

Project Title:

**Graphical User Interface Development for Coordinated
Ramp Metering System**

Final Report

UCB-ITS-PRR-2023-02

Contract Number: 65A0689, Task #3246

Project Team:

Dr. Xiao-Yun Lu – Principal Investigator and Technical Leader
Xi Cheng and John Spring

California PATH Program
Institute of Transportation Studies
University of California Berkeley
Richmond Field Station, Building 452
1357 S. 46th Street, Richmond, CA 94804-4648

September 15, 2023

DISCLAIMER STATEMENT

This document is disseminated in the interest of information exchange. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This publication does not constitute a standard, specification or regulation. This report does not constitute an endorsement by the Department of any product described herein.

For individuals with sensory disabilities, this document is available in alternate formats. For information, call (916) 654-8899, TTY 711, or write to California Department of Transportation, Division of Research, Innovation and System Information, MS-83, P.O. Box 942873, Sacramento, CA 94273-0001.

Project Panel

Kin Hung Yeung, kin.hung.yeung@dot.ca.gov, Caltrans District 3, Freeway Traffic Operation,
Tel: (530) 708-7102

Nelson Xiao, nelson.xiao@dot.ca.gov, Caltrans District 3, Freeway Traffic Operation,
Tel: (530) 682-6515

Jose Camacho, Jose.Camacho.Jr@dot.ca.gov, Caltrans HQ, Division of Research and
Innovation, Tel: (916) 387-5291

Nicholas Liccardo, Nicholas.Liccardo@dot.ca.gov, Caltrans District 3, Freeway Traffic
Operation,

Luis Munoz, Luis.Munoz@dot.ca.gov, Caltrans District 3, Freeway Traffic Operation,
Stephen Bandirola, Caltrans District 3, Freeway Traffic Operation,
Tel: (916) 859-7956, email: stephen_p_bandirola@dot.ca.gov

Leo Anselmo, Caltrans District 3, Freeway Traffic Operation,
Tel: (916) 859-7954, email: leo_anselmo@dot.ca.gov (retired)

Larry Hall, Caltrans District 3, Freeway Traffic Operation,
Tel: (916) 859-7955, email: larry_hall@dot.ca.gov

Bojana Gutierrez, Caltrans District 3 Freeway Operations,
Tel: (916) 859-7940, email: bojana.gutierrez@dot.ca.gov

Greg Larson, Caltrans HQ, Division of Research and Innovation,
Tel: (916) 657-4369, email: greg_larson@dot.ca.gov, (retired)

Zhongren Wang, Caltrans HQ, Traffic Operation, Tel: (916) 653-4575,
zhongren.wang@dot.ca.gov, (retired),

Gurprit Hansra, Caltrans HQ, Division of Research and Innovation,
Tel: (916) 654-7252, email: gurprit_hansra@dot.ca.gov, (retired)

Hassan Aboukhadijeh, *Project Manager*, Caltrans Division of Research and Innovation,
Tel: (916) 654-8630, email: hassan_aboukhadijeh@dot.ca.gov, (retired)

James Anderson, Caltrans HQ Division of Traffic Ops
Tel: (916) , email: james.r.anderson@dot.ca.gov

Terry Thompson, Caltrans HQ Division of Traffic Ops
Tel: (916), email: terry.thompson@dot.ca.gov;

Xiao-Yun Lu, PATH, University of California, Berkeley,
Tel: (510) 665-3644, email: xylu@path.berkeley.edu

John Spring, PATH, University of California, Berkeley,
Tel: (510) 665-3575, email: jspring@path.berkeley.edu

Key Words: Coordinated Ramp Metering (CRM), Graphical User Interface (GUI)

Abstract

This report documents the Graphical User Interface (GUI) development of Coordinated Ramp Metering (CRM). CRM algorithm was developed, implemented, and tested on SR 99 North Bound under Caltrans DRISI support projects [1, 2]. Local responsive Ramp Metering (LRM) designed and implemented to the immediate upstream loop detector occupancy in the way that if the occupancy is over the critical occupancy which indicated traffic congestion, then ramp metering rate would be low to release less vehicles into the mainline. The CRM algorithm is designed to coordinate the traffic of all sections and onramps to achieve system level optimization. Since the performance indicated positive impact on the traffic flow,

Disclaimer Statement

This document is disseminated in the interest of information exchange. The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This publication does not constitute a standard, specification or regulation. This report does not constitute an endorsement by the Department of any product described herein.

For individuals with sensory disabilities, this document is available in Braille, large print, audiocassette, or compact disk. To obtain a copy of this document in one of these alternate formats, please contact: the Division of Research and Innovation, MS-83, California Department of Transportation, Division of Research, Innovation, and System Information, P.O. Box 942873, Sacramento, CA 94273-0001.

Acknowledgements

This work was performed by California Partners for Advanced Transportation Technology (PATH) at the University of California at Berkeley, in cooperation with the California Department of Transportation (Caltrans), Division of Research & Innovation and System Information (DRISI) through the Interagency Agreement under Contract Number: 65A0682. The contents of this report reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California.

Executive Summary

This report documents the work conducted under the California Department of Transportation (Caltrans) Project 65A0689 entitled “*Graphical User Interface Having have development for Coordinated Ramp Metering System*”.

The project was sponsored by Caltrans and undertaken by the California Partners for Advanced Transportation Technology (PATH), of the University of California, Berkeley. The project duration was 24 months from 6/30/2018 to 6/29/2020. The project was delayed partially due to COVID-19 and partially due to several pavement project along the corridor which damaged the traffic detector stations.

The project includes the following stages:

- Overall system design
- Operating system selection
- GUI modules design and development
- Interactive presentation to and discussion with Caltrans District 3 Freeway traffic engineers
- System refinement
- GUI tool validation on SR-99 NB by comparing with the previous code implemented
- Preparation User’s Manual
- Training Caltrans District 3 traffic engineers

In this project, we have developed a Graphical User Interface (GUI) for the Coordinated Ramp Metering (CRM) algorithm which was developed and tested in a previous on SR 99 North Bound (NB) corridor near the US50 interchange in a previous Caltrans project. In particular, this project has developed several modules to enable Caltrans freeway traffic engineers to use the GUI for Coordinated Ramp Metering (CRM) control for a give freeway corridor. Those modules include: freeway corridor modeling, traffic detector data mapping, traffic state parameter estimation, control parameter tuning, CRM activation or deactivation for an onramp, output and display traffic state parameters, ramp metering rate and VSL at each sign location. and fault detection and warning. After system integration, the developed CRM GUI tool would be used for validation on SR 99 NB and US 50 East Bound corridors. The PATH project team has also trained Caltrans District 3 traffic engineers so that they would be able to use the CRM GUI tool independently to other freeway corridors as long as the data is centralized and available in real-time.

GUI overall system design: we have designed the overall systems, modules and sub-modules, their functionalities and data flows. The design was summarized in a detailed report sent to Caltrans DRISI as a deliverable.

We have Generalized the research software code of the previous project [1, 2] to allow for arbitrary expansion of its database and algorithm calculations based on the needs of road geometry. A data manager starts up a set of operating system scripts (a set of commands to the Linux operating system, much like DOS batch files) that were written for starting up a ramp metering program for communicating with each controller in the field.

The data manager also starts up another set of scripts for polling the URMS programs for field data. Currently these data are written to log files, but they also have the ability to broadcast the data locally (within the PATH host) so other programs can pick up the data for display on the GUI.

The GUI itself is, for the present, a web-based tool which means that the user can work on it remotely through internet. The data can be entered in certain fields on the website (such as IP address), and the data entered is sent to a PHP script for reading and execution.

A previous Caltrans, Division of Research, Innovation and System Information (DRISI) funded project replaced the existing individually controlled LRRM ramp meters with a new, Coordinated Ramp Metering (CRM) system. The test site managed 11 onramps in a 9-mile corridor of California State Route 99 Northbound (SR99 NB), in Sacramento between Calvine Road and the US50 Interchange.

The CRM system introduced a series of improvements in ramp meter management including:

- 1) The CRM system collects data continuously along the entire corridor and use all the valid data to control each of the individual ramp meters from a system approach simultaneously using a simplified version of Optimal Control,
- 2) The data is used in an algorithm (a simplified Optimal Control strategy, called Model Predictive Control) that employs an optimization method (known as a linear program) that controls ramp metering rate to maximize total Vehicle Miles Traveled, while minimizing total Vehicle Hours Traveled, on the mainline freeway. Mathematically, this is non-zero-sum game approach.
- 3) The availability of route-wide real time data allows the algorithm to consider traffic conditions created by prior ramp meter control points, and then improve the traffic conditions by providing revised ramp meter timing to all ramp meters under control (at regular time intervals, usually 30 s).

F. The CRM system and its Model Predictive Control can be applied to other freeway corridors, which replicate the conditions of the CRM test section on SR99 NB. The CRM test was conducted on a single corridor of medium size, with more than one bottleneck and with RM on all the onramps. Most importantly, traffic congestion on US 50, at the end of the CRM test section, did not back propagate through the interchange onto SR99 NB (North Bound). Had this source of congestion occurred, the CRM algorithm would not work. Clearly, if the freeway system under

control includes more than one freeway corridor, and traffic on one corridor affects the adjacent, intersecting corridor, then both corridors would need to be controlled by the same ramp metering system to properly balance the traffic density over the whole network involved. Further research would be necessary to extend the current CRM system to freeway networks involving multiple freeway corridors.

Table of Contents

Project Panel	i
Abstract	ii
Disclaimer Statement	iii
Acknowledgements	iv
Executive Summary	v
Table of Contents	viii
List of Figures	x
List of Table	xi
List of Acronyms and Abbreviations	xii
1. Introduction.....	1
1.1 Background	1
1.1 Project Overview	2
1.2 What is Our Goal.....	3
1.3 What is the Benefit?	3
1.4 Report Organization	3
2. Graphical User Interface (GUI) Design.....	4
2.1 Operating System Determination	4
2.2 Concept of Operation for CRM.....	4
2.2 Overall Picture of GUI Design.....	5
2.3 Level 1 Tabs.....	7
2.4 Level 2 Tabs	7
2.5 Functions of Level 2 Tabs.....	13
3. GUI Development.....	23
3.1 Determining the Real-time Operating System (RTOS) for GUI	23
3.2 Building a module for freeway corridor modeling for CRM.....	23
4. User Manual and Training Caltrans District 3 freeway traffic engineers	28
4.1 Main CRM GUI Pages	28
4.1.1 Corridor Definition	29
4.1.2 Section Definition	30
.....	30
4.1.3 Time Interval Control	32
4.1.4 Section Controllers Definition	33

.....	33
4.1.5 Onramp Controllers:	33
4.1.6 TMS Controllers	33
4.2 Traffic engineer training.....	34
5. Extension of The CRM Control Range from 11 Onramps to 17 Onramps	36
6. References:.....	38
7. User Manual: CRM GUI Website Survey	39

List of Figures

Figure 1 CRM Concept of Operation	4
Figure 2. Functions and Data Flows of CRM Control and Execution	5
Figure 3. GUI Overall Software System Structure, Main Modules and Data Flows	7
Figure 4. Level 1 Tabs	7
Figure 5. Level 2 Tab - Input the Highest-Level Command: Mainline, Onramp and Off-ramp.....	8
Figure 6. Level 2 Tabs under the Traffic Data Input	9
Figure 7. Level-2 Tabs under the User High Level Control Tab	10
Figure 8. Level-2 Tabs for Traffic State Parameters to be Monitored under the Traffic Monitoring Tab	11
Figure 9. Level-2 Tabs for Parameters to be Outputted under the Output Display Tab.....	12
Figure 10. Level-2 System Definition	13
Figure 11. Level-2: Traffic Data Input.....	14
Figure 12. Level-2: User High Level Control Parameters Input	15
Figure 13. Traffic Data Input.....	16
Figure 14. Traffic Data Processing.....	17
Figure 15. CRM System Modeling Based on Parameter Input.....	18
Figure 16. CRM Algorithm Based on Parameters Input and System Modeling.....	19
Figure 17. System Output Parameters	20
Figure 18. System Monitoring	21
Figure 19. Traffic state parameters as inlay on Caltrans PeMS Map and Google Traffic map.....	22
Figure 20 Corridor Definition	29
Figure 21. Section Definition	30
Figure 22. Operation time interval selection	32
Figure 23. Section traffic controller information	33

List of Tables

Table 1. Extension of CRM operation range by adding 6 upstream onramps	36
--	----

List of Acronyms and Abbreviations

ALINEA	(Asservissement LINéaire d'Entrée Autoroutière) A local occupancy based traffic responsive ramp metering algorithm
ATM	Active Traffic Management
BN	Bottleneck
Caltrans	California Department of Transportation
CMS	Changeable Message Sign
CRM	Coordinated Ramp Metering
CTM	Cell Transmission Model
EAR	Exploratory Advanced Research
FD	Fundamental Diagram
FHWA	Federal Highway Administration
FLOW	A coordinated ramp metering algorithm
GEH	after the name of Geoffrey E. Havers, who created a statistics test similar to a chi-squared test
GP LANE	General purpose lane
GPL	General Purpose Lane
GUI	Graphical User Interface
HERO	HEuristic Ramp metering coOrdination
HOV	High Occupancy Vehicle
LARM	Local Adaptive Ramp Metering
LP	Linear Programming
LQI	Linear Quadratic Control with Integral Action
LRRM	Local Responsive Ramp Metering
LWR	Lighthill-Witham-Richards
METANET	A second order traffic model including speed and density as state variables
MPC	Model Predictive Control
NGSIM	Next Generation Simulation
OFR	Exit ramp
ONR	Entrance ramp
OpenStreetMap	A map of the world, an open source
PATH	California Partners for Advanced Transportation Technology
PeMS	Performance Measurement System
PM	Postmile
RM	Ramp Metering
RMSE	Root Mean Square Error
RMSP	Root Mean Square Percentage
RTMC	Regional Traffic Management Center

SR	State Route
SVO	Speed, Volume, Occupancy
SWARM	System-wide Adaptive Ramp Metering
TD	Total Delay
TMC	Traffic Management Center
TOD	Time-of-Day
TOPL	Tools for Operations Planning
TNOS	Total Number of Stops
VMT	Total Travel Distance
TTS	Total Time Spent
VHT	Total Travel Time
VDS	Vehicle Detector System
VHT	Vehicle Hours Travelled
VII	Vehicle Infrastructure Integration
VMS	Variable Message Signs
VMT	Vehicle Miles Travelled
VSA	Variable Speed Advisory
VSL	Variable Speed Limit

1. Introduction

This report documents the work conducted under the California Department of Transportation (Caltrans) Project 65A0689 entitled “*Graphical User Interface Having have development for Coordinated Ramp Metering System*”.

The project was sponsored by Caltrans and undertaken by the California Partners for Advanced Transportation Technology (PATH), of the University of California, Berkeley. The project duration was 24 months from 6/30/2018 to 6/29/2020.

1.1 Background

Ramp metering (RM) is the most widely used freeway traffic control in California to mitigate freeway traffic congestion. Essentially, RM controls the flow of onramp traffic onto the mainline freeway to ensure that these merging vehicles do not overwhelm mainline traffic flow and create traffic congestion.

Although freeway ramp metering (RM) has been widely used for California highways for traffic management and control, they are mostly Local Responsive Ramp Metering (LRRM). LRRM determines RM rate only based on the information from its immediate upstream mainline traffic detectors. The LRRM metering approach is unable to use any downstream data of the ramp meter. Therefore, the traffic throughput along the freeway corridor is not optimized.

