US 50 ICM

Deployment Alternatives and Potential Strategies
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1. Introduction

The District 3 US 50 Integrated Corridor Management Implementation Plan (Plan) is a partnership-based development for a portion of US 50 transportation corridor through Yolo, Sacramento, and El Dorado counties, that include the jurisdictions or cities of West Sacramento, Sacramento, Rancho Cordova, and Folsom, and the unincorporated areas of Rosemont, El Dorado Hills, and Cameron Park. Series of project development team (PDT) workshops were conducted with these partner agencies and consensus decision was reached to select the 37-mile corridor from Enterprise Blvd. in eastern Yolo County, thru Sacramento County, to Cameron Park Blvd. in western El Dorado County for the Plan, see Figure 1.

The PDT also decided that the ICM approach should seek a solution and implementation that address the following in the order of priority:

- non-recurrent congestion (incident and event management)
- corridor-specific traveler information
- multi-modal operations
- goods movement and truck traffic
- recurrent congestion (everyday commuter traffic congestion)

It was generally accepted that all of the approaches mentioned were meaningful for the US 50 corridor and should be considered for eventual implementation. To accomplish this, a phased implementation of targeted operations would be considered, addressing non-recurrent congestion initially along with corridor-specific traveler information. From experiences and lessons learned from the maturity of ICM projects around the country, the remaining three targeted operations of multi-modal operations, goods movement and truck traffic, and recurrent congestion would be addressed in added phases.
2. US 50 ICM Vision, Goals and Objectives

The PDT spent considerable effort in developing a vision statement for the ICM project that encompasses the desires of the participants, agreeing to the following:

“US 50 Integrated Corridor Management (ICM) is the proactive multiagency integration and management of the US 50 multimodal transportation corridor to move people and goods more effectively and ensure the greatest gains in operational performance across the entire corridor network.”

This vision statement may require slight modifications over time; however, the PDT felt this statement summarized many of the goals and objectives for the ICM project concept. The ICM partners also identified key objectives for the project to consider as the development of the ICM concept moved forward. These objectives were to:

- **Improve system performance**
  - Improve VMT, VHT, Delay, Collisions (fatalities), travel time reliability, flow, average speeds
- **Provide transportation choices**
  - Increase non-auto modes usage
  - Multimodal options provided
- **Increase accessibility**
  - Improve travel times, traveler information, multimodal connections made
- **Enhance sustainability**
  - Increase non-auto modes usage (transit, bicycles, pedestrians, and HOV)
- **Improve environment**
  - Reduce GHG emissions, green infrastructure added
- **Improve collaborative partnerships**

The US 50 ICM project, as proposed, would support the goals and objectives identified in District 3 Regional Concept of Transportation Operations (RCTO), presented in Table 1. The RCTO goals and objectives align with the Sacramento Area Council of Governments (SACOG’s) 2016 Metropolitan Transportation Plan/Sustainable Communities Strategy (MTP/SCS) guiding principles, which include:

- **Smart Land Use** - Design a transportation system to support good growth patterns, including increased housing and transportation options, focusing more growth inward and improving the economic viability of rural areas.
- **Environmental Quality and Sustainability** - Minimize direct and indirect transportation impacts on the environment for cleaner air and natural resource protection.
- **Financial Stewardship** - Manage resources for a transportation system that delivers cost-effective results and is feasible to construct and maintain.
- **Economic Vitality** - Efficiently connect people to jobs and get goods to market.
- **Access and Mobility** - Improve opportunities for businesses and citizens to easily access goods, jobs, services and housing.
- **Equity and Choice** - Provide real, viable travel choices for all people throughout our diverse region.
The concepts and principles associated with ICM implementations across the nation have demonstrated that these goals and objectives are reasonable and obtainable.

