 0	10 0	3 0	3 0	1 0	1 0	1 0
07:30:00	1 0	1 0	10 0	15 1	3 0	1 0	1 0	1 0
07:30:30	1 0	1 0	15 0	15 1	4 0	1 0	1 0	1 0
07:31:00	1 0	1 0	15 0	15 0	3 0	1 0	1 0	28 0

07:31:30 1 0 1 0 15 0 15 0 15 1 1 0 1 0 30 0
07:32:00 1 0 1 0 15 0 15 0 15 1 1 0 1 0 30 0
07:32:30 1 0 1 0 10 0 10 0 15 1 1 0 1 0 30 0
…

For each on-ramp, there are a metering rate and a queue override flag outputs. The unit of the metering rate is vehicle per minute. If the value of the metering rate is 1, it means there is no metering at the on-ramp (or called greenball). The queue override flag can be a value of either "1" or "0". "1" represents that the metering at the on-ramp is under the default queue override strategy control. The default queue override strategy can be described as follows:

> If the occupancy value of the queue detector exceeds a threshold, i.e. 50%, the maximum metering rate will be applied to the corresponding meter in order to release more vehicles to freeway

The corresponding metering rate of the on-ramp will be the maximum rate defined in the "swarm_control".

2. "Log-sat_density"

"Log-sat_density", used to store the calculated saturation density at each mainline detector station. The following is an example of the resulting "Log-sat_density" file:

time 405n5.74ml 405n5.55ml 405n4.03ml 405n3.86ml 405n2.99ml 405n1.93ml 405n1.11ml 405n0.93ml 405n0.6ml
06:30:00 45 45 45 45 45 45 35 45 45

time vds_name old_sat new_sat smoothed_sat
08:13:30 405n0.93ml 45 45 45
08:15:00 405n2.99ml 45 44 45
08:16:30 405n4.03ml 45 52 45
08:17:00 405n3.86ml 45 45 45
08:19:30 405n1.93ml 45 47 45
08:28:00 405n1.11ml 35 34 35

There are two parts in "Log-sat_density". In the first part, the first row listed names of all mainline loop detector stations. The second row shows the saturation density values of these stations obtained from "vds_control".

The second part shows the calculated saturation densities of mainline detector stations. The "Sample size required to compute saturation density" is a user-specified variable ranging from 6 to 1200. Its default value is 200.

The second part has 5 columns, i.e., the time of calculation, name of detector station, original saturation density, calculated saturation density, and the smoothed saturation

density. The calculation of the smoothed saturation density uses a parameter, i.e. "Smoothing factor for saturation density computation", defined in the second part of "swarm_global". The default value of this parameter is 0.05.

$$smoothed\_sat = old\_sat * (1 - \alpha) + new\_sat * \alpha$$

If you do not know the saturation density at a detector station, we strongly recommend users to use the first simulation run to calculate saturation density values at all detector stations. The value shown in the column of "new_sat" is a good value of the saturation density because it does not involve the use of the smoothing factor. Then you can update the saturation density values in "vds_control".

For a following simulation run, the saturation density values shown in "vds_control" are applied before enough data are collected for the calculation of new saturation density values. If a new saturation density is calculated, the smoothed saturation density will be applied instead of the value shown in "vds_control".

As a result, the first simulation run will help users know what the saturation density is at mainline detector stations. In order to update an inaccurate saturation density, users need to edit the "vds_control" file manually.

9.3.7 Error checking

Under network directory, a file named "Log-swarm.txt" is generated for storing all temporary calculations and outputs of SWARM control. This file employs two purposes:

(1) It can be used to check if there is any problem in the "global_control", "vds_control", and "swarm_control" files.

(2) It can be used to check if SWARM is operated as expected or if the implementation of SWARM in the target network is proper. At each time step, the detailed metering rate calculations (including SWARM 2a, SWARM 2b, SWARM 1) are recorded.

Since this file is saved to the network directory, the file is generated based on the latest simulation run.

9.3.8 Fine-tuning parameters of SWARM

There are many parameters in SWARM. During the testing process, users can modify all parameters. A parameter or the combination of a set of parameters may be appropriate for a network, but may not be appropriate for another network.

Some performance measures are needed to fine-tune parameters of SWARM. Users can use the "measurements" file to collect statistical data or use the freeway MOE plugin we developed to collect these measures.