The control strategy employed for ramp meters throughout most of California is known as “Local Responsive Ramp Metering (LRRM)”. Under LRRM, the timing of the ramp metering lights varies, based on the volume of mainline traffic measured by a set of detectors installed in the freeway - local to the inbound ramp. Thus, LRRM determines the inbound traffic flow rate based on a single measurement location of traffic on the mainline, upstream of the ramp merge, and does not consider the dynamic traffic interactions of the ramp under control with other sections of the freeway that are adjacent to the RM’s location. Since traffic in different sections of the freeway corridor affect each other, especially when traffic demands are high and fluctuating, system performance can be improved if individual ramp meters considered a broader set of traffic conditions and coordinated the metering rates of all ramps along a freeway corridor to balance the entrance flow, in totality.

Our previous project funded by Caltrans Division of Research, Innovation and System Information (DRISI) project (#65A0537) focused on field test of Coordinated Ramp Metering (CRM) on SR99 North Bound section near Sacramento. The overall corridor traffic efficiency (or average speed) was improved by 7.25% in AM peak hours. After the project was completed, Caltrans District 3 RTMC (Regional Traffic Management Center or TMC) traffic engineers made the following

request after the performance analysis: (a) to continue using the CRM control as the daily operation for the SR99 NB corridor; and (b) to have developed a Graphical User Interface (GUI) for the CRM algorithm so that Caltrans freeway traffic engineers can easily apply it to other freeway corridors.

In this project, we have developed a Graphical User Interface (GUI) for the Coordinated Ramp Metering (CRM) algorithm which was developed and tested in a previous on SR 99 North Bound (NB) corridor near the US50 interchange in a previous Caltrans project. In particular, this project has developed several modules to enable Caltrans freeway traffic engineers to use the GUI for Coordinated Ramp Metering (CRM) control for a give freeway corridor. Those modules include: freeway corridor modeling, traffic detector data mapping, traffic state parameter estimation, control parameter tuning, CRM activation or deactivation for an onramp, output and display traffic state parameters, ramp metering rate and VSL at each sign location. and fault detection and warning. After system integration, the developed CRM GUI tool would be used for validation on SR 99 NB and US 50 East Bound corridors. The PATH project team has also trained Caltrans District 3 traffic engineers so that they would be able to use the CRM GUI tool independently to other freeway corridors as long as the data is centralized and available in real-time.

1.1 Project Overview

The project team has built user-friendly GUI capable of hiding all the complications of the mathematical algorithms. With this GUI, Caltrans Freeway Ramp Metering traffic engineers can set up the system to control a freeway corridor using the CRM strategy by simply inputting a set of traffic parameters manually or from a file, which include:

- freeway name
- start Post Mile (PS) and end Post Mile (PM
- total number of lanes of each freeway section (subsection – part of a section)
- number of HOV lanes of each freeway section (subsection – part of a section)
- number of onramps in sequence and their locations (PM) and lengths
- total number of lanes and number of HOV lane for onramps
- number of off-ramps in sequence and their locations (PM) and lengths
- traffic (or loop) detector station locations (PM)
- IP addresses of all the detectors in mainline, onramps and off-ramps

The project would include the following tasks:

- Determine the Real-time Operating System (RTOS) for GUI
- Having built a GUI Module for freeway corridor modeling for CRM
- Having built GUI module for data link and data mapping between field 2070 controllers IP addresses and CRM algorithm
- Having built GUI module for traffic data processing and traffic state parameter estimation
- Having built GUI module for link with new data types such as connected vehicle data

- Having have developed GUI module for control parameter tuning with CRM deactivation capability; after the deactivation, the RM would go back to LRRM by default
- Having have developed GUI module for fault detection and warning capability which can handle most common CRM system faults
- CRM GUI System integration
- Validate (to test and make sure it works) the CRM GUI have developed on SR99 NB corridor
- Write an Operation Manual and train Caltrans District 3 freeway traffic engineers for CRM GUI operation
- Write Final Report to document all the algorithms, lessons learned and experiences gained in the project and make recommendations

1.2 What is Our Goal

The goal of the proposed project is to have developed a GUI software, e. g. a Linux or Windows-based application, such that the Caltrans district freeway traffic engineers can easily use it to control freeway corridors traffic in California. The GUI would be have developed to be as user-friendly as possible.

1.3 What is the Benefit?

The immediate benefit of CRM with GUI tool capability is convenient for Caltrans traffic engineers to apply the CRM control strategy to a freeway corridor for traffic control.

The tested CRM algorithm to be built in the GUI Tool uses a simplified *optimal control approach* along a freeway corridor. The algorithm determines the RM rate at each onramp by considering the overall traffic along the freeway corridor. The traffic improvement benefit should be more significant than the LRRM currently in operation in almost all Caltrans Districts. Therefore, wide use of the CRM for freeway corridor traffic control would lead to direct benefits in freeway throughput improvement and congestion reduction. This would reduce Total Travel Time and increase Total Travel Distance, which match with the Mobility Improvement of the Caltrans Strategic Goal. Indirect benefits would include but are not limited to energy and emission reduction and safety improvement.

1.4 Report Organization

2. Graphical User Interface (GUI) Design

In this chapter, we describe a higher level design of the CRM GUI Tool which is in a hierarchical structure from the highest level down to each lower levels.

2.1 Operating System Determination

After careful consideration of the following factors:

- interface capability with 2070 controllers in the field
- the original OS used for SR-99 corridor for field test of CRM
- Application Programming Interface (API) capability
- Networking capability
- Windows application capability

The project team has decided to use Linux as the OS for the CRM GUI Tool have development, and HTML/PHP/MySQL as the have development platform for the GUI. Using common web interface tools would allow interoperability among different operating systems (e.g. Windows, Linux, Macintosh).

2.2 Concept of Operation for CRM

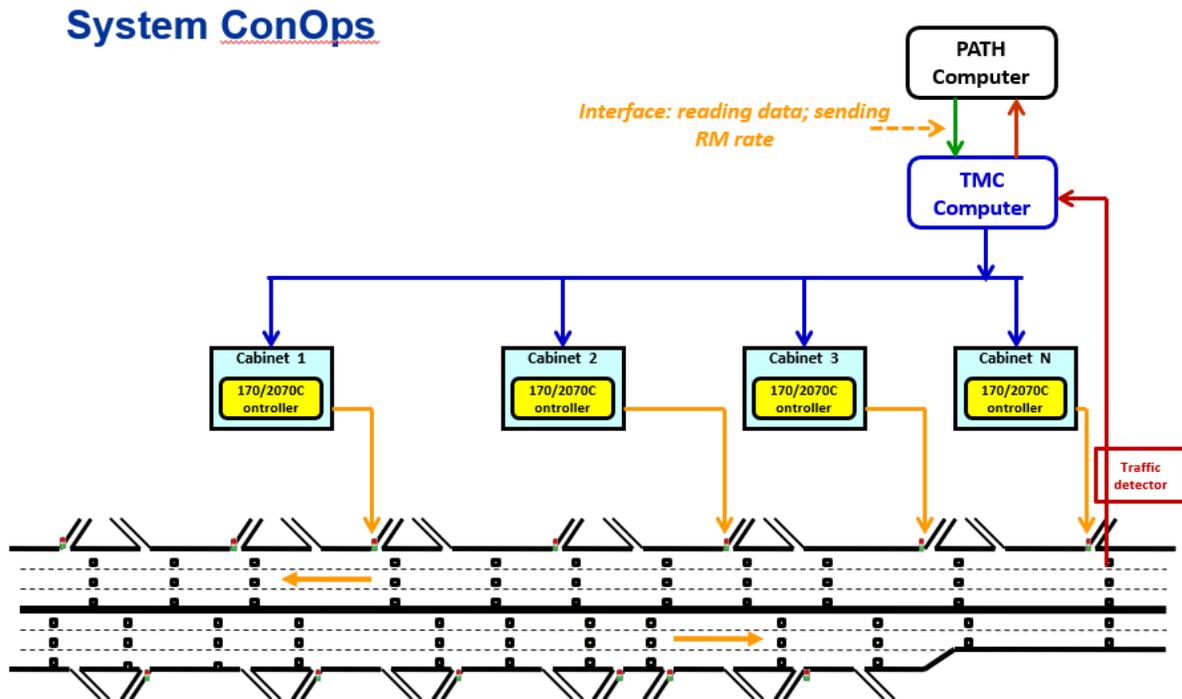


Figure 1 CRM Concept of Operation

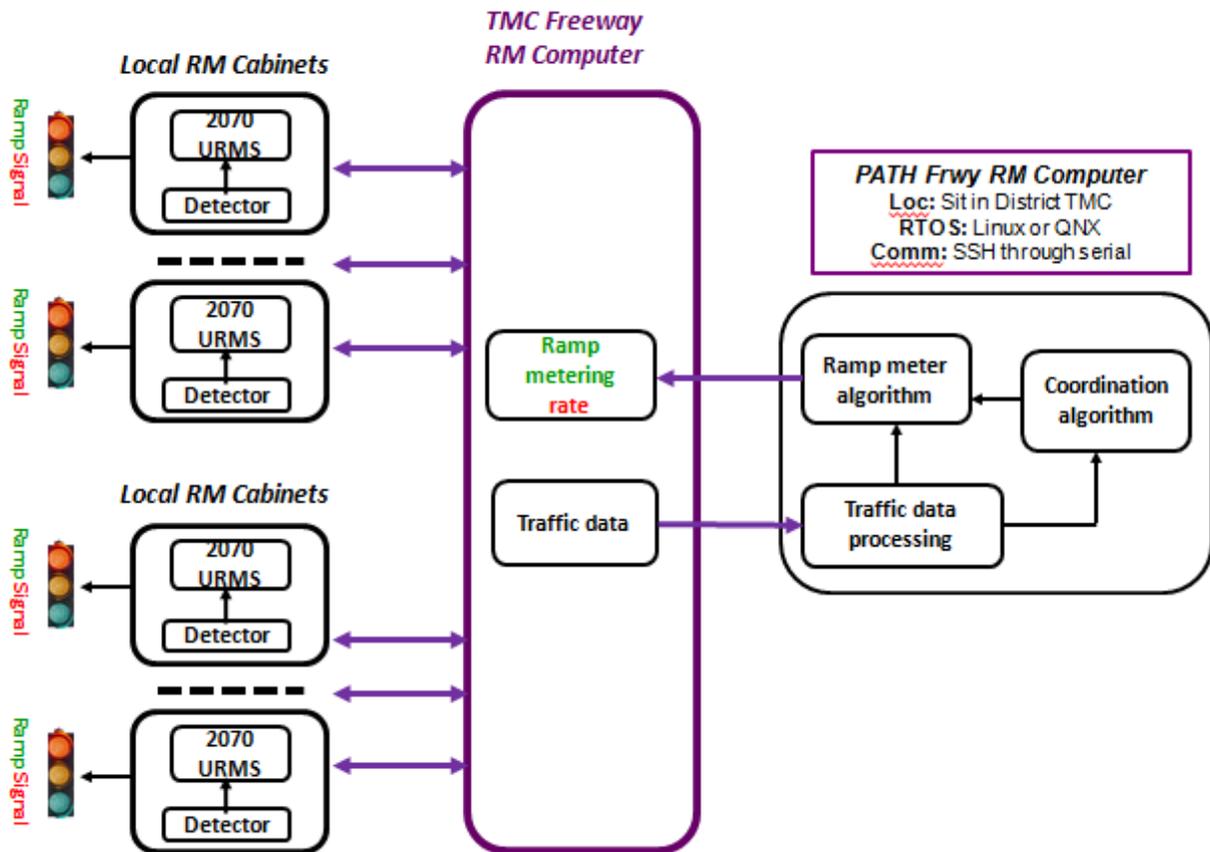


Figure 2. Functions and Data Flows of CRM Control and Execution

Figure 1 shows the overall system structure of the CRM system. PATH CRM computer sitting in Caltrans District 3 RTMC directly link with its Intranet for data acquisition, processing, traffic state parameter estimation, calculating optimal RM rate, and sending it to the corresponding onramps activation. The intranet connection with 2070 controllers in the field used fixed IP addresses. Such an implementation scheme is obviously very advantageous. First of all, it is very simple and direct. Secondly, there is no middle ware in between PATH CRM computer and 2070 controllers in the field; therefore, it is not necessary for support of any third party. Thirdly, PATH computer can access all the raw field data which were not changed by any middle ware; therefore the data were trustable. Fourthly, such a direct link practically avoided any delays and data passing errors caused by middle ware/system(s).

2.2 Overall Picture of GUI Design

Before have developed the modules and sub-modules for the CRM GUI, it is necessary to have an overall software system structure. This design has taken into consideration the following factors:

- Meeting all the functionality requirements proposed
- Convenience of user interface
- Convenience of user to some high-level control input preferences
- Hiding complicated algorithms and other processes
- To make sure all the major components in Level 1 and modules and sub-modules in Level 2 work coherently and efficiently

The project team has designed the overall software structure of the GUI including:

- Major components of the software in Level 1
- Functionality of each component in Level 1
- Data flow path between those components Level 1
- Model definition and functionality determination in Level 1
- Sub-module determination in Level 2: the Level 2 modules would be have developed for supporting the functionality and data flow of Level 1 components

The following Figure 2 is the Level 1 system structure:

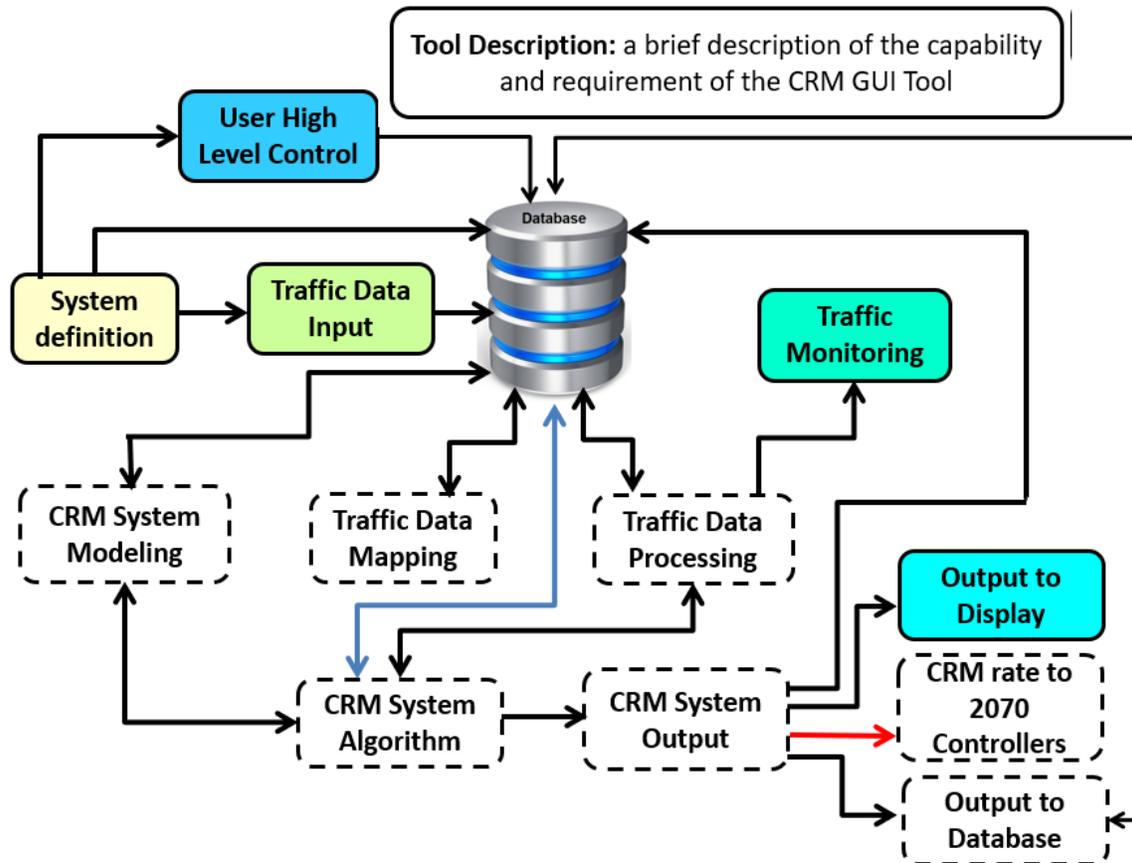


Figure 3. GUI Overall Software System Structure, Main Modules and Data Flows

2.3 Level 1 Tabs

There are only 5 Tabs shown to the users as shown in Figure 4. Other Tabs with dashed-line borders are hidden. The Database is actually a data buffer created to store information temporarily, not permanently, for data exchange among all the components of the GUI software



Figure 4. Level 1 Tabs

2.4 Level 2 Tabs

The Level 2 structure should be defined for each major Level 1 component. In Figure 3, solid line block would need would involve user observation and/or action, and dashed line would be hidden to the user for simplicity.