**Table 1: District 3 RCTO Goals and Objectives**

<table>
<thead>
<tr>
<th>District 3 RCTO Goals &amp; Objectives</th>
<th>District 3 Performance Targets</th>
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<tbody>
<tr>
<td><strong>Goal 1 (Caltrans SMP Goal #1) - Safety and Health</strong></td>
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| 1. Reduce user fatalities and injuries | • Result in 0.5 or less fatalities per 100 million VMT on SHS every year  
• 10% reduction in number of fatalities in calendar year in each mode type |
| **Goal 2 (Caltrans SMP Goal #2) - Stewardship and Efficiency** | |
| 1. Effectively manage transportation assets with asset management plan (fix-it-first) | • By 2020, maintain 90% or better ITS elements health |
| **Goal 3 (Caltrans SMP Goal #3) - Sustainability, Livability, and Economy** | |
| 1. Provide mobility choice, increase accessibility to all transportation modes and create transportation corridors | • By 2020, increase non-auto modes (triple bicycles, double pedestrians, and double transit ridership)  
• By 2020, 15% reduction of GHG (from 2010 levels)  
• By 2020, 20% increase incorporating green infrastructure into projects |
| 2. Support statewide reduction of GHG emissions | |
| **Goal 4 (Caltrans SMP Goal #4) - System Performance** | |
| 1. Improve travel time reliability for all modes | • By 2020, improve buffer time index reliability ranking by one level or 15%  
• By 2020, reduce to 8% rate of growth in daily vehicle hours’ delay (DHVD) under 35 mph on urban SHS |
| 2. Reduce peak period travel times and delays for all modes | |
| 3. Improve integration and operations | • By 2020, provide real-time multimodal system information to public along integrated corridors  
• By 2020, increase annual number of Complete Streets features by 5% |
| 4. Increase number of Complete Streets features on SHS | |
| 5. Develop integrated corridor management (ICM) strategies | • By 2020, complete one ICM implementation plan in District 3  
• By 2025, implement one ICM corridor in District 3, reduce to 6% rate of DVHD growth on corridor |
| **Goal 5 (Caltrans Goal #5) - Organizational Excellence** | |
| 1. Improve internal and external communication to demonstrate professionalism and service levels to the public and stakeholders | • By 2020, increase approval rating by stakeholders by at least 5% annually  
• By 2020, have at least 75% approval rating by collaborative partners |
| 2. Improve collaborative partnerships | |
3. Deployment Alternatives and Potential Strategies

The US 50 transportation corridor is ideal for an ICM deployment because it has multimodal characteristics and good alternative roadway routes. The corridor has light rail and bus transit, bicycle and pedestrian facilities, parallel arterial routes, and park and ride lots. It also has High-Occupancy Vehicle (HOV) lanes, ramp metering system, advanced signal operations, and Intelligent Transportation System (ITS) infrastructure for incident management and traveler information. These assets and their operations have been effectively used but are not integrated for integrated operations.

As the Project Development Team (PDT) has gained a deeper understanding of the potential benefits that implementation of the ICM concept can provide on US 50 with integrated operations, they have moved from building a consensus around the “concept generation” and have begun to explore alternatives for implementation and operation of the US 50 ICM corridor. This document provides a review of the implementation, operations, and management alternatives and potential strategies for deployment.

Implementation alternatives under consideration include “segmenting the corridor” into logical sub-segments based on the participating jurisdictions. This “segmenting” should not deter various jurisdictions from pursuing improvements that will support the ICM concept, rather help them make cost-effective investments while the “proof of concept” testing is taking place along the other sub-segments. Another alternative is staggering implementation with the agencies and technologies that are deployed along each segment. A discussion of staggering deployment technologies is also presented for consideration along with the potential strategies for deployment.

The operations alternatives section discusses the various “degrees and methods” under which an ICM deployment may be implemented. The number of partners involved and a large number of modes desired as part of the implementation may require the staggering of phases depending on individual agencies’ ability to participate both fiscally and with personnel required to fine tune the ICM system. Constraints imposed by limitations on operational staffing and infrastructure can delay the most willing of participants from implementing ICM on an aggressive schedule. Some initial element deployments and intersection upgrades may be required for the initial phase ICM implementation.

The operational management alternative section provides a discussion on how the implementation of the ICM deployment can be “soft launched” by taking advantage of previous investments through the coordination of manual operational changes when events occur outside a formally implemented ICM segment. Performance data should be collected where possible to document the benefits of inclusion when requesting funding for an expanded ICM project. The lessons learned will strengthen the implementation of the ICM when the segment length for implementation on the formal system encompasses these areas.

How the partners secure funding for the implementation of the ICM will most likely require taking advantage of multiple funding sources. To aid in this process a review of potential sources of funding is also presented. This presentation includes the “source of funding” and the applicability of “matching fund” use or requirements. Examples of ICM funding obtained in other regions are provided. All sources of funding are highly competitive and are oversubscribed, making the application process
critical. Including data to show the application and the leveraging of previous investments will be of high importance as funding applications are prepared.