The saturation density is an important parameter of SWARM. The goodness of this parameter affects the performance of SWARM. Users can start the first simulation run with the SWARM control with a series of assumed saturation values. Then you can check the "Log-sat_density" file under Log directory, which is used to record the saturation density values of all mainline loop detector stations in the network, calculated based on the second degree polynomial method. The value in the column of "new_sat" might be a better value of saturation density that can be used to replace your assumed values.

9.4 Technical Supports

9.4.1 Limitations of this plugin

1. Failure management

SWARM in the real world considers the situation that loop detector data are missing or deficient. However, in the simulation world, detector data are obtained based on another plugin module, loop data aggregator, which provides aggregated detector data as accurately as possible.

As a result, this developed SWARM plugin works with good loop detector data all the time. The failure management part of SWARM never has chance to be used.

2. Queuing strategies

Based on the design document of SWARM, the central SWARM system will have four options about queuing control:

(1) Use local controller strategy, i.e., when a queue is detected, go to maximum rate
(2) Gradually increase rate to maximum
(3) Ignore queuing for a fixed number of periods then switch to gradual rate increase
(4) Totally ignore queuing

However, the source code shows that there are only two options, using the local strategy and disable queue strategy. See the following for reference.

```
typedef enum RMS_queue_strat
{
  QUEUE_STRAT_UNKNOWN = 0,
  DISABLED_QUEUE_STRATEGY,
  LOCAL_CONTROLLER
} RMS  queue  strat  enum;
```

In the Traffic Engineer's manual of District 7, there is another description of queuing strategy. "Local queuing strategies, such as forcing maximum rates when a queue is detected, affect SWARM 1 operations. The final SWARM 1 metering rate will have a lower bound equal to the rate selected by the queuing strategy. The difference between the forced rate (due to local queuing strategies) and the desired SWARM 1 rate will be propagated by SWARM (apportionment) to upstream metered ramps." Therefore, we can judge that the earlier design of SWARM was not implemented. If this description is right, the queuing strategies should be operated before the calculation of SWARM 1 rate. However, we cannot find any code in the source code. As a result, we only implement the "local controller strategy" in this SWARM plugin.

3. Kalman filtering

The default forecast lead time is 15 minutes, or 30 intervals ahead. The number of points used to estimate density slope as input to the Kalman filter is 6. The accumulated density is used in Kalman filtering, which has a typical trend like the following:

```
29
60
87
119
150
…
```

However, the variation in the accuracy of the density measurements is 0.04 (allowed range is from 0.02 to 0.5); the variance representing the inaccuracy of the model is 1.0 (allowed range is from 0.5 to 10). We think these two default values need to be calibrated.