Figure 5 shows the Level 2 component for System Definition. It requires user's input for the definition of the system including road geometry etc.

2.4.1 The highest information input by the user

Each tab represents a lower level page/table for the driver to input the corresponding information. The page contains a table with inputs including:

- Freeway corridor Name (to be inherited in other pages)
- Number of on sections
- Number of onramps (each section has 1 onramp)
- Number of off-ramps (each section: 0 or more than 1)
- Number of controllers

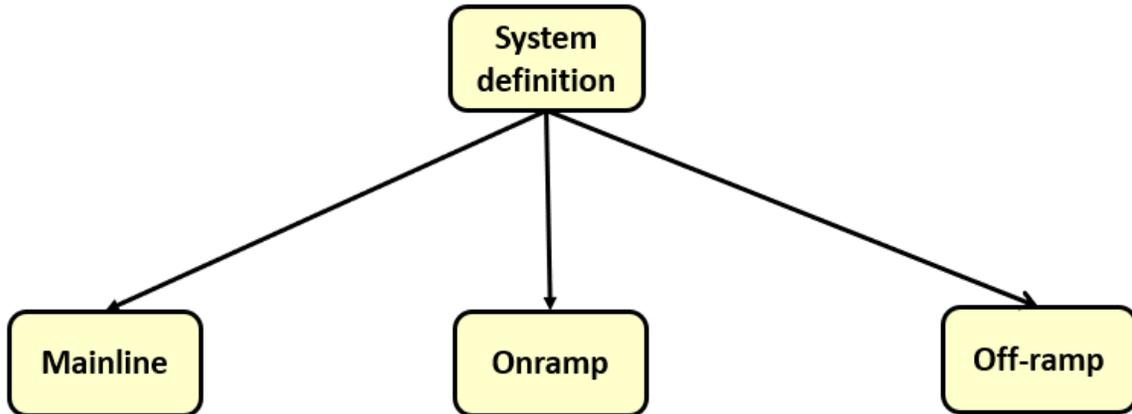


Figure 5. Level 2 Tab - Input the Highest-Level Command: Mainline, Onramp and Off-ramp

(1) A table to input of mainline info contains the following information:

- Section Name is inherited onramp name (downstream of that section)
- Start and end PMs (with error checking)
- Number of lanes in each section
- Number of detector stations in each section

(2) A table to input of onramp info

- Onramp name
- PM
- Number of lanes

- Number of detector stations
- Number of HOV lanes

(3) A table to input of off-ramp info

- Off-ramp name
- PM locations
- Number of lane
- Number of detector stations

2.4.3 Traffic Data Input

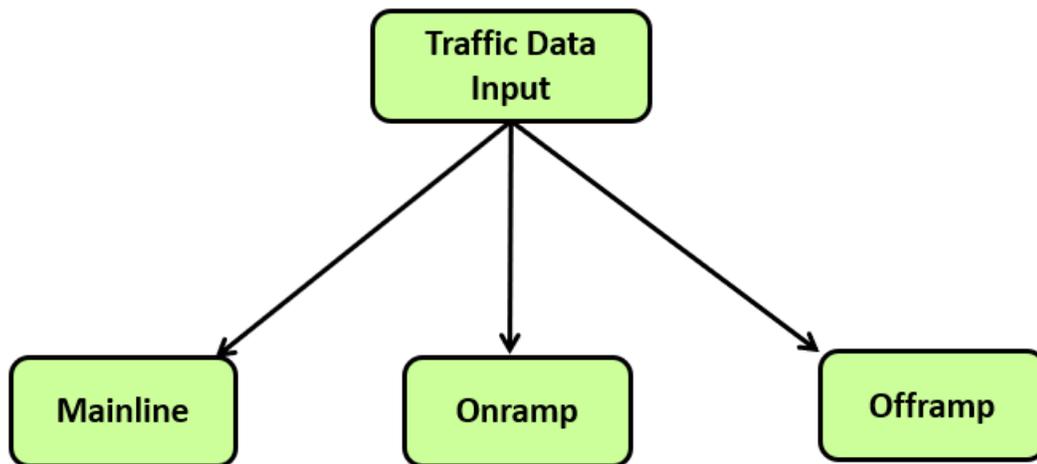


Figure 6. Level 2 Tabs under the Traffic Data Input

(1) Mainline Tab: A table to input of mainline information lane-by-lane

Create a sub-table below for:

Lane-wise IP addresses:

Station 1 Lane 1

Station 1 Lane 2

Station 1 Lane 3

...

PM location

Link the IP address to mainline, onramp and offramp

(2) Onramp Tab: A table to input of onramp info

Number of lanes □ create a sub-table to input info lane-by-lane for:
 Detector IP address 1: upstream Q-detector
 Detector IP address 2: before meter
 Detector IP address 3: after meter

(3) Offramp Tab: A table to input of off-ramp info

Off-ramp name
 PM
 Number of lanes
 Detector IP address

2.4.4 User High Level Control Tab

This tab allows the user to selection RM control strategies including LRRM and CRM, setting the maximum RM rate, data processing and control update time interval, and whether the Q-overwrite function will be activated. This function is particularly designed for LRRM and CRM when the queue in the onramp is too long with danger of back propagating to local arterial(s), the maximum metering rate will be used for all lanes of the onramps to release more vehicles to the mainline. Essentially, using the maximum RM rate to overwrite the calculated CRM rate temporarily until the queue has been released.

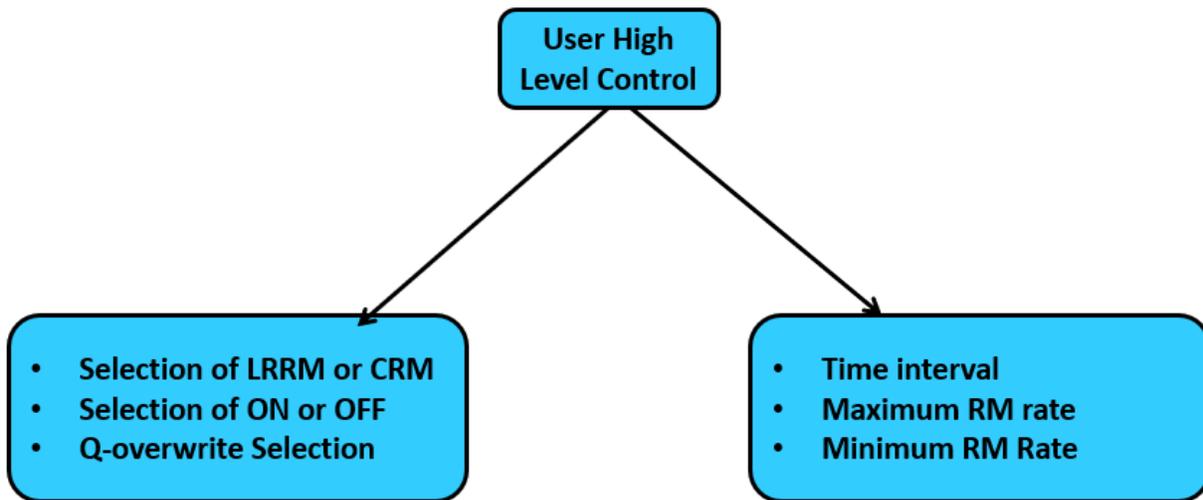


Figure 7. Level-2 Tabs under the User High Level Control Tab

(1) The left tab provides a table to input user control info including:

- Inherit names of all onramps
- Selecting control method: Using LRRM, CRM or no control at all

- Disable button: PATH would not send control signal, instead, it will return to D3 default control
- Queue overwrite activation

(2) The right Tab will provide a table for inputting user control information such as:

- Inherit names of all onramps
- Minimum and maximum RM rate for 10 time-periods
- With error checking for time-interval for consistence
- LRRM rates which are preferred to be applied

Obviously, if the user wanted to use their own preferred RM rate, it would affect the overall system performance to some extent. Even though, this is a necessary functionality required by traffic operation engineers which may be required by local jurisdictions.

2.4.5 Traffic Monitoring –

It would be convenient to intuitively display all the traffic detect sensor output, state parameters, and RM rate etc. to the traffic engineers so that they monitor the system’s operation performance, and potential fault such as sensor malfunctioning, and data problem(s). For this reason, three tabs have been designed which provide three web pages to show the relevant information as shown in Figure 8 and Figure 9.

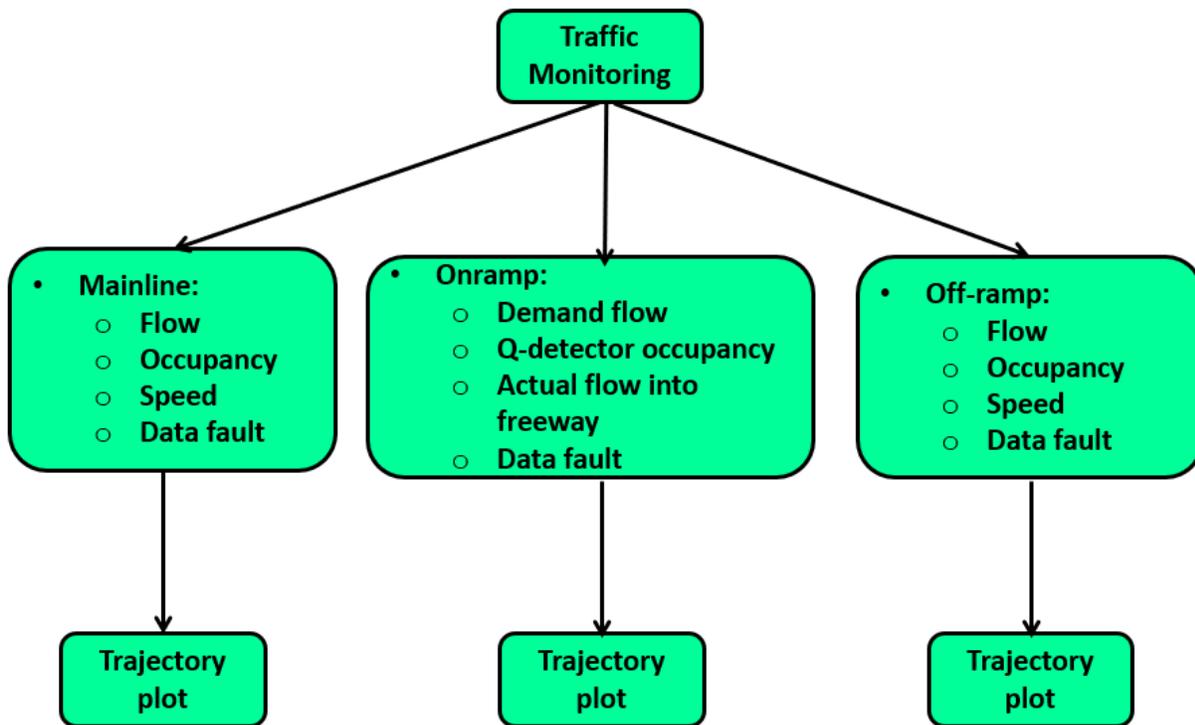


Figure 8. Level-2 Tabs for Traffic State Parameters to be Monitored under the Traffic Monitoring Tab

All the major traffic state parameters are also plotted against the distance and updated as time evolves – almost real-time.

2.4.6 Output Display Tab

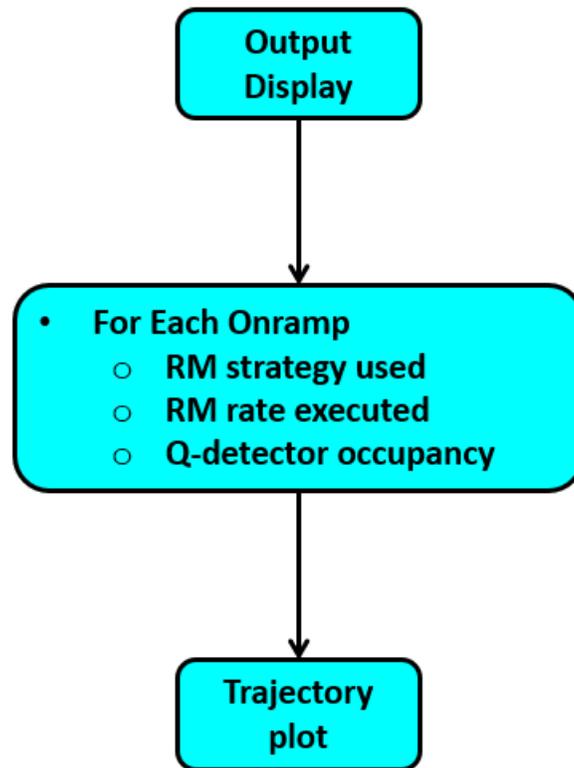


Figure 9. Level-2 Tabs for Parameters to be Outputted under the Output Display Tab

2.5 Functions of Level 2 Tabs

With the input information described in the previous section, this section presents the functions of the major modules and sub-modules and their relationships within the GUI tool.