4. Implementation Considerations

4.1. Corridor Segmentation Alternatives

The complete US 50 multimodal transportation corridor under consideration for ICM deployment is a section of the US 50 through Yolo, Sacramento, and El Dorado counties, including the cities of West Sacramento, Sacramento, Rancho Cordova, and Folsom, and the unincorporated areas of Rosemont, El Dorado Hills, and Cameron Park. The multimodal transportation corridor includes the freeway facility, arterials running parallel and connecting to the freeway facility, public transit systems, park and ride lots, transit parking structures and surface lots, and bicycle and pedestrian facilities.

The phased implementation of an initial deployment can also be dependent on the limits of corridor segments. Starting the ICM deployment project with as many as 12 agencies for 37 miles could be daunting in reaching consensus on all aspect of the ICM implementation, not to mention the high cost and resource needs.

The US 50 ICM corridor was divided into three segments for initial data collection and implementation considerations. The geographic boundaries are:

- Segment 1 (12 miles) – Enterprise Blvd. in West Sacramento thru the City of Sacramento to Watt Ave. in Sacramento County
- Segment 2 (18 miles) – Watt Ave. thru the cities of Rancho Cordova and Folsom to the Sacramento/El Dorado County Line.
- Segment 3 (7 miles) – Sacramento/El Dorado County Line to Cameron Park Dr. in El Dorado County

Although there is significant interest by the stakeholders to undertake the entire 37 miles, funding limitations may affect the breadth of initial deployment. The PDT and stakeholders have reached consensus on forwarding a single segment for implementation of proof of concept. All segments were considered for initial deployment, but Segment 2 was favored by the PDT for several reasons. Many of the arterials which run parallel to US 50 have received considerable funding commitments for traffic signal improvements or have recently completed modernization improvements. Some additional
improvements will be required for the implementation along these arterials; however, it appears as if the total cost for a proof of concept segment would be significantly less along segment 2. In addition, this segment includes fewer jurisdictions and less complex interfaces which the PDT consider advantageous as part of an initial implementation.

The implementation of the ICM corridor focusing on a single segment for initial deployment is favored in order to show the benefits the ICM approach will deliver. If the investments are spread over a larger geographic area the benefits may not prove as apparent as they would if funding was focused on segment 2.

As funding becomes available and additional improvements are implemented in the adjoining segments by the respective jurisdictions, it will be important to consider the future needs of ICM when designing those improvements. Further as being a good steward of public funds by considering the future investments necessary for the implementation of the ICM system and incorporating those into designs as time and funding allow.

4.1.1. Potential Strategy (Initial deployment starting with Segment 2)
The US 50 ICM initial deployment effort should focus on Segment 2. The jurisdictions that are adjoining the remaining two segments should continue their signal system upgrades, ITS and communication improvements projects as planned. Consideration should be given for the future needs of ICM deployment along these corridors and investments should consider the future deployment of ICM as they complete the project development process.

4.2. Staggered Deployment of ICM Elements Alternatives
The staggered deployment of technologies presents another method by which the implementation may be divided to reduce the cash flow demand for the ICM implementation. Various technologies should proceed other investments and the costs associated with the proposed very complex integration can be minimized while the proof of concept is being demonstrated by the initial technologies deployed. Deployment of technology for US 50 ICM elements include:

- ICM System (multiagency system)
- Freeway Management System (Caltrans)
- Arterial Management Systems (Caltrans and local agencies)
- Traveler Information (multiagency, Caltrans, or regional system)
- Transit Systems (transit agencies)
- Park and Ride Lots and Parking Management Systems (Caltrans, regional and local agencies, transit agencies)
- Active Transportation (Caltrans, regional and local agencies)
- Trucks and Goods Movement (multiagency)

The staggering of the implementation of these features will not occur in the order provided, as many functions will be desired for other purposes along the corridor in advance of the ICM system implementation. The Partnership should continue to work together to assure themselves that investments made by other projects contain the necessary data collection and distribution features necessary for sharing with the ICM system. The best method to allow for this future data sharing to require a “standards-based data output flow” as part of the initial purchase. The inclusion of a
requirement for an Institute of Transportation Engineers (ITE) based Traffic Management Data Dictionary (TMDD) Center to Center (C2C) data output is likely the best insurance of this future capability. If the vendor is required to provide a “key” to the data flow format, any reformatting of data required for integration into the ICM will be greatly simplified. By having this information for the new systems, risks will be reduced and will aid in controlling the future costs for the integration of these systems.