9.4.2 References

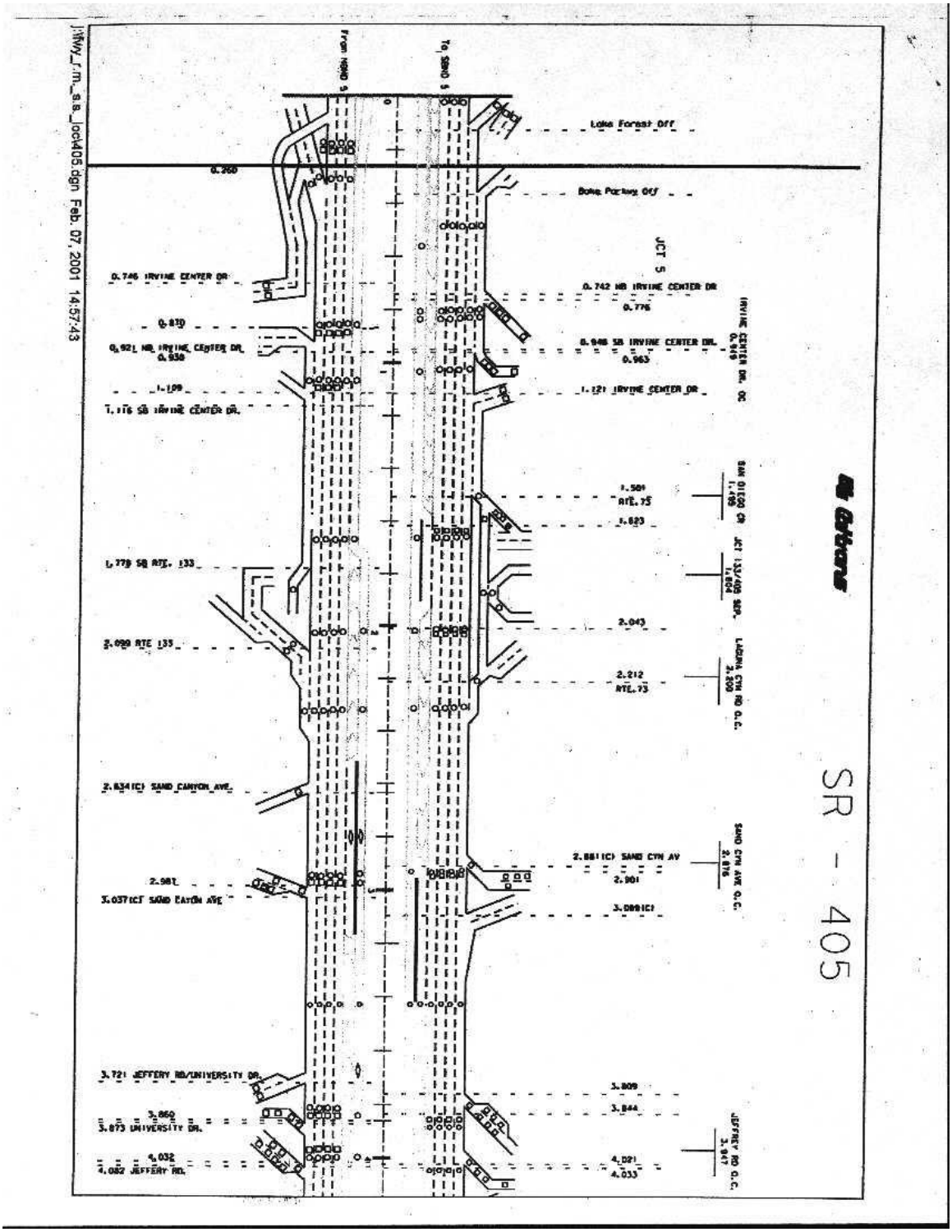
1. "Advanced Transportation Management System Traffic Engineer's Manual", Revision 1, Prepared by NET for Caltrans District 7, June 2000.

2. "Integrated Ramp Meter / Arterial Signal Control Project - Detailed Design: System Wide Adaptive Ramp Metering", Prepared by NET for FHWA FOT, City of Irvine, and Caltrans Distrct 12, August 30, 1996.

3. "System Wide Adaptive Ramp Metering - High Level Design", Final Draft, Prepared by NET for Caltrans and FHWA, June 19, 1996.

9.5 APPENDIX

An example of the “infrastructure layout” obtained from Caltrans



10. Freeway MOE

10.1 Introduction

This API plug-in can be used to collect the following two types of data:

- Point-to-point travel time between two loop detectors along freeway
- On-ramp delay

10.2 Step-by-step user manual

10.2.1 Preparation of the "moe_freeway_control" file

The name of the input file of this API plug-in is "moe_freeway_control", which should be placed to the network directory. The format of this input file can be demonstrated through an example of the file shown below.

```
number of sections          3
checking control file       yes
report cycle                300
collection start time       06:00:00
collection end time         10:00:00

loop detectors              405n0.93ml 405n5.55ml
links                       2:3 12:16
sample rate                 10
destination zone            2
entrance ramp               no

loop detectors              405n0.93orspill 405n0.93ora
links                       426:524 33:34
sample rate                 50
destination zone            2
entrance ramp               yes

…
```

There are two parts in "moe_freeway_control". The first part is the global options that need to be specified for the API plug-in. "number of sections" is the number of sections that needs to perform a travel time related data collection. The option of "checking control file" is used for checking if there are any mistakes in the control file. If "yes", this

API plug-in will print out the information obtained from “moe_freeway_control” file when the API plug-in is loaded. The data collection interval is specified as “report cycle”. Its unit is second. For example, if the report cycle is 300 seconds, it means all collected data will be output once every 300 seconds. “collection start time” and “collection end time” are the time period that data are collected.