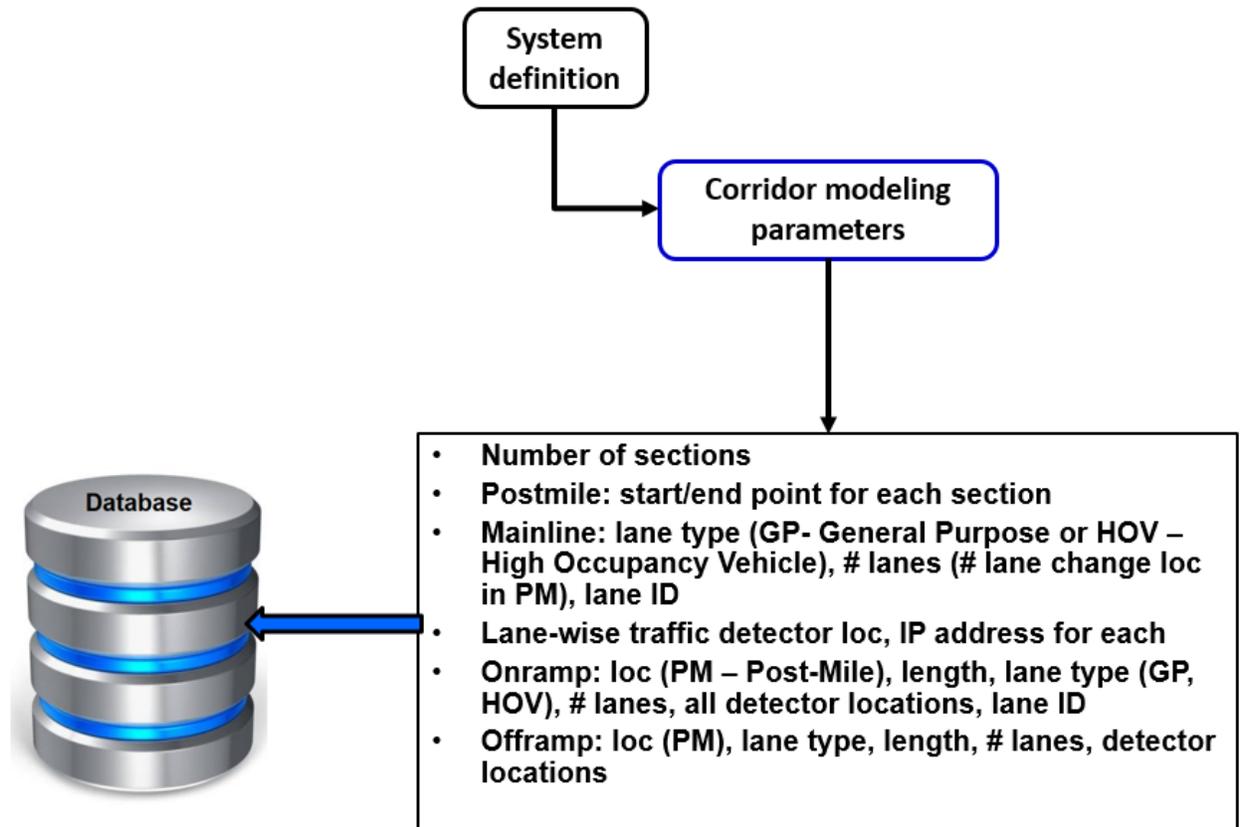


Figure 10. Level-2 System Definition

As shown in Figure 10, all the user input information will be saved in internal database for later use.

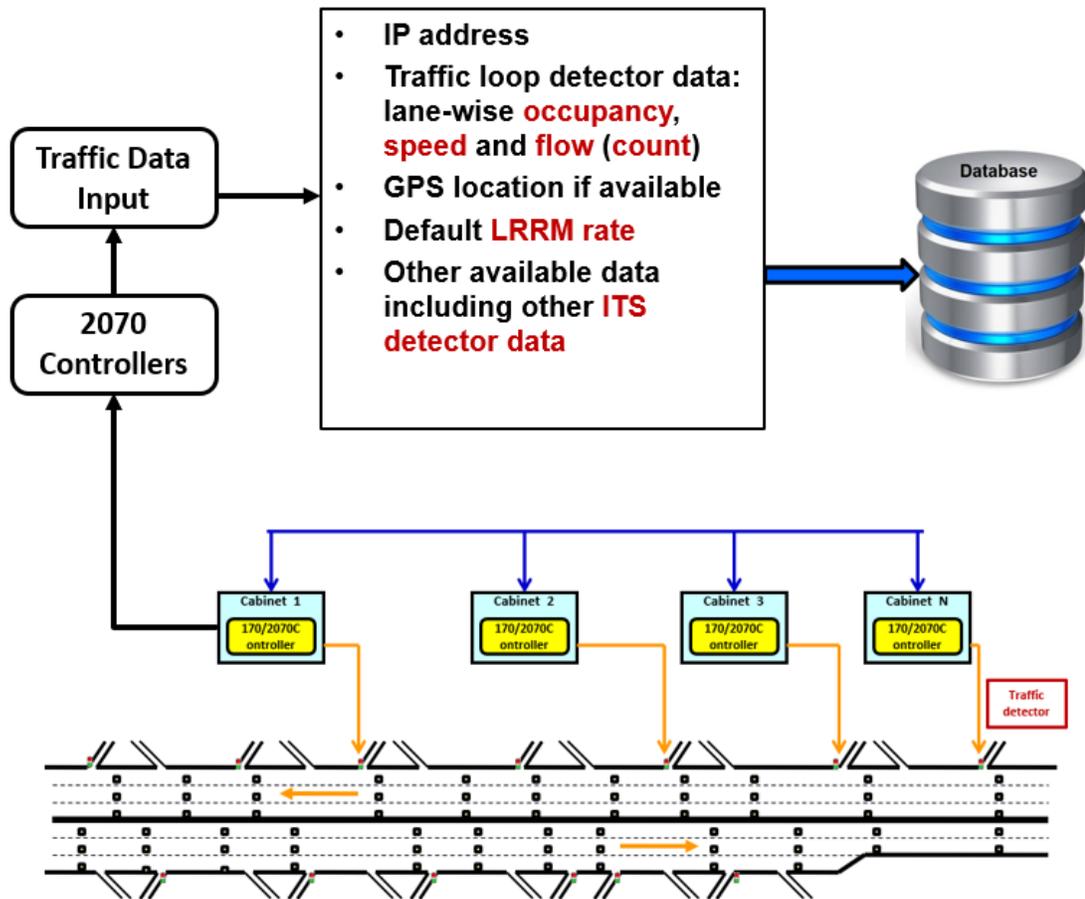


Figure 11. Level-2: Traffic Data Input

Figure 11 shows traffic data input from detectors though Caltrans Intranet – data acquisition. This module would regularly poll traffic data from 2070 controllers every 30 s. This is the first stage in data mapping.

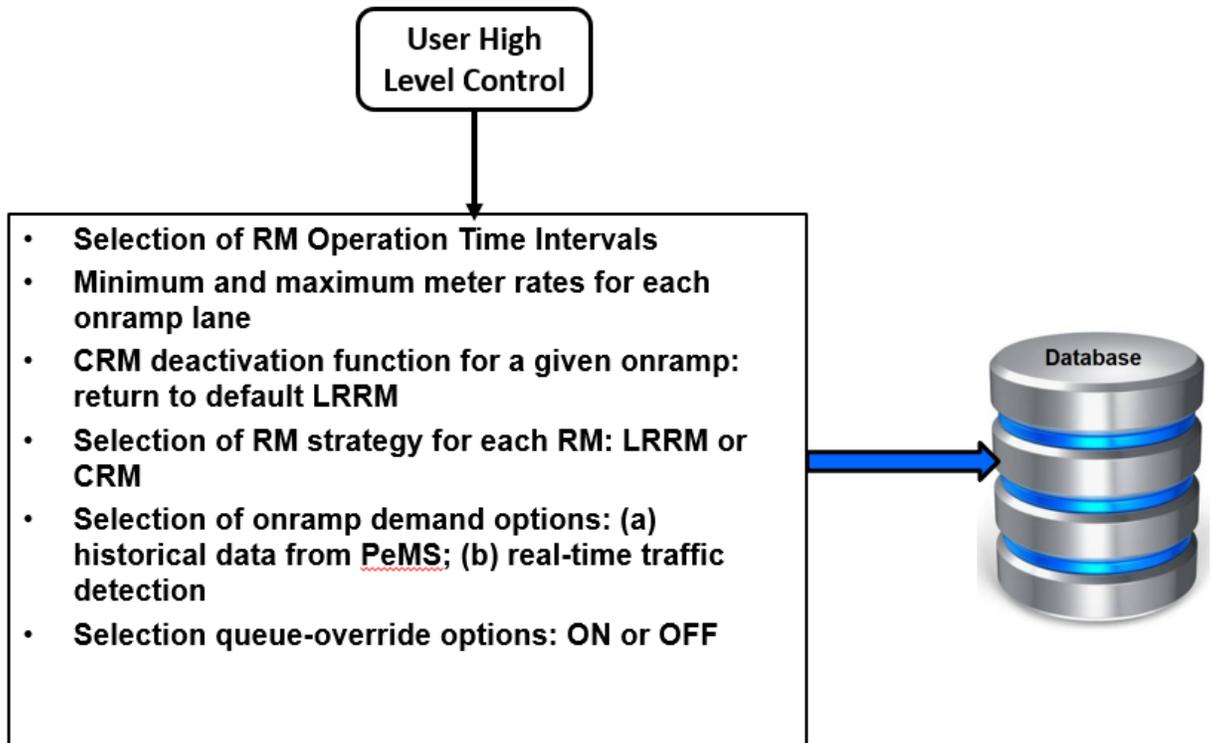


Figure 12. Level-2: User High Level Control Parameters Input

Figure 12 shows the user control functionalities which determines the user preferences.

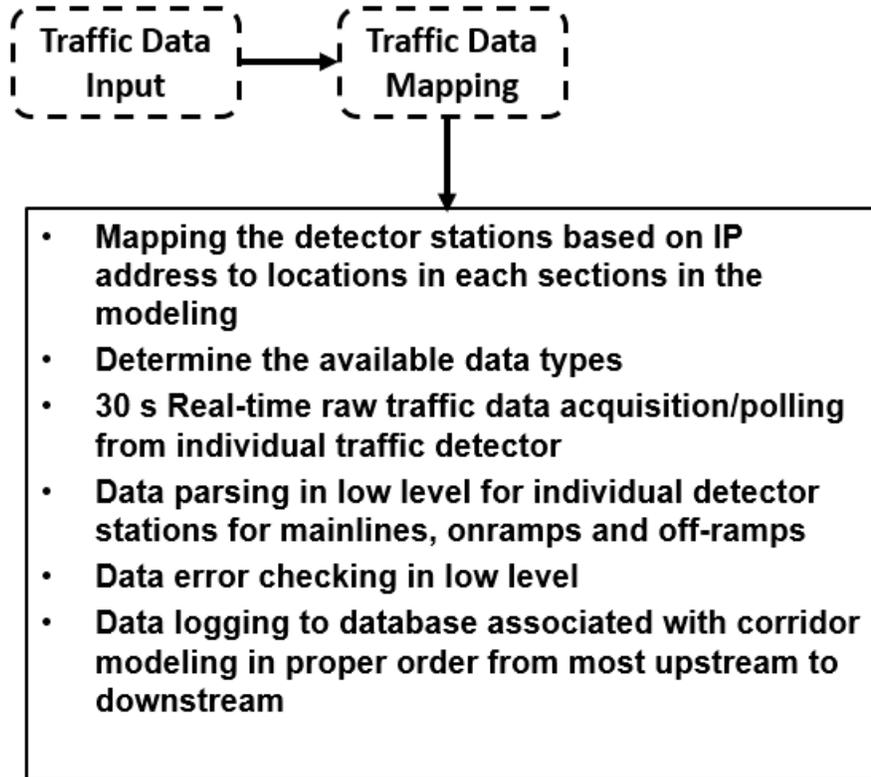


Figure 13. Traffic Data Input

Figure 13 shows the module of the second stage for data mapping. This is a complicated and critical part in GUI. The module represented by this block it to have built a detailed data mapping between the traffic detector in the field and the data to be used for modeling and control. If any traffic detector assignment is wrong, the corridor data would be inconsistent.

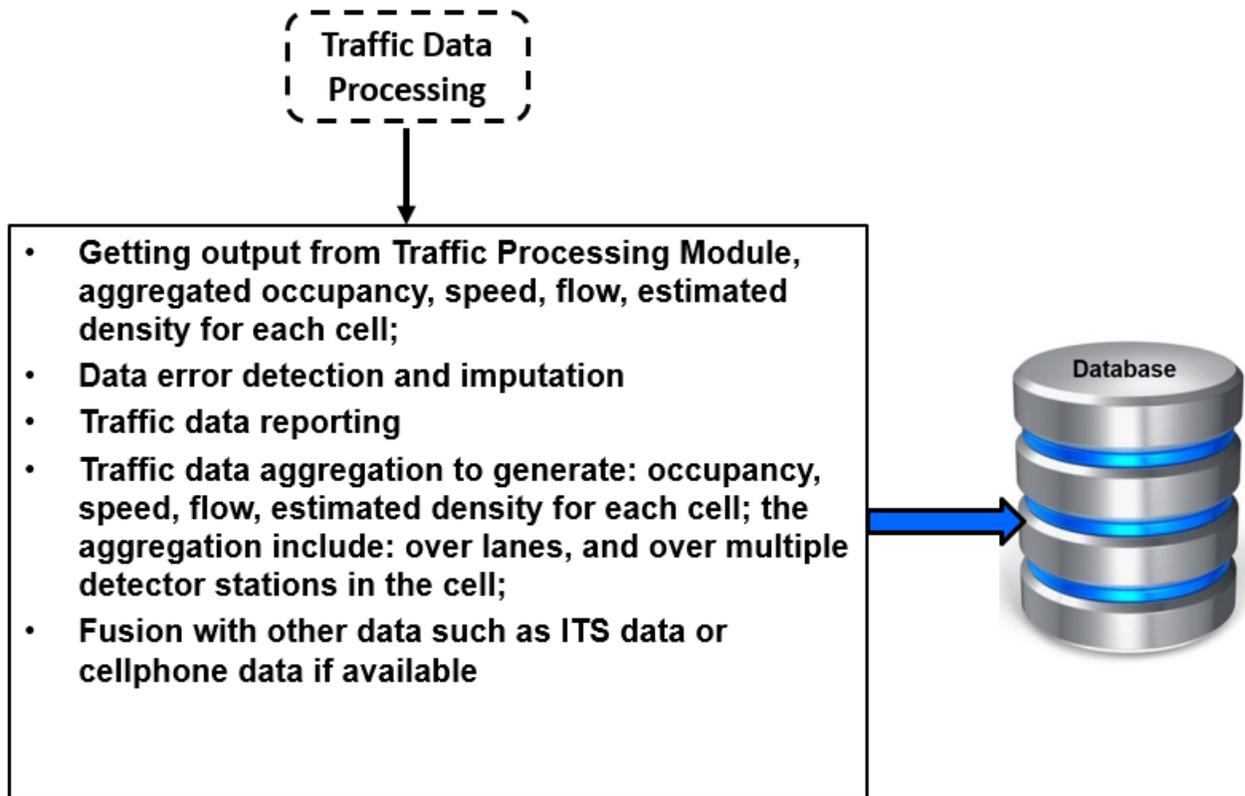


Figure 14. Traffic Data Processing

Figure 14 shows the function of the module for data processing. It takes input from the raw data from the traffic detector and generate/estimate traffic state parameters for each section including: flow, density, speed and occupancy. The processing includes data aggregation, filtering, estimation such as density which is not directly measured. It also conducts some data fault detection, imputation and correction. It reports any persistent data error to traffic engineers. The output of this module would be used directly in CRM system modeling and algorithm for metering rate determination using *optimal control*.