4.2.1. Potential Strategy (Initial deployment starting with ICM system, FMS, AMS, and TI)
The initial integration and deployment should include as a minimum the development of the ICM system and include the necessary components to provide coordination between the freeway management system and the arterial management system, as well as provisions for the dissemination of traveler information directly through existing avenues and by third party providers.

If a staggered implementation of ICM system is required, the following could be considered in phases:

- **Initial Integration and Deployment**
  - ICM System
  - Freeway Management System (FMS)
  - Arterial Management Systems (AMS)
  - Traveler Information (TI)
- **Future Add-on Phase 2**
  - Transit Systems
  - Parking Management Systems
  - Active Transportation
- **Future Add-on Phase 3**
  - Trucks and Goods Movement
  - Other
5. Operations Alternatives

5.1. Operational Mode Alternatives

The active management of the roadway network required by ICM can present new challenges to agencies not accustomed to actively manning their systems. While the ultimate outcome from an effective ICM program is likely to increase mobility, reduce the occurrence of secondary or parallel arterial incidents, and reduce motorists’ frustrations, the initial effort may require staff training and increased workload. With that in mind, the deployment of the ICM can be accomplished through different implementation modes. Depending on the level of involvement preferred by corridor stakeholders, the ICM system could operate in one of the following three modes:

- **Automatic mode** – This mode would allow for ICM operations with minimal interventions required from transportation system operators. All control devices would be directly managed by the ICM system based on information received from surveillance systems, external information systems, and predefined operational schedules. Predetermined response plan(s) would be selected depending on the corridor conditions and implemented without a required user intervention. System users would have the ability to review the selected response plan(s) to be activated and can make any adjustments, if needed. This is the most difficult operational mode to design and configure, as the absence of user intervention requires good decision-making by the system. This mode thus places the greatest responsibility for successful operations on the individuals tasked with designing, developing, and configuring the decision-support system.

- **Semi-automatic mode** – This mode differs from the automated mode in that it would require an operator’s approval of all proposed response plan for activation prior to their implementation by the system. An operator approval requirement would add a level of user oversight on system operations. However, this mode of operation also introduces a risk for stalled operation if the user approval cannot be obtained in a timely basis, either due to the unavailability of the responsible individuals or the continuous rejection of recommended actions by specific operators or stakeholders. This mode may be the best mode initially for staff to gain confidence in the decision-making before they feel confident in transitioning to an automatic mode.

- **Manual mode** – This mode would require the system operator(s) to make the appropriate decision to apply a recommended response plan by the system or take an appropriate course of action to address a corridor condition. In essence, this operational mode requires direct and continuous intervention by the system operator(s).

Among the three modes described above, the automated mode is viewed as being the preferred default mode of operation. However, this is also the most difficult mode to design, develop, and configure as it implies that the ICM system would be able to make the best system management decisions on its own. This means developing a system capable of making rational decisions considering not only the results of quantitative operational analyses but also the knowledge built with each decision implemented and results ensued. To gain confidence with an automatic system staff may need to routinely analyze and validate the systems decision-making. To reach that goal may require additional up-front effort.

With manual mode, direct and continuous intervention by the system operator(s) would be required. Past performances of such mode of operations tell us that slower reaction times and delayed response
times could be expected. In some cases, responses could be missed altogether. This mode would require the system operators to have a high level of expertise and experience.

5.1.1. Potential Strategy (Initial deployment starting with semi-automated system)

For the initial system deployment, the participating partner agencies in Segment 2 may be best served by deploying a semi-automated system. This is in part dictated by the new deployment and system management operations of the project within the Sacramento region. While the potential for operating in a fully automated mode for some times of the day may ultimately be desirable, a semi-automated operation would add a level of user oversight by the system operator(s) to ensure effective decision-making. A semi-automated operation might also be favored to help manage special events or unusual situations for which there may not be a clear response strategy or a need to consider factors not adequately modeled within the ICM system.