The second parts are used to input the information of each section. There are two sections in the example. The first one is an example of the point-to-point travel time collection. Two loop detectors are the boundaries of a section. The names of them are specified on the line of “loop detectors”. The first detector is located at the upstream of freeway and the second one is located at the downstream. The links where these two loop detectors are located also need be specified on the line of “links”. Since there will be many vehicles passing through a section, if all of them are traced in order to get travel time / delay information, it will take a lot of computation time. As a solution, users can specify the percentage of passing vehicles on the line of “sample rate”. In order to make sure that all vehicles that are traced at the first loop detector station will pass the second loop detector station, users need to specify the destination zone of passing vehicles. The zone should be located at the downstream end of the freeway on the line “destination zone”. If there are not many vehicles heading for the end of the freeway, users can specify another zone, which should be located at the downstream side of the second loop detector station. Since the current section is a freeway section, it is not located on the entrance ramp, “entrance ramp” is “no”.

The second one is an example of the on-ramp delay collection. The loop detectors specified here should be located on the entrance ramp. The first detector is the queue detector. The second detector is located at the link beyond the on-ramp signal. Figure 9.2 shows the typical loop detector configuration at an on-ramp. For the current section, “entrance ramp” is “yes”.

10.2.2 Loading plugin

This plugin has two files:

freeway_moe.dll: Modeller Plugin
freeway_moe-p.dll: Processor Plugin

After the completion of the “moe_freeway_control” file, you can load the simulation network together with this plugin. Run simulation and then you will see that this plugin generate output files continuously.

10.2.3 Output file

The name of the output file of this plugin is “moe-freeway.txt”. It can be found in the subdirectory:

network/Log/run-xxx

where network is the name of the current working directory, and xxx is a three-digit sequence number.

The format of the output file is as follows.

405n0.93ml-405n5.55ml

time	vol	mean-tt	tt-std	spd	spd-std	delay	tot-delay
06:05:00	9	248.0	17.9	68.9	5.0	0.0	0.0
06:10:00	75	249.0	18.1	68.7	4.9	0.0	0.0
06:15:00	72	250.6	16.4	68.2	4.4	0.0	0.0
06:20:00	76	254.8	20.7	67.2	5.5	0.0	0.0
…							

Where “time” is the report time, which is the end time of a collection period. “vol" is the number of vehicles having been traced in last collection period. “mean-tt” and “tt-std”are the average travel time and its standard deviation of all traced vehicles in a time period. Accordingly, “spd” and “spd_std” are the travel speed and its standard deviation of all traced vehicles. “delay” is defined as the difference between actual travel time and ideal travel time calculated based on the speed limit of freeway sections. If the actual travel time is higher than the ideal travel time, “delay” will be a value larger than 0; otherwise, “delay” is 0. “tot_delay” will be calculated if “delay” is higher than 0. “tot_delay” represents the total delay experienced by all traced vehicles.

“delay and ”“tot_delay” are estimated based on “mean_tt” and the ideal travel time. They may be larger than 0 although “spd” (average speed) is higher than the speed limit of the corresponding section. The reason is that “spd” is equal to the average speed of all traced vehicles while “mean_tt” is equal to the average travel time of all traced vehicles. The value of “spd” times “mean_tt” is not exactly equal to the length of two measurement points.

10.2.4 Error checking

If any mistakes happened in the “moe_freeway_control” file, this plugin will be disabled. The report window of PARAMICS will show whether this plugin is working. Through enabling the option: “checking control file” in the “moe_freeway_control” file, you can check if there is any error in the “moe_freeway_control” file.

10.3 PROGRAMMER capabilities

An interface function has been provided by this plugin for external modules to acquire the point to point travel time between two loop detectors. The prototype of the interface function is as follows:

PROBE uci_probe_travel_time(char *up_loop, char *down_loop)
Function: Obtain travel time statistics between up_loop and down_loop.
Return Value: Average travel time and its variance
Parameters: *up_loop* and *down_loop* are names of the upstream loop detector and downstream loop detector.
PROBE is a data structure with the following format:

```
type PROBE
{
        int index;
        int time;
        int interval;
        int sampleRate;
        int num;
        float tt;
        float var;
}
```

where:
index is the ID of the travel time collection;
sampleRate is the sampling rate of the travel time collection;
interval is the report cycle of the travel time data collection;
num is the number of traced vehicles of the last report cycle;
tt is the average travel time between two loop stations;
var is the variance of all collected travel times.