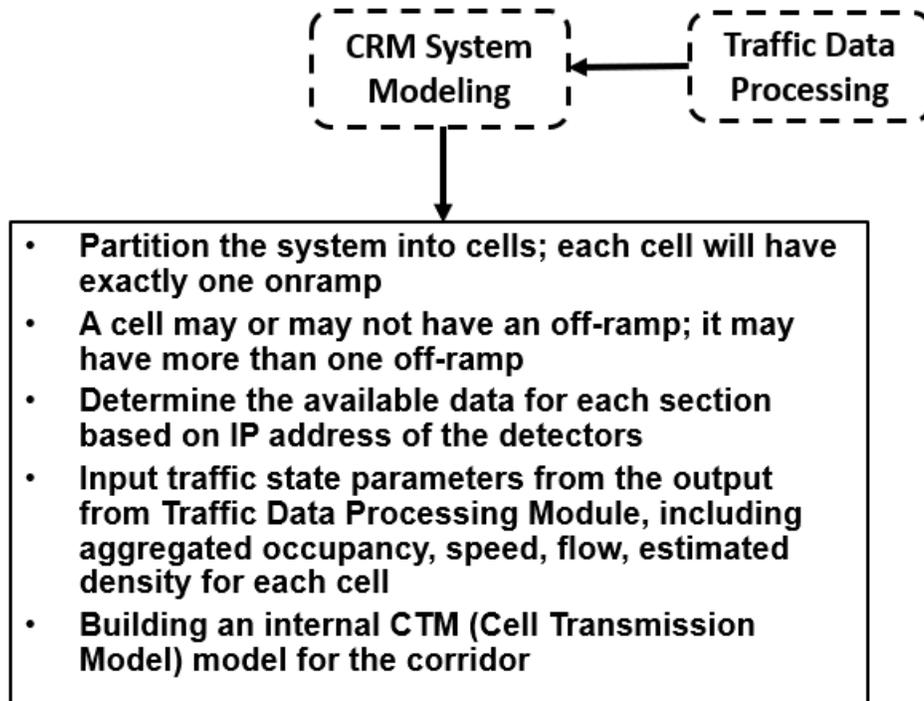


Figure 15. CRM System Modeling Based on Parameter Input

Figure 15 shows how an internal Cell Transmission Model (CTM) is built based on the user's input information on road geometry and traffic data etc. The CTM is the foundation of the CRM algorithm. This block is hidden to the user for simplicity.

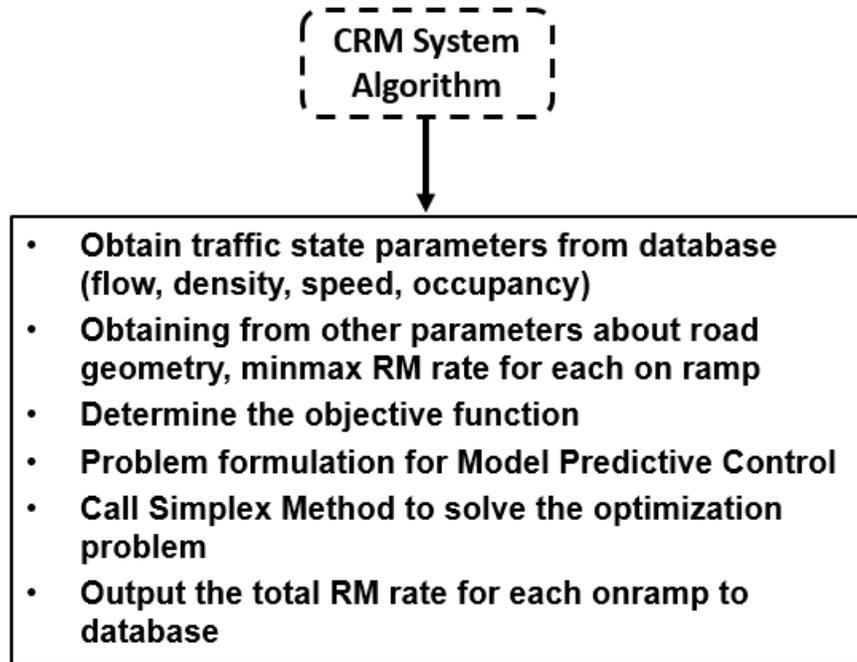


Figure 16. CRM Algorithm Based on Parameters Input and System Modeling

Figure 16 depicts the process of the module to formulate the optimal control problem based on the user's input information and the CTM as described in the previous step, which is the core of the CRM algorithm. The critical part is the construction of the objective function for the Model Predictive Control. After this step, an internal programming will be called to resolve the optimization problem at each time step using Simplex Method numerically. The output is the total RM rate for each onramp. This module would be hidden to the user for simplicity.

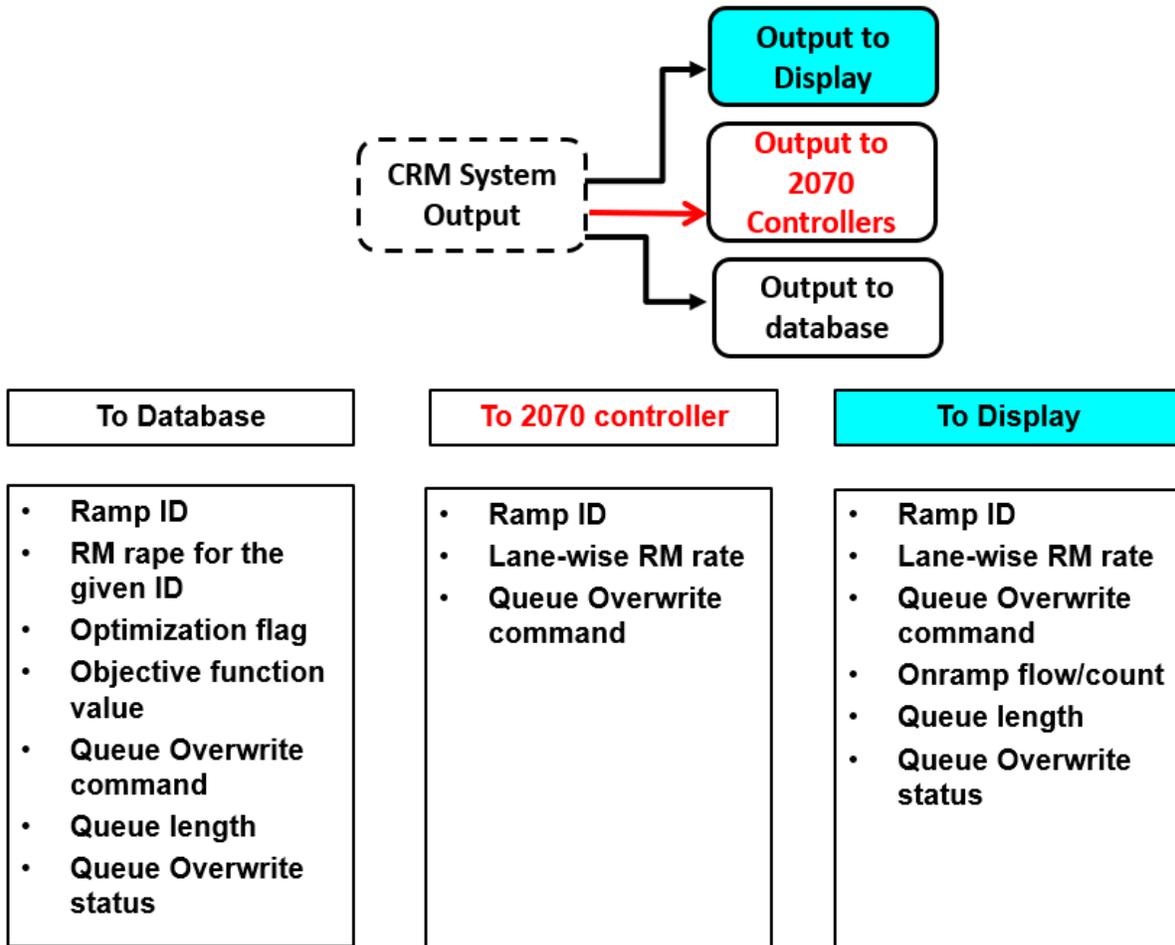


Figure 17. System Output Parameters

Figure 17 shows the three system outputs:

- To database: all the output and some critical intermediate parameters are saved in database for later stage analysis;
- To 2070: the RM rate is sent to specific traffic controller in the field for execution;
- To Display: selected output to the Display is what to be showed to the user on the screen.

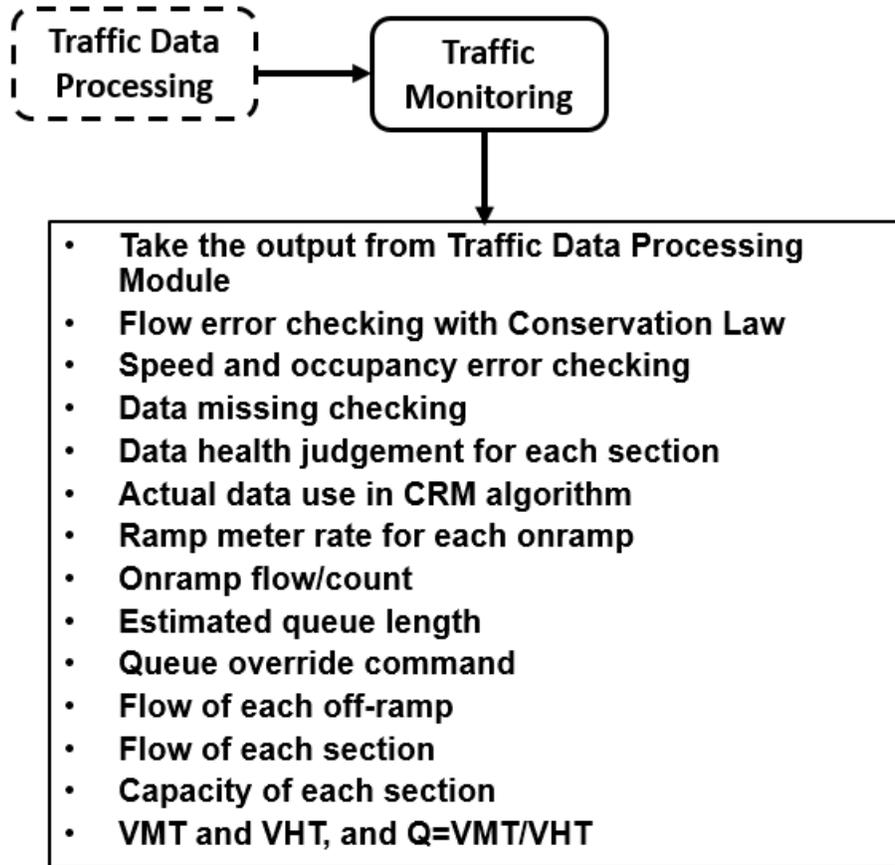


Figure 18. System Monitoring

Figure 18 shows the modules for traffic monitoring: displaying all the important traffic state parameters and RM rate for user observation. Based on the traffic display, the user can judge if the RM rates determined by the algorithm are reasonable. By comparing the traffic state parameters with respect to the historical data, the user can observe the CRM system performance along the corridor. It is noted that not all parameters listed here are displayed. Instead, we only display those parameters which are used in common practice of a freeway traffic engineers.

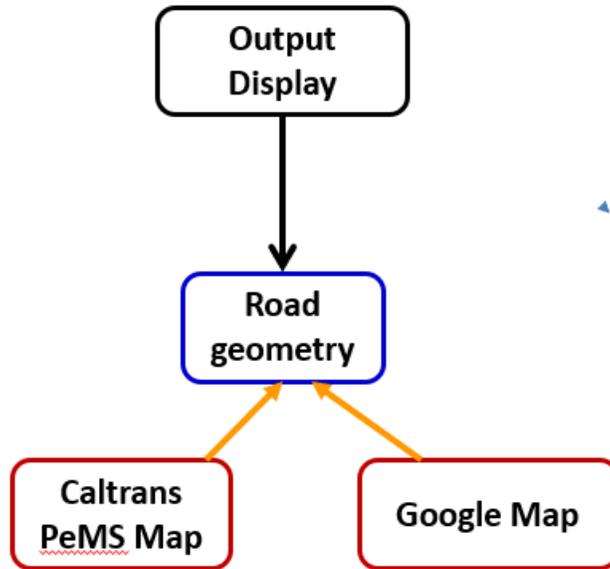


Figure 19. Traffic state parameters as inlay on Caltrans PeMS Map and Google Traffic map.

As indicated in Figure 19, we also display some key traffic state parameters we estimated and used for the CRM algorithm as inlay on Caltrans PeMS Map and the real-time Google traffic map. From the latter, the user can observe the traffic congestion situation intuitively for a comparison.

3. GUI Development

After the system design, the project team has developed all the models and submodules and integrated them and validated. The following presents all the system development.

3.1 Determining the Real-time Operating System (RTOS) for GUI

Before the system design and implementation, the first thing is to determine the operating system that would be suitable to host the CRM GUI. We have considered several alternatives including Linux, Windows, or Web-based. The selection process would be based on the following factors:

- 1) Ability of the Real-Time Operating System (RTOS) to communicate with the CRM system and 2070 controllers. This would be determined in an experimental setting where a prototype GUI is installed on a computer (with the candidate operating system) and connected to the Caltrans intranet – at the Caltrans District 3 Traffic Management Center (TMC). A series of tests would be performed to evaluate the effectiveness of communication (with 2070 controllers in the field and the CRM in District 3 TMC) over the range of operations expected. The GUI, operating system, CRM system should be applicable to other Caltrans districts.
- 2) The level of security embedded in the RTOS would be evaluated to ensure that it meets Caltrans standards.
- 3) Computation capabilities of the operating system would meet the algorithm requirement. These tests would focus on the data communication rates (to the 2070 controllers and the CRM) as well as selected computations and data communication.
- 4) An appropriate integrated have development environment (IDE) must be available for the RTOS. Thus, one of the selection criteria is the availability of commercial IDE to support the have development and use of a Graphical User Interface.

3.2 Building a module for freeway corridor modeling for CRM

The objective of this project is to construct the graphical user interface for real time operation of the CRM system on a freeway corridor. The GUI tool would behave as an interface for the user to interact with the CRM algorithm underneath. This would require the GUI to have the following capabilities:

- To allow the user to set the parameters for modules or sub-modules and systems that are used by the CRM algorithms;
- To allow the user to determine the control strategies for a given onramp;

- To hide any complicated algorithms and processes, only allow the absolutely necessary information for input and the output to the user;
 - To establish a direct connection from the TMC to the 2070 controllers that are located in the field for the purpose of directing data from specific controllers/loop detectors to specific onramp locations;
- 1) We have developed an interface that enables the customization of the freeway model to be used by the CRM algorithm. In this interface the user is able to manually input some necessary information that is mostly related to road geometry:
- freeway name
 - start Post Mile (PM) and end PM
 - number of lanes of each section (subsection)
 - number of HOV lanes of each section (subsection)
 - traffic (or loop) detector station PM locations for mainlines
 - IP addresses of all the detectors in mainline, onramps and off-ramps
 - IP addresses of all the traffic controllers and their ports assignments
 - number of onramps
 - for each onramp:
 - the PM location in sequence
 - number of lanes
 - number of HOV lanes;
 - onramp length
 - the departure (metering) loop location
 - the advance-loop (or queue detection loop locations)
 - number of off-ramps
 - for each off-ramp:
 - the PM location in sequence
 - number of lanes
 - off-ramp length
 - the departure loop location
 - the advance-loop (or queue detection loop locations)
- 2) Provide the functionality to divide the freeway into multiple sections. Each section would be associated with a specific, individual onramp, the loop detectors and any downstream detectors.
- 3) Provide the functionality to differentiate between General Purpose (GP) lanes and High Occupancy Vehicle (HOV) lanes, for individual onramps -because the metering rate of these two classes of ramps is usually different.