5.2. Alternatives of Alternate Route Infrastructure Improvements

To implement an effective ICM there may be additional infrastructure needs including alternative route navigational signing and potentially some intersection control improvements. Alternative routing signage may be accomplished by fixed or electronic signing, Variable Message Signs (VMS), depending on the complexity and number of optional routes that would be recommended for use. Electronic signs would have additional communication requirements and would be a greater cost than fixed signs. Electronic messaging would also provide greater flexibility and allow for the more complex intersections to be signed with information specifically related to an alternate route, reducing driver confusion. Some locations have used fixed guide signs with specific alternate route letter and numbers combined with arrows to indicate proper movements. When this “fixed sign” wayfinding system is combined with highway advisory radios (HARS) they can be effective at providing alternate route guidance. A hybrid approach to the electronic (at the more complex movement intersections) and fixed signs (at the more simple movement intersections) could be the best solution to reducing costs and providing the necessary wayfinding guidance. Another alternative is to allow third party wayfinding applications and route navigation systems to provide the alternate route information the portion of the public that uses/has the technology available. While this may not be a fully feasible alternative today, technology trends are moving in this direction and this should remain an information methodology worth revisiting as the deployment nears implementation.

The intersections requiring control improvements depend on location and operating agency. Most locations have been found to have signal controllers and communication systems capable of supporting ICM systems. Those that do not have advanced controllers or the necessary communication systems would require upgrades if they were to be controlled remotely as part of the ICM system. The other aspect of intersection upgrade only exists at a few intersections. That is at locations where intersections are either uncontrolled or controlled by 2/4-way stop signs. At these locations the throughput capacity for the intersections is limited. If the demand is very large drivers may be tempted to ignore the posted
controls which could result in an increase in incidents. Police manual traffic control may be needed in these cases to move traffic through these locations as conditions require.

A mapping of the locations requiring infrastructure improvements is represented in Figures 3 to 6. In the figures, alternate routes identified in the District 3 2014 Corridor System Management Plan (CSMP) are depicted (in black lines if viable for ICM or in red lines if not viable for ICM). Additional alternative routes, potentially viable for ICM, are also proposed for consideration. Viable alternate routes include those that provide most logical arterial facilities that are likely to be used as alternative routes by motorists during incidents. Among the arterial facilities along the freeway corridor, the viable alternate routes are those that the local agencies prefer to keep the diverting motorists kept to, instead of using other local arterials. Residential arterials are generally not viable for ICM.

5.2.1. Potential Strategy (Initial deployment starting with alternate route wayfinding signs)
Alternate route wayfinding signage or Variable Message Signs (VMS) will need to be implemented for guiding the public along alternate routing. As the deployment of ICM nears implementation a review of the available technologies will need to be completed to find the most cost-effective method to deliver the service. It is likely that some hybrid of the proposed approaches would be ultimately selected; however, depending on the location of “alternate route” application of fixed or electronic signage may be required. As implementation of the ICM package draws closer to implementation, consideration should be given to utilizing third party information/navigation providers to deliver the routing information.

Signal system controllers and intersection controls would also need to be reviewed to determine if the capacity to handle alternate demand exists. If intersection upgrades are required, they should be installed or consideration given to the non-utilization of that specific roadway as an alternate route.
Figure 3: West Sacramento US 50 Alternate Route Infrastructure Improvements
Figure 4: Central Sacramento US 50 Alternate Route Infrastructure Improvements
Figure 5: Mid-East Sacramento US 50 Alternate Route Infrastructure Improvements
Figure 6: East Sacramento / West El Dorado US 50 Alternate Route Infrastructure Improvements
6. Operational Management Alternatives

The proposed US 50 ICM system is to be operated at various levels of functionalities from the following Operational control center types:

- Caltrans’ Sacramento Regional Transportation Management Center (RTMC)
- Arterial Traffic Operation Centers (ATOC’s)
- Transit Operations Centers (TOC’s)

The ICM components to be controlled from each of these center types is largely dependent on the systems they manage, operational hours as well as staff and infrastructure capabilities. As the ICM system moves towards an automated design the level of staff time and effort dedicated to the operation of the ICM corridor will likely decrease. The level of effort required for the first adopters or implementers of the ICM concept will likely see an initially increased workload as the Decision Support System (DSS) and the acceptable scenario concepts are created and tuned to meet the regional parameters.

6.1. RTMC

ICM system components operated from the RTMC are to support the following operations:

- Collection, processing and archiving of traffic data from traffic and equipment monitoring systems operated by Caltrans on US 50 and at State-controlled signalized intersections
- Monitoring the operation of freeway ramp and connector meters, traffic signals, changeable message signs, and control devices directly operated by Caltrans
- Processing and archiving of relevant traffic and control data sent to the ICM server by local traffic management centers
- Implementing control actions recommended by the ICM system on field devices operated by Caltrans
- Performing various other freeway and intersection control management activities

Because of the new nature of system management with the project, it is possible that all control actions affecting Caltrans-operated devices could initially be manually entered into each management system by Caltrans operators, with possible automation after the system’s initial phase.

6.1.1. Freeway Management System (FMS) – Advanced Ramp Metering System (RMS)

The heart of the ICM is effective and safe movement onto and off the US 50 freeway mainline as well as a non-congested movement of traffic through the corridor on the freeway. All ramps need ramp metering equipped with 2070 controllers, centrally controlled as a part of the freeway management system. Ramp meter bypass for transit and emergency vehicles should also be considered where appropriate. Preferred operations would be an advanced (adaptive) corridor-wide ramp metering system. Decision support for addressing instances of non-recurring congestion requires thorough corridor-wide performance monitoring, which means adequate and dependable sensors deployed along the US 50 corridor to monitor traffic demand and roadway conditions. This consists of mainline and on/off ramp detector stations, monitoring stations (using Bluetooth for example), and CCTV for surveillance. It also includes CMS and HAR for informed traveler decisions. Incident and event management practices must be proactive – managing in route traffic with documented response plans,
real-time active traffic modeling, freeway service patrol, and necessary field elements (i.e., trailblazer signs). This involves close coordination with public safety, collaboration with local partner agencies, and staff training to support the traffic incident management program.

### 6.1.2. Freeway Management System (FMS) – Other Systems

Although it is not essential for initial ICM deployment, other advanced systems could be considered as part of the Caltrans FMS. This includes the following but not limited to:

- Variable Speed Limit/Speed Harmonization or Variable Advisory Speeds (with Electronic Signage)
- Dynamic Lane Management or Lane Use Signs (with Overhead Gantry)
- Hard Shoulder Running (with Electronic Signage or Overhead Gantry)
- Junction Control (at Freeway to Freeway Interchanges)
- Interchange Modification (e.g., Center Lane HOV Drop Ramps)
- HOV Lane Conversion to HOT Lane
- Reversible Lane Control

Most of these require a high capital cost to implement and longer lead times to design and construct. Some of these systems also have high visibility and can be controversial. As such, consideration of their implementation for initial deployment can add significant risk to public acceptance and approval and overall success of the deployment. Studies of additional benefits gained by these systems have proved mixed results.

### 6.1.3. Potential Strategy (Initial deployment starting with advanced RMS)

For an effective ICM operations on the US 50 corridor, advanced ramp metering system (RMS) is critically needed. Along with the ICM system implementation, the advanced ramp metering system should be implemented either before or at the same time. There are many different types of advanced RMS. Appendix A provides reference documents for advanced RMS options developed for the Caltrans District 7 I-110 Dynamic Corridor Congestion Management (DCCM) – Dynamic Corridor Ramp Metering System (DCRMS) project. The DCCM is a version of an ICM deployment. The I-80 ICM in the San Francisco Bay Area recently deployed utilizes the fuzzy logic algorithm adaptive RMS. The District 3 staff should determine which system could be the most appropriate for the District depending on the staff preference of algorithm, the existing system hardware, maintenance requirements, and other such factors. Specifically for the ICM, any of the advanced RMS type could be integrated.

### 6.2. Arterial Traffic Operation Centers

Outside the SACRTMC, access to key ICM functionalities is to be provided to each of the local jurisdictions operating traffic management devices along arterials within the corridor. At each location, the implementation of desired functionalities translates into a need to connect various data collection and control systems to the ICM servers. Local agency staff is further to be provided with a computer terminal, or web-based interface, enabling them to access the ICM system online and to perform specific functions from their location. System components to be
installed at local traffic management centers are to support more specifically the following system operations:

- Collection and processing of data generated by the traffic monitoring systems operated by the agency
- Monitoring of the operation of traffic sensing, traffic signals, and informational devices operated by the agency
- Implementing control actions by the ICM system on field devices operated by the agency
- Operating field devices from other jurisdictions for which they have the authorization to do so
- Performing various other traffic management functions
- Collection of parking availability at City owned/operated facilities

Depending on final system design decisions, these control actions may be either manually entered into the respective management systems by local operators or automatically implemented by the ICM system. In particular, automated implementation may be considered to help with the management of incidents occurring during off-peak travel periods when local traffic management centers are not normally staffed.