- 4) Provide the functionality, in the GUI, to display information in Caltrans' QuickMap format, with live traffic and links to CCTV (video not jpg).
- 5) Provide the functionality to click on ramp meters and detectors, in the GUI, to display the release rates and other real-time traffic detector data including estimated onramp queue length.

The project team has have developed several versions of the CRM GUI software modules and presented to the project panel for comments. Based on the comments, the project team has revised the GUI modules.

3.3 Building a module for data link and data mapping between field 2070 controllers and CRM algorithm

Real-time traffic data is critical to the CRM algorithm. Caltrans's freeway data are obtained from loop detector stations which are linked with the traffic controllers on freeway. To obtain the firsthand data, it is necessary for the GUI to know which station is wired with which port of the controller. For this purpose, we have built a module that would allow the user to input information to relate a given detection station to a specific IP address. This is essentially to map the geometric location of the loop detectors, through the 2070 controllers (located in road side cabinets) to the proper database location of the freeway model (that is embedded in the CRM). This should be done at the time when CRM implemented, or when wiring of the loops have been changed for whatever reasons. This process is necessary because there is no common wiring-rule implemented between 2070 controllers and loop detectors. Every roadside cabinet may be different and only Caltrans freeway traffic engineers know the configuration of the individual cabinets and the relevant loops. The following are the details on what we have done on this respect.

Each loop detector station (mainline, onramp and off-ramp) has a unique IP address. Data transmitted by that detector would be associated with that IP address – within the Caltrans Intranet. This identifying characteristic would be used to direct data packs with different IP addresses to different locations in the CRM database. Once the geolocation (section, lane, mainline/onramp/offramp) of a specific IP address is established a specific database location can be defined for data originating from this location. When completed this relationship is known as a 'data link'. This task would include the following activities:

- 1) Having built GUI data link with all traffic detector stations with the Transmission Control Protocol/Internet Protocol (TCPIP) communication protocol;
- 2) Having built a separate GUI that enables the mapping of all mainline detector stations using data communicated from the field to the traffic management center, the freeway corridor models based on the detector location and other information. This

- map needs to be built manually because the detector data assignment in each controller is quite arbitrary (from controller cabinet to controller cabinet);
- 3) Having built a separate GUI that enables data mapping, using the data link method, of all onramp detector stations;
 - 4) Having built a separate GUI that enables data mapping of all off-ramp detector stations, using the data link method;
 - 5) After the specific data links have been constructed, they would be password protected; however, the user (traffic engineers) would be able to unlock these to make future modifications.

In summary, we have built a GUI module for traffic data input interface and data mapping, which is separated for mainline, on-ramp and off-ramp detector stations. The input information is saved in an internal database.

3.4 Building a module for traffic state parameter estimation

The traffic data we obtained directly from the loop detector station is raw data. It is necessary to have a module to process the data to generate reliable traffic state parameters such as flow, speed, and density (or occupancy) in certain aggregated levels. Considering the detector characteristics, we use 30 s as the aggregation time interval.

The data from the loop detector stations are raw traffic data from individual loops including occupancy and traffic counts and may include speed. Raw data usually contains noise and measurement errors [3, 4, 5]. For the application of CRM, we need the data to be clean and reasonably accurate (for aggregated flow, density and speed) for each detector section. Therefore, the CRM system needs to conduct the following data processing procedures in real-time:

- 1) automatic data health check for the data from each individual loop
- 2) for temporary data errors, the data will be replaced with interpolated data using its upstream, downstream and/or previous time steps data
- 3) the data will then be aggregated across lanes at the same detector station
- 4) after that, the data will be further aggregated across stations of its immediate upstream and downstream

The two aggregation steps will improve the reliability of the data. Finally, the fused data will go through a low-pass filter for further smoothing. The output data of the filter would be fed into the CRM algorithm to generate onramp RM rates for all sections.

3.5 Building a module for control parameter tuning and CRM deactivation capability

The objective of this function is to provide the CRM user the ability to modify model control parameters to better fit, or tune, the CRM system to unique geographic-specific situations in individual CRM implementations. Each independent freeway corridor has its own variety of unique road geometries and traffic situations (such as the location of bottlenecks and their impact, scope etc.). Thus, the CRM implementation process would allow some flexibility for Caltrans traffic engineers to modify the selected CRM control parameters (according to certain rules) and observe the results in the corridor.

- 1) Strategic selection of control parameters for experiential modification
- 2) Displays the selected control parameters (from the CRM's models) and allow Caltrans Traffic Engineers to modify each parameter within certain limits.
- 3) Observing the control parameter changes in a corridor traffic level in real time
- 4) Allowing Caltrans Traffic Engineers to deactivate the operation of the CRM system at an onramp, or allow the control to return to the default LRRM

3.6 CRM GUI System integration

After the development of all the modules and sub-modules, the project team has integrated them all into a single CRM GUI tool, for testing and validation. We have accomplished the following activities:

- 1) Integrating data mapping GUI module with traffic state parameter estimation module
- 2) Integrating traffic state parameter estimation GUI module with CRM calculation module
- 3) Adding data output module which including:
 - saving traffic state parameters and calculated CRM rate in database
 - sending CRM rate to 2070 controllers in the field
 - display the relevant output parameters on Windows
- 4) Integrating with the existing CRM algorithm module by changing all the fixed configuration parameters to reading them from the databased from user's input

As an outcome, we have achieved an integrated CRM GUI Software Package which is able to run remotely through the internet.

4. User Manual and Training Caltrans District 3 freeway traffic engineers

This chapter is to documents the following two tasks:

- Main pages for information input
- Train Caltrans District 3 freeway traffic engineers in operation (including civil, electric and software engineers) for CRM GUI operation

To facilitating the application of the CRM GUI tool, the project team has developed an operating User Manual. In this chapter, we have provided more details for the major window pages to demonstrate how to use the GUI. More detailed page-by-page survey is in the Appendix 1 (User Manual: CRM GUI Website Survey) from page 39.

In addition, we have trained some Caltrans District 3 freeway traffic engineers in practice how to use the CRM GUI top start with a new freeway corridor. It is noted that, this CRM GUI tool can be applied to any other freeway corridors, not just those in District 3.

4.1 Main CRM GUI Pages

The following are some main pages with descriptions as how to open the page, input and correct the information, and save the input information to database for the underneath algorithm use.

4.1.1 Corridor Definition

CRM GUI System — Mozilla Firefox

128.32.234.154/CRM_GUI/corridor_definition.php

home corridor definition section definition traffic monitor instructions

Corridor Definition: Corridor modeling parameters

Corridor definition module helps users to define freeway corridor by inputting corridor name, number of onramps, sections, controllers, offramps, start postmile and end postmile.

Freeway corridor Name

--select-- Next (Section Definition) -> Sort Update

Freeway Corridor Name	No. Sections	No. Onramps	No. Offramps	No. Controllers	Start Postmile	End Postmile	Start/Stop		
SR99NB	18	17	12	28	287.07	298.50	Stop	Delete	Add

Home Corridor Definition Section Definition User Control Traffic Monitor Display Contact Us

Figure 20 Corridor Definition

A sample corridor, SR99NB, has already been defined. It has 18 sections, 17 onramps, 12 offramps, 28 controllers, and its start postmile is 287.07 miles and stop postmile is 298.50 miles. Note that the Start/Stop pulldown menu is defaulted to "Stop". This should not be changed to "Start" until the corridor is fully configured. The last two buttons, Delete and Add, delete and add a row from the corridor definition, respectively.

- (1). If "Add" is selected, the current row is copied to the row just below it. The corridor name should be changed to something else to avoid overwriting the SR99NB configuration.
- (2). Click "Update" in the row of control buttons above the corridor configuration. A popup window should say "File Saved". This would save the new configuration under its own directory on the server.
- (3). Click on the pulldown menu showing "--select--". Both of the configured corridors should be listed. Select the corridor name that was just created.
- (4). Click on the "Next (Section Definition)-->" button. Doing so would open the **Section Definition** page for the selected corridor.

4.1.2 Section Definition

The screenshot shows a web browser window displaying the 'SR99NB Section Definition' page. The page has a green header with navigation icons for 'home', 'corridor definition', 'section definition', 'traffic monitor', and 'instructions'. Below the header, the title 'SR99NB Section Definition' is centered, followed by a brief description: 'Section Definition module helps users to input traffic configuration of selected corridor, which can be the detailed information about sections'. There are 'Sort' and 'Update' buttons above a table. The table is divided into two main sections: 'Onramp Controllers' and 'TMS Controller #1'. The 'Onramp Controllers' section has columns for Name, Postmile, IP_Address, Port, En/Disable, Control Source, and Time Intervals. The 'TMS Controller #1' section has columns for Name, Postmile, IP_Address, and Port. Each row in the table includes 'Edit', 'Delete', and 'Add' buttons. The footer contains links for Home, Corridor Definition, Section Definition, User Control, Traffic Monitor, Display, and Contact Us.

Onramp Controllers				En/Disable	Control Source	Time Intervals	TMS Controller #1				Edit	Delete	Add
Name	Postmile	IP_Address	Port				Name	Postmile	IP_Address	Port			
E_Stockton	287.07	10.253.28.96	10014	Disable	LRR	Interval					Edit	Delete	Add
EK_Grove	287.23	10.253.28.96	10012	Disable	LRR	Interval	Red Fox	287.615	10.254.25.11	1000	Edit	Delete	Add
EB_Laguna	288.25	10.254.25.12	1002	Disable	LRR	Interval					Edit	Delete	Add
WB_Laguna	288.47	10.254.25.12	1000	Disable	LRR	Interval	Laguna Cree	288.88	10.253.28.10	1000	Edit	Delete	Add
EB_Sheldon	289.274	10.253.28.10	1000	Disable	LRR	Interval					Edit	Delete	Add
WB_Sheldon	289.423	10.253.28.10	1000	Disable	LRR	Interval	Jacinto	290.003	10.254.27.67	1000	Edit	Delete	Add

Figure 21. Section Definition

The section definition page for a new corridor is blank. The configuration table contains the same number of lines as the number of onramps that was configured on the Corridor Definition page. If the corridor "SR99NB" had been selected on the Corridor Definition page, the configuration for SR99NB would appear on the Corridor Definition page

- (1).Name: The name of the onramp cross street. Important: All of the names in a given corridor must be unique. Section definitions are named with the corridor and onramp name, so a given corridor and onramp pair must be unique or the configuration would be overwritten with the second name.
- (2).Postmile: Make sure the postmile is correct. After Section Definition is complete, the Sort button would sort the sections (onramps) according to postmile. The order is important because that's how the optimization is done.
- (3).IP Address: This and the port must be correct or we'll end up barking up the wrong tree.
- (4).Port: The port on the cell modem must be used, not the local port number that the connection is forwarded to,
- (5).Enable/Disable: This is the control enable for the ramp meter controller. If this control is set to "Disable", the CRM system would not even poll the controller for data. Leave it Disabled until everything is done.

- (6). Control Source: Local vs. Coordinated Ramp Metering. This control tells the CRM system whether or not to use the optimizing algorithm in determining the metering rates. This does almost the same thing as Enable/Disable except that the CRM system would continue to poll the controller for data.
- (7). Time Intervals: This opens a web page (described under **Time Interval Control** below) that allows the user to modify the control time intervals, maximum and minimum metering rates, and lower occupancy thresholds.
- (8). TMS Controller #1-3: The settings for the Traffic Monitoring Stations are the same as those for the onramp controllers. Make sure the postmiles are sequential AFTER the postmile for the onramp controller. The TMS stations are sorted with their onramp controller, not by themselves.
- (9). Edit: This opens a web page (described under **Section Controllers Definition** below) in which parameters specific to a section, such as onramp number of lanes and length, or mainline lane type, are configured.
- (10). Delete: Delete this row, and therefore section, from the corridor.
- (11). Add: Add a row beneath this row, copying the values of this row to the new one. Then change the parameter settings.
- (12). Sort: Hit the Sort button to sort the sections by onramp postmile. This must be done before saving the configuration.
- (13). Update: Hit the Update button to save the configuration. The next time this corridor is selected from the Corridor Definition page, the fields would automatically be populated.

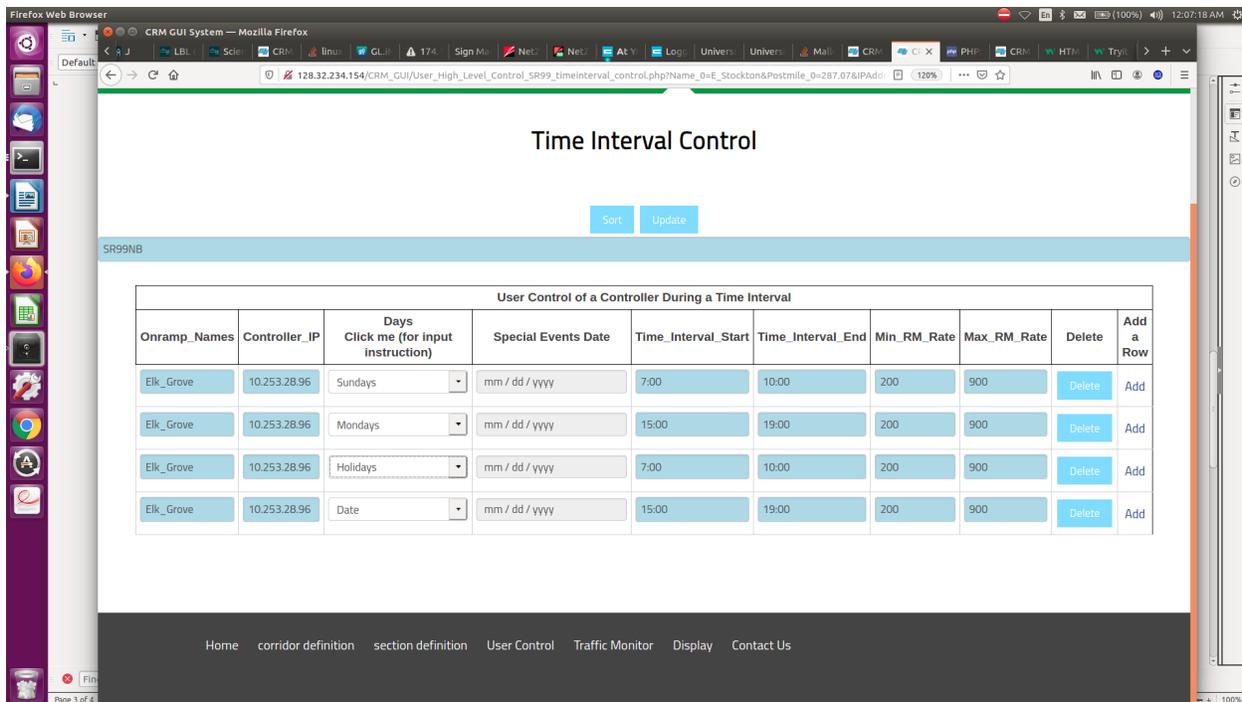


Figure 22. Operation time interval selection

4.1.3 Time Interval Control

Time Interval Control is the web page where the user can modify the control time intervals, maximum and minimum metering rates, and lower occupancy thresholds. It opens when the user clicks on the Control button for one of the sections in Section Definition. The name and controller IP for the onramp that was clicked on appear in "Onramp Names" and "Controller IP", respectively

- (1). Days: This is a pulldown menu containing a list of the days of the week, Sunday through Saturday, Holidays, and Special Events. One time interval pair, one rate pair, and one minimum occupancy threshold may be set for the chosen day. For more than one interval on a given day, the "Add a row" button at the end of the row is clicked, and a new row is added with the settings of the row from which it was chosen, already filled in. So if, for instance, there are two peak periods on Wednesdays, the first period is entered, Add a row is clicked, and the changed parameters for the afternoon peak are entered.
- (2). If the button at the end of the row is clicked, and a new row is added with the settings of the row from which it was chosen, already filled in. So if, for instance, there are two peak periods on Wednesdays, the first period is entered, Add a row is clicked, and the changed parameters for the afternoon peak are entered.
- (3). One set of parameters may be configured for Holidays. The holidays covered are New Year's Day, Martin Luther King, Jr. Day, President's Day, Memorial Day, Independence Day, Labor Day, Thanksgiving Day and the day after that, and Christmas.