The parallel and connector roadway components were selected for inclusion in the US 50 ICM corridor through consultation with the respective local agencies. Many intersections along the alternative routes have been upgraded to 2070 control. Remaining key intersections need to be upgraded to 2070 or ATC controllers. Central operational control is in place in all jurisdictions along US 50 (Rancho Cordova’s system is in design). Intersection approaches need to have advance detectors for actuated or traffic responsive signal control. In addition, mid-block detectors may also be needed at select locations along all key arterial corridors for performance analysis and monitoring of signal systems. CCTV coverage at select locations may also be needed for visual verification of conditions and effect of operational changes. CMS at select locations for routing and guidance (e.g. near transit hubs) could be essential for active mode travel time information.

Heightened operations and maintenance of the jurisdictional systems will be necessary as ICM operations unfolds. Adaptive arterial signal operations should be considered along certain arterials. Select connector and parallel routes will need to have trail blazer signs (fixed and/or electronic message signs) to move traffic to and from US 50 freeway mainline in accordance with documented response plans. To ultimately advance to ICM operations, the Caltrans District should begin to evaluate for and implement integration of ramp signals with ramp metering at select locations, in addition to coordination with adjacent intersections owned by partner agencies.

Collaboration with partner agencies is essential for corridor-wide arterial management and should begin early to identify standardized method of data/information collection, analysis, and sharing in real-time, including signal operations, arterial performance measures, and video surveillance. A key to success in this development is breaking down the jurisdictional silos and beginning to collaborate on improvements along arterials across boundaries. Targeted ITS and operational roadway improvements at select locations will be necessary. This can include for example:
Appendix F
US 50 ICM Deployment Alternatives and Potential Strategies

- Arterial capacity enhancements (e.g., widening, gap closures, driveways eliminated)
- Intersection capacity improvements (e.g., additional turn/thru lane, extend turn lanes, bus turnouts, bike lanes)

6.2.1. Potential Strategy (Initial deployment starting with advanced AMS)
For an effective ICM operations on the US 50 corridor, advanced arterial management system (AMS) with centrally controlled traffic signal operations, preferably adaptive, is critically needed. Along with the ICM system implementation, the advanced AMS should be implemented either before or at the same time. Caltrans District 3 is implementing the Traffic Signal Management and Surveillance System (TSMSS), and adaptive signal coordination system. Many of the local agencies along the US-50 corridor, including Rancho Cordova and Sacramento County are using the Econolite’s CENTRACS ATMS, a flexible and scalable Advanced Traffic Management System (ATMS). Adaptive module for CENTRACS is available should the local agencies decide to implement it, but it is not necessarily required for an effective ICM deployment. However, it is critically important that every traffic signal along the ICM corridor is centrally controlled to remotely send instructions to change the signal timing plans when needed.

6.3. Transit Operation Centers
In addition to the local traffic management centers, ICM system connections could be provided to the following locations from which various transit services operating within the US 50 transportation corridor

In addition to the local traffic management centers, ICM system connections could be provided to the following locations from which various transit services operating within the US 50 transportation corridor are managed:

- Sacramento Regional Transit (RT) Bus Network
- Sacramento RT Light-Rail System
- Yolo County Transportation District
- El Dorado Transit

These ICM system connections will:

- Enable the ICM system to collect relevant transit operational data from the performance systems operated by the various agencies
- Enable transit dispatchers to obtain from the ICM system information about travel conditions within the corridor
- Enable transit dispatchers to enter manually into the ICM system, when relevant, information about enacted transit service changes that may affect the operation of the ICM system
- Provide a link to the Traveler Information network for distributing transit deviation notices.

All transit vehicles (buses and trains) need to be equipped with AVL/GPS (locators), and have a central control/monitoring system (communications with vehicles) to provide sufficient real-time transit operations data for ICM. SAC RT is currently working to implement AVL/GPS system on some of their buses. However, additional investments may be needed to upgrade all buses along the US 50 corridor instrumented.
6.3.1. Potential Strategy (Initial deployment preferable to have transit)

The selection of the operational management participants will be driven by the available funding for integration, data gathering and sharing capacities of the collection systems and staff availability. While the initial effort will target the freeway and arterial systems the ability and desire for inclusion of transit providers and other alternatives modes of travel is very high amongst the partners. The operational management participants should remain as wide as possible and include all modes and avenues of support.