- (4). Clicking on Special Events brings up a calendar, from which a date may be chosen. Parameter sets for that day may be entered in the day's row.

4.1.4 Section Controllers Definition

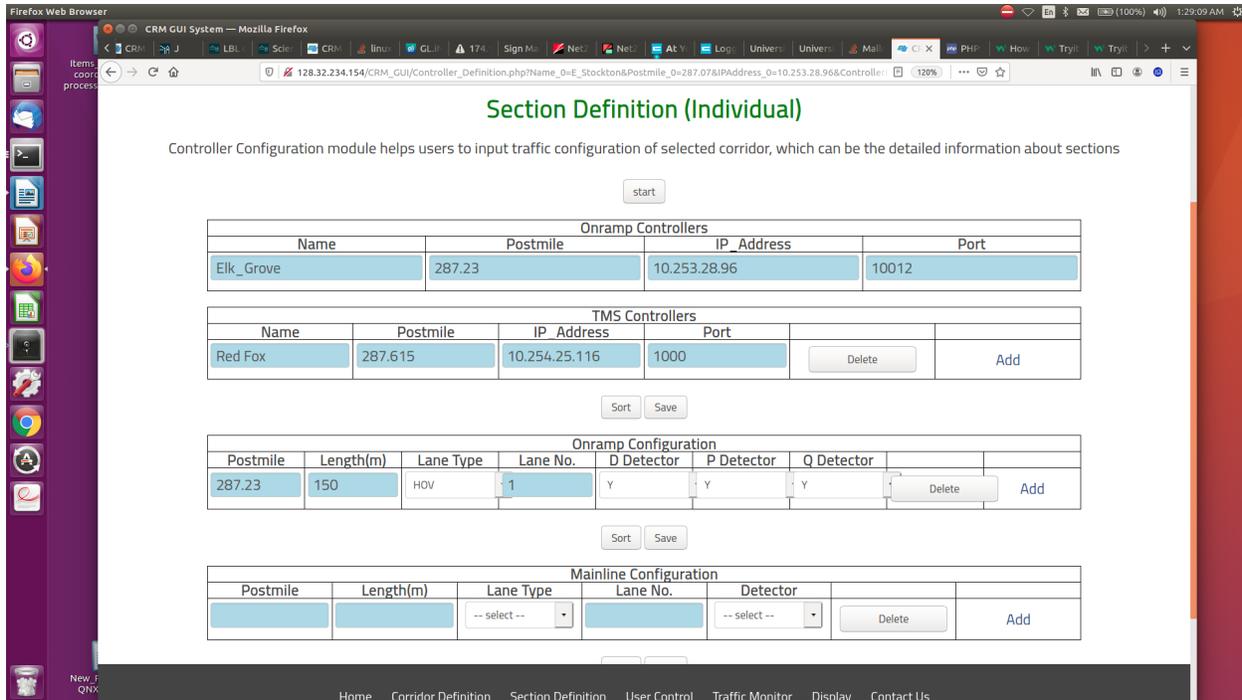


Figure 23. Section traffic controller information

The Section Controllers Definition web page is where parameters for a particular section are configured. It opens when the user clicks on the Edit button for one of the sections in **Section Definition**.

4.1.5 Onramp Controllers:

The name, postmile, controller IP, and port app for the onramp that was clicked on in **Section Definition** should appear in the entries under "Onramp Controllers"

4.1.6 TMS Controllers

The name, postmile, controller IP, and port for the TMS controller(s) pertaining to the onramp that was clicked on appear in the entries under "TMS Controllers"

Onramp Configuration:

- (1). Postmile: The postmile should be automatically entered in the first column.

- (2). Length: Enter the length of the onramp in meters.
- (3). Lane Type: Choose one of "HOV" for High Occupancy Vehicle or "GP" for General Purpose lane type.
- (4). Lane No.: Enter the lane number
- (5). D Detector: Choose "Y" or "N" if the lane has a demand detector.
- (6). P Detector: Choose "Y" or "N" if the lane has a passage detector.
- (7). Q Detector: Choose "Y" or "N" if the lane has one or more queue detectors.
- (8). Delete: Hit Delete to remove this row.
- (9). Add: Hit Add to add another row below this row, and copy the contents to the new row.

Mainline Configuration:

- (1). Postmile: The postmile should be automatically entered in the first column.
- (2). Length: Enter the length of the section in meters.
- (3). Lane Type: Choose one of "HOV" for High Occupancy Vehicle or "GP" for General Purpose lane type.
- (4). Lane No.: Enter the lane number
- (5). Detector: Choose "Y" or "N" if the lane has one or more detectors.
- (6). 8. Delete: Hit Delete to remove this row.
- (7). Add: Hit Add to add another row below this row, and copy the contents to the new row.

Offramp Configuration:

- (1). Postmile: The postmile should be automatically entered in the first column.
- (2). Length: Enter the length of the offramp in meters.
- (3). Lane Type: Choose one of "HOV" for High Occupancy Vehicle or "GP" for General Purpose lane type.
- (4). Lane No.: Enter the lane number
- (5). Detector: Choose "Y" or "N" if the lane has any detector.
- (6). Delete: Hit Delete to remove this row.
- (7). Add: Hit Add to add another row below this row, and copy the contents to the new row.

4.2 Traffic engineer training

On June 21 2023, the project team conducted hands-on training of Caltrans District 3 freeway traffic engineers on site. Before the training, we provided them a User Manual and Online website. Therefore, they knew much of the processes already. The face-to-face hand-on training included the explanation “how” as the following:

- (1). How to link the D3 computer with Caltrans Intranet
- (2). How to login the engineering computer
- (3). Display with a large LED for show-and-tell

- (4). How to open the GUI and get the tool started
- (5). How to input all the required parameters step-by-step from GUI
- (6). How to define the directory structure on the D3 engineering computer to run the CRM GUI tool
- (7). How to access the Working Directory on the Caltrans D3 computer
- (8). How to compile (assuming they do not know the online command in Linux or QNX)
- (9). How to find the data directory for all the engineering data we saved with the C-code underneath, in case the user needs to conduct data analysis
- (10). How to run the program - command of Script File
- (11). What data set should be looked at to check if all the parameter passing to the underneath program is correct
- (12). How to debug if:
 - the generate GUI generated program code is not compiling
 - the compiled code does not run or execute
 - there is any other problems

The training turned out to be successful.

5. Extension of The CRM Control Range from 11 Onramps to 17 Onramps

This task is outside of the scope of work of this project.

The objective of this task is to extend the CRM control range from 11 onramps (Calvine to 12th Ave) to 17 onramps with 6 upstream onramps from E. Stockton to Sheldon WB. This is required by Caltrans District 3 RTMC and agreed by the project team without additional funding request. The following Table 1 includes the extended range of SR 99 North Bound direction with additional six onramps:

Table 1. Extension of CRM operation range by adding 6 upstream onramps

Entrance ramp ID	Street Names	RM strategy	Entrance ramp ID	Street Name	RM strategy
1	E. Stockton Blvd	CRM	10	Mack Road WB	CRM
2	Elk Grove	CRM	11	Florin EB	CRM
3	Laguna Blvd EB	CRM	12	Florin WB	CRM
4	Laguna Blvd WB	CRM	13	47 th Ave EB	CRM
5	Sheldon EB	CRM	14	47 th Ave WB	CRM
6	Sheldon WB	CRM	15	Fruitridge EB	CRM
7	Calvine EB	CRM	16	Fruitridge WB	CRM
8	Calvine WB	CRM	17	12 th Ave	CRM
9	Mack Road EB	CRM			

We have conducted the following subtasks:

- 1) Link the field real-time data of the upstream 6 onramps with the control system and to have built a data mapping.
- 2) Extend the data processing to include the upstream 6 onramps to generate traffic state parameters for upstream mainline, onramps and off-ramps.
- 3) Extend the CRM control to upstream 6 onramps.
- 4) Conduct dry-run (without CRM activation) for data analysis to make sure the overall system is working;
- 5) Progressively switching on for field operation.

After the extension, the CRM system has been thus operating on 17 onramps on SR-99 corridor from E. Stockton to SR-50 interchange for Caltrans District 3 daily operation. Since this part of work was not originally proposed by the project team, we did not have any resources for data analysis on the outcome of this extension.

6. References:

- [1]. X. Y. Lu, D. J. Chen, and S. E. Shladover, 2014 Preparations for Field Testing of Combined Variable Speed Advisory (VSA) and Coordinated Ramp Metering (CRM) for Freeway Traffic Control, Final Report, UCB-ITS-PRR-2014-1, Jan 2014, DOI: 10.13140/2.1.3612.5442
- [2]. Xiao-Yun Lu, Chen-Ju Wu (GSR), John Spring, and Dr. Steven E. Shladover, Field Test of Coordinated Ramp Metering (CRM), Final Report, UCB-ITS-PRR-2017
- [3]. X. Y. Lu, Kim, Z., Cao, M., Varaiya, P., Horowitz, R., and Palen, J., 2009, Portable loop fault diagnosis tool development for control cabinet level, CD ROM of 88th TRB Annual Meeting, Washington D. C., Jan.
- [4]. X. Y. Lu, P. Varaiya, R. Horowitz, J. Palen, 2008, Systematic Loop Fault Detection and Data Correction for Traffic Monitoring, presented at North American Traffic Monitoring Exposition and Conference (NATMEC) August 5th ~ 8th, Washington D. C.
- [5]. X. Y. Lu, P. Varaiya, R. Horowitz, J. Palen, 2008, Systematic Loop Fault Detection and Data Correction for Traffic Monitoring, NATMEC, Aug. 5th ~ 8th, Washington D. C.
- [6]. X. Y. Lu, Z. Amini, M. Mauch, and A. Skabardonis, Congestion-Responsive On-Ramp Metering: Recommendations toward a Statewide Policy, California PATH Research Report, UCB-ITS-PRR-2019-01
- [7]. X. Y. Lu, T. Z. Qiu, P. Varaiya, R. Horowitz, and S. Shladover, 2010, Combining Variable Speed Limits with Ramp Metering for freeway traffic control, CD ROM of 2010 American Control Conference, Baltimore, Maryland, June 30 - July 2
- [8]. X. Y. Lu, P. Varaiya, R. Horowitz, D. Su and S. E. Shladover, 2011, A novel freeway traffic control with variable speed limit and coordinated ramp metering, 90th TRB Annual Meeting, Washington, D. C., Jan. 23-27
- [9]. X. Y. Lu, P. Varaiya, R. Horowitz, D. Su and S. E. 2011, Shladover A novel freeway traffic control with variable speed limit and coordinated ramp metering, Transportation Research Record, No. 2229, pp. 55–65. DOI: 10.3141/2229-07
- [10]. X. Y. Lu, T. Z. Qiu, R. Horowitz, A. Chow, and S. Shladover, 2014, METANET Model Improvement for Traffic Control, Int. J. of Transportation, Vol. 2, No. 2, August , pp.65-88

7. User Manual: CRM GUI Website Survey

This chapter documents the CRM GUI website User Manual which was used for traffic engineer training. It can be used as references for future projects on the implementation of the CRM GUI Tool by Caltrans freeway traffic engineers.

Coordinated Ramp Metering Graphical User Interface

Survey of CRM GUI website

Open a browser to: http://128.32.234.154/CRM_GUI

CRM GUI System — Mozilla Firefox

128.32.234.154/CRM_GUI/

home corridor definition section definition instructions

Coordinated Ramp Metering Graphical User Interface

This tool is to help traffic engineers define, configure, and control the coordinated ramp metering of highway corridors and their sections. It is also used to store the database and monitor the status of highways.

This system consists of four modules: corridor definition, section definition, user control, and traffic monitoring.

128.32.234.154/CRM_GUI/corridor_definition.php

Click on the Corridor Definition tab. The corridor definition page opens up with an example (SR99NB) already filled in. Drag the menu select to the named corridor and hit “Next”

Corridor Definition: Corridor modeling parameters

Corridor definition module helps users to define freeway corridor by inputting corridor name, number of onramps, sections, controllers, offramps, start postmile and end postmile.

Freeway corridor Name

-- select -- Next (Section Definition) -> Sort Update

Freeway Corridor Name	No. Sections	No. Onramps	No. Offramps	No. Controllers	Start Postmile	End Postmile	Start/Stop			
SR99NB	18	17	12	28	287.07	298.50	Stop	Start	Delete	Add

The section definition page is where all of the onramps and TMS controllers are defined. Time intervals and individual section definitions are done via sub screens accessed by buttons from this screen. Note that the corridor name is in the title.

Click on the Interval/Rate control button for Elk Grove.

SR99NB Section Definition

Section Definition module helps users to input traffic configuration of selected corridor, which can be the detailed information about sections

Sort Update

Onramp Controllers				En/Disable	LRRM/CRM	Interval/Rate Control	TMS Controller #1				TMS Controller #2				TMS Controller #3				Section Definition (Individual)	Delete	Add
Name	Postmile	IP_Address	Port				Name	Postmile	IP_Address	Port	Name	Postmile	IP_Address	Port	Name	Postmile	IP_Address	Port			
E_Stockton	287.07	10.253.28.191	10014	Dis	LRI	Control											Edit	Delete	Add		
Elk_Grove	287.23	10.253.28.191	1004	Dis	LRI	Control	Red Fox	287.61	10.254.25.11E	1000							Edit	Delete	Add		
EB_Laguna	288.25	10.253.29.99	1000	Dis	LRI	Control											Edit	Delete	Add		
WB_Laguna	288.47	10.253.28.198	2000	Dis	LRI	Control	Laguna Creel	288.88	10.253.28.177	1000							Edit	Delete	Add		
EB_Sheldon	289.274	10.253.28.207	10012	Dis	LRI	Control											Edit	Delete	Add		
WB_Sheldon	289.423	10.253.28.203	1002	Dis	LRI	Control											Edit	Delete	Add		
EB_Calvine	290.662	10.254.27.82	1000	Dis	LRI	Control											Edit	Delete	Add		
WB_Calvine	290.791	10.254.27.81	1000	Dis	LRI	Control	Stockton	291.54	10.253.28.21E	1000							Edit	Delete	Add		
EB_Mack	292.084	10.254.28.213	1000	Dis	LRI	Control											Edit	Delete	Add		
WB_Mack	292.383	10.254.28.212	1000	Dis	LRI	Control	Pomegranat	292.77	10.253.28.107	1000	Orange	292.77	10.253.28.1	1000			Edit	Delete	Add		
EB_Florin	293.986	10.253.29.103	1000	Dis	LRI	Control											Edit	Delete	Add		
WB_Florin	294.217	10.253.29.28	10012	Dis	LRI	Control											Edit	Delete	Add		

Home Corridor Definition Section Definition User Control Traffic Monitor Display Contact Us

All the ramp metering time intervals, rates, and minimum occupancies for those rates are configured here.

Click on the back button in the top tab to return to the section definition page.

The screenshot shows a web browser window with the URL `128.32.234.154/CRM_GUI/User_High_Level_Control_SR99_timeinterval_control.php?Name_0=E_Stockton&Postmile_0=287.07&IPAddress_0=10.253.28.191&Contr`. The page has a green header with navigation icons for home, corridor definition, section definition, and instructions. Below the header is the title "Time Interval Control" and two buttons: "Sort" and "Update".

The main content area displays a table titled "User Control of a Controller During a Time Interval". The table has the following columns: Onramp_Names, Controller_IP, Days (with a dropdown menu), Special Events Date, Time_Interval_Start, Time_Interval_End, Min_RM_Rate, Max_RM_Rate, Min_occupancy, Delete, and Add a Row. The table contains 8 rows of data for the Elk_Grove onramp, covering days from Sundays to Holidays.

Onramp_Names	Controller_IP	Days Click me (for input instruction)	Special Events Date	Time_Interval_Start	Time_Interval_End	Min_RM_Rate	Max_RM_Rate	Min_occupancy	Delete	Add a Row
Elk_Grove	10.253.28.19	Sundays	mm / dd / yyyy	00:00	23:59	400	750	5	Delete	Add
Elk_Grove	10.253.28.19	Mondays	mm / dd / yyyy	00:00	23:59	400	750	5	Delete	Add
Elk_Grove	10.253.28.19	Tuesdays	mm / dd / yyyy	00:00	23:59	400	750	5	Delete	Add
Elk_Grove	10.253.28.19	Wednesdays	mm / dd / yyyy	00:00	23:59	400	750	5	Delete	Add
Elk_Grove	10.253.28.19	Thursdays	mm / dd / yyyy	00:00	23:59	400	750	5	Delete	Add
Elk_Grove	10.253.28.19	Fridays	mm / dd / yyyy	00:00	23:59	400	750	35	Delete	Add
Elk_Grove	10.253.28.19	Saturdays	mm / dd / yyyy	00:00	23:59	400	750	5	Delete	Add
Elk_Grove	10.253.28.19	Holidays	mm / dd / yyyy	00:00	23:59	400	750	5	Delete	Add

At the bottom of the page, there is a navigation bar with links: Home, corridor definition, section definition, User Control, Traffic Monitor, Display, and Contact Us.

Click on the Section Definition (Individual) button for Elk Grove to go to the individual section definition page for Elk Grove.

SR99NB Section Definition

Section Definition module helps users to input traffic configuration of selected corridor, which can be the detailed information about sections

Sort Update

Onramp Controllers				En/Disable	LRRM/CRM	Interval/Rate Control	TMS Controller #1				TMS Controller #2				TMS Controller #3				Section Definition (Individual)	Delete	Add
Name	Postmile	IP_Address	Port				Name	Postmile	IP_Address	Port	Name	Postmile	IP_Address	Port	Name	Postmile	IP_Address	Port			
E_Stockton	287.07	10.253.28.191	10014	Dis	LRI	Control												Edit	Delete	Add	
Elk_Grove	287.23	10.253.28.191	1004	Dis	LRI	Control	Red Fox	287.61	10.254.25.116	1000								Edit	Delete	Add	
EB_Laguna	288.25	10.253.29.99	1000	Dis	LRI	Control												Edit	Delete	Add	
WB_Laguna	288.47	10.253.28.198	2000	Dis	LRI	Control	Laguna Creel	288.88	10.253.28.177	1000								Edit	Delete	Add	
EB_Sheldon	289.274	10.253.28.207	10012	Dis	LRI	Control												Edit	Delete	Add	
WB_Sheldon	289.423	10.253.28.203	1002	Dis	LRI	Control												Edit	Delete	Add	
EB_Calvine	290.662	10.254.27.82	1000	Dis	LRI	Control												Edit	Delete	Add	
WB_Calvine	290.791	10.254.27.81	1000	Dis	LRI	Control	Stockton	291.54	10.253.28.216	1000								Edit	Delete	Add	
EB_Mack	292.084	10.254.28.213	1000	Dis	LRI	Control												Edit	Delete	Add	
WB_Mack	292.383	10.254.28.212	1000	Dis	LRI	Control	Pomegranate	292.77	10.253.28.107	1000	Orange	292.77	10.253.28.1	1000				Edit	Delete	Add	
EB_Florin	293.986	10.253.29.103	1000	Dis	LRI	Control												Edit	Delete	Add	
WB_Florin	294.217	10.253.29.28	10012	Dis	LRI	Control												Edit	Delete	Add	

Home Corridor Definition Section Definition User Control Traffic Monitor Display Contact Us

The Section Definition (Individual) page is where the onramp, mainline, and offramp parameters are entered. Note the onramp and TMS controllers are displayed on this page for reference.

CRM GUI System — Mozilla Firefox

128.32.234.154/CRM_GUI/Controller_Definition.php?Name_0=E_Stockton&Postmile_0=287.07&IPAddress_0=10.253.28.191&ControllerPort_0=10014&DataName1

Section Definition (Individual)

Controller Configuration module helps users to input traffic configuration of selected corridor, which can be the detailed information about sections

Onramp Controllers				
Name	Postmile	IP_Address	Port	
Elk_Grove	287.23	10.253.28.191	1004	

TMS Controllers			
Name	Postmile	IP_Address	Port
Red Fox	287.615	10.254.25.116	1000

Onramp Configuration							
Postmile	Length(m)	Lane Type	Lane No.	D Detector	P Detector	Q Detector	
287.23	500	HOV	1	Y			Delete Add
287.23	500	GP	2	N			Delete Add
287.23	500	GP	3	Y			Delete Add

Mainline Configuration					
Postmile	Length(m)	Lane Type	Lane No.	Detector	
		HOV	1	Y	Delete Add
		GP	2	N	Delete Add

Offramp Configuration					
Postmile	Length(m)	Lane Type	Lane No.	Detector	
100.0	100.0	GP	1	Y	Delete Add

Coordinated Ramp Metering Graphical User Interface

**Configuring a corridor for ramp metering using the CRM
GUI website**

Click on the Corridor Definition tab. The corridor definition page opens up with an example (SR99NB) already filled in. Click on the Add button at the end of the SR99NB configuration line. The SR99NB configuration is copied to a new line.

Corridor Definition: Corridor modeling parameters

Corridor definition module helps users to define freeway corridor by inputting corridor name, number of onramps, sections, controllers, offramps, start postmile and end postmile.

Freeway corridor Name

-- select -- Next (Section Definition) -> Sort Update

Freeway Corridor Name	No. Sections	No. Onramps	No. Offramps	No. Controllers	Start Postmile	End Postmile	Start/Stop			
SR99NB	18	17	12	28	287.07	298.50	Stop	Start	Delete	Add

Change the corridor name to another, unique name and hit “Update”. (Note: Hitting “Update” in all of the configuration web pages is how the displayed configuration is implemented.)

CRM GUI System — Mozilla Firefox

128.32.234.154/CRM_GUI/corridor_definition.php#

home corridor definition section definition instructions

Corridor Definition: Corridor modeling parameters

Corridor definition module helps users to define freeway corridor by inputting corridor name, number of onramps, sections, controllers, offramps, start postmile and end postmile.

Freeway corridor Name

-- select -- Next (Section Definition) -> Sort Update

Freeway Corridor Name	No. Sections	No. Onramps	No. Offramps	No. Controllers	Start Postmile	End Postmile	Start/Stop			
SR99NB	18	17	12	28	287.07	298.50	Stop	Start	Delete	Add
SR99NB	18	17	12	28	287.07	298.50	Stop	Start	Delete	Add

After the update, the new name appears in the dropdown menu. Change the fields for the new onramp and hit “Update”. Drag down on the menu select again to get the new onramp. Hit “Next” to get to the Section Definition page.

Corridor Definition: Corridor modeling parameters

Corridor definition module helps users to define freeway corridor by inputting corridor name, number of onramps, sections, controllers, offramps, start postmile and end postmile.

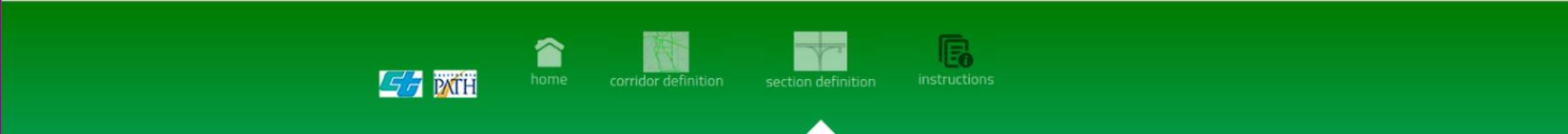
Freeway corridor Name

-- select --
 SR99NB
 John

Next (Section Definition) -> Sort Update

Freeway Corridor Name	No. Sections	No. Onramps	No. Offramps	No. Controllers	Start Postmile	End Postmile	Start/Stop	Start	Delete	Add
SR99NB	18	17	12	28	287.07	298.50	Stop	Start	Delete	Add
John	18	17	12	28	287.07	298.50	Stop	Start	Delete	Add

Here we enter the corridor's onramp names, their postmiles, IP addresses and ports. We do the same thing for any TMS controllers. Finally, we choose whether to enable the onramps and whether they will be metered according to CRM or LRRM. Hitting "Update" saves the changes. To configure each onramp controller, hit the "Section Definition (Individual) button near the end of each line. Here we choose A_Street.



John Section Definition

Section Definition module helps users to input traffic configuration of selected corridor, which can be the detailed information about sections

Sort Update

Onramp Controllers				En/Disable	LRRM/CRRM	Interval/Rate Control	TMS Controller #1				TMS Controller #2				TMS Controller #3				Section Definition (Individual)	Delete	Add
Name	Postmile	IP_Address	Port				Name	Postmile	IP_Address	Port	Name	Postmile	IP_Address	Port	Name	Postmile	IP_Address	Port			
A Street	100	10.253.99.83	1000	En		Control												Edit	Delete	Add	
B Street	101	10.253.99.84	1000			Control												Edit	Delete	Add	
C Street	102	10.253.99.85	10012			Control												Edit	Delete	Add	
D Street	103	10.253.99.86	10013			Control												Edit	Delete	Add	

The individual section definition pages are used for configuring the optimizer with important parameters such as number of lanes, detector type, length of mainline and ramp lengths, etc. Hit “Update” separately for each configuration. Onramp and TMS controller parameters are read in from the Section Definition page for reference and are not changed here. Hit the back button to return to the Section definition page.

Section Definition (Individual)

Controller Configuration module helps users to input traffic configuration of selected corridor, which can be the detailed information about sections

Onramp Controllers			
Name	Postmile	IP_Address	Port
A_Street	100	10.253.99.83	1000

TMS Controllers			
Name	Postmile	IP_Address	Port

Onramp Configuration								Sort	Save
Postmile	Length(m)	Lane Type	Lane No.	D Detector	P Detector	Q Detector			
100	100	GP	1	N	Y	Y	Delete	Add	

Mainline Configuration							Sort	Save
Postmile	Length(m)	Lane Type	Lane No.	Detector				
100	1500	GP	1	Y	Delete	Add		

Offramp Configuration							Sort	Save
Postmile	Length(m)	Lane Type	Lane No.	Detector				
100.0	100.0	GP	1	Y	Delete	Add		

Metering times, rates, and minimum occupancy are set in the Time Interval Control page, which is displayed by hitting the Control button for an onramp. Here we choose A_Street.

The screenshot shows a web browser window with the URL `128.32.234.154/CRM_GUI/Section_Definition.php?CorridorName=John`. The page title is "John Section Definition". Below the title, there is a description: "Section Definition module helps users to input traffic configuration of selected corridor, which can be the detailed information about sections". There are "Sort" and "Update" buttons. The main content is a table with columns for Onramp Controllers and TMS Controller #1, #2, and #3. The table has 4 rows of data for A Street, B Street, C Street, and D Street. Each row has an "Interval/Rate Control" button. At the bottom, there is a navigation menu with links: Home, Corridor Definition, Section Definition, User Control, Traffic Monitor, Display, and Contact Us.

Onramp Controllers				En/Disable	LRRM/CRM	Interval/Rate Control	TMS Controller #1				TMS Controller #2				TMS Controller #3				Section Definition (Individual)	Delete	Add
Name	Postmile	IP_Address	Port				Name	Postmile	IP_Address	Port	Name	Postmile	IP_Address	Port	Name	Postmile	IP_Address	Port			
A Street	100	10.253.99.83	1000	En		Control											Edit	Delete	Add		
B Street	101	10.253.99.84	1000			Control											Edit	Delete	Add		
C Street	102	10.253.99.85	10012			Control											Edit	Delete	Add		
D Street	103	10.253.99.86	10013			Control											Edit	Delete	Add		

The Time Interval Control page is used to set the metering intervals, maximum and minimum rates, and the minimum occupancy for starting the CRM.

CRM GUI System — Mozilla Firefox

http://128.32.234.154/CRM_GUI/User_High_Level_Control_SR99_timeinterval_control.php?Name_0=A_Street&Postmile_0=100&IPAddress_0=10.253.99.123&ControllerIP_0=10.253.99.123

home corridor definition section definition instructions

Time Interval Control

Sort Update

John

User Control of a Controller During a Time Interval										
Onramp_Names	Controller_IP	Days Click me (for input instruction)	Special Events Date	Time_Interval_Start	Time_Interval_End	Min_RM_Rate	Max_RM_Rate	Min_occupancy	Delete	Add a Row
A_Street	10.253.99.12	Mondays	mm / dd / yyyy	06:00	10:00	200	900	5	Delete	Add
A_Street	10.253.99.12	Tuesdays	mm / dd / yyyy	06:00	10:00	200	900	10	Delete	Add

Home corridor definition section definition User Control Traffic Monitor Display Contact Us

Here we enter the corridor’s onramp names, their postmiles, IP addresses and ports. We do the same thing for any TMS controllers. Finally, we choose whether to enable the onramps and whether they will be metered according to CRM or LRRM. Hitting “Update” saves the changes. To configure each onramp controller, hit the “Section Definition (Individual) button near the end of each line. Here we choose A_Street.

The screenshot shows a web browser window with the URL `128.32.234.154/CRM_GUI/Section_Definition.php?CorridorName=John`. The page has a green header with navigation icons for home, corridor definition, section definition, and instructions. Below the header, the title "John Section Definition" is displayed, followed by a description: "Section Definition module helps users to input traffic configuration of selected corridor, which can be the detailed information about sections". There are "Sort" and "Update" buttons. The main content is a table with columns for Onramp Controllers and TMS Controller #1, #2, and #3. The table contains four rows for A Street, B Street, C Street, and D Street.

Onramp Controllers				En/Disable	LRRM/CRM	Interval/Rate Control	TMS Controller #1				TMS Controller #2				TMS Controller #3				Section Definition (Individual)	Delete	Add
Name	Postmile	IP_Address	Port				Name	Postmile	IP_Address	Port	Name	Postmile	IP_Address	Port	Name	Postmile	IP_Address	Port			
A Street	100	10.253.99.83	1000	En		Control												Edit	Delete	Add	
B Street	101	10.253.99.84	1000			Control												Edit	Delete	Add	
C Street	102	10.253.99.85	10012			Control												Edit	Delete	Add	
D Street	103	10.253.99.86	10013			Control												Edit	Delete	Add	

At the bottom of the page, there is a footer with navigation links: Home, Corridor Definition, Section Definition, User Control, Traffic Monitor, Display, Contact Us.