6.4. Parking

There are a number of parking facilities both transit parking and park and ride lots along the US 50 corridor that could be integrated into the ICM. It is very likely that parking availability at the light rail stations (LRT) along the ICM will be some of the first available parking capacity data. Data from Regional Transit’s LRT stations will be integral in the future integration of the corridor and every effort should be made to assure that the raw parking capacity data can be provided in an open format for the future integration. If other transit agencies consider parking capacity data collection, they too should consider providing this capability for possible integration.

6.4.1. Potential Strategy

Implementing parking management system will provide parking availability for the motorist in real-time. This is important as part of the multimodal strategy to encourage non-vehicle mode usage. Depending on the funding availability, priority should be given starting with the most critical parking facilities at multimodal hubs.
7. ICM System Components

7.1. ICM Data Flow
By definition, ICM involves coordinating various component parts of a corridor so they work together harmoniously. These parts (freeways, arterials, transit, etc.) are identified and managed by sending and receiving data about them.

Traffic sensors and data feeds provide data to the corridor management systems and the people who operate them. With the help of a Decision Support System (DSS), a decision about how to manage a traffic situation on the corridor is made and implemented. However, when we add the stakeholders who contribute to the input and receive the output, it becomes evident that the process is more complex. Stakeholders in multiple jurisdictions and data from multiple traffic management systems must communicate with each other, pointing to the need for standardized interfaces and data communication protocols across the entire system. Adding the types of stakeholder data entering the system and the controllers and communication channels needed to carry out any changes reveals the range of information that must flow through the system. The strands of data intersect in the central subsystems of Corridor Management and Decision Support and ultimately could look like the following depiction on Figure 7.

![ICM Data Flow Diagram](image)

Figure 7: ICM Data Flow

7.2. Data Hub (e.g., STARNET, IEN)
The Data Hub includes the sensor and feeds interfaces into the Corridor Management subsystem and the interfaces out to the Decision Implementation flow of data. It focuses on detection and management of corridor incidents and performance. That means linking data from Caltrans’ Advanced Traffic Management System (ATMS)—including freeway ramp metering control, freeway changeable
message signs (CMS), and arterial signal control at ramp intersections—with city/county arterial signal control and CMS, along with metrics to gauge system performance.

Options available for the DATA hub to the US 50 corridor are:

- STARNET
- Information Exchange Network
- I-210 Data Hub configuration

**7.2.1. STARNET**

Many of the features required to be contained in the Data Hub are presently implemented within the existing STARNET/CARS 5.0 System. SACOG and the Region have invested significant resources in the development of STARNET, that have helped to prepared the Region for implementation of an ICM corridor. Management and control functions are built into the STARNET interface and allowing for separation of control and access by agency or individual operator, while providing a communication/data exchange mechanism between all partner agencies. The information contained in the STARNET system could provide an opportunity to quickly implement many of the features required for the Manual Mode ICM operation and become the gateway to jump start the Semi-Automatic Mode of ICM.

Standardized data flows are presently being “imported” to the system from many of the involved stakeholder agencies. These imports occur through the use of custom “STARGATES” which convert legacy data flows to the TMDD 3.0 format for use by the STARNET system. Presently data hub imports include CHP incident data, CMS data, PeMS speed data, Transit scheduling, as well as CCTV snapshot and streaming video feeds. Currently no signal or ramp specific data is being imported and additional “STARGATE” development work would be required before Automatic or full Semi-Automatic ICM implementation would be possible.
Caltrans and the City of Sacramento are both members of the “Connected Citizens Program” with WAZE allowing for a new and varied source of incident, travel-time and speed data. Partners within the CARS group have implemented WAZE incident and public reports which could further enhance the data flowing into the ICM system. Implementation of the WAZE interface as part of the STARNET system may provide a unique source of information to the ICM partners.

Existing features of STARNET include some of the interfaces that are required for agency management, public and third party coordination with in the ICM deployment are presently available and active. Those interfaces include RESTful and XML Application Programming Interfaces (API’s), which provide all data for third party developers to further distribute ICM data, interfaces to messaging systems (email, text messaging, etc.) and direct public website and mobile device interfaces.

7.3. Decision Support System (DSS)

At the heart of the proposed ICM system is a Decision Support System (DSS) that will use information gathered from monitoring systems, in the Data Hub, to estimate the current operational performance of systems being managed, simulation and analytical tools to forecast near-future operational conditions under alternative scenarios, and imbedded decision algorithms to recommend courses of action to address specific problems being observed.

![Decision Support System Diagram](image)

**Figure 9: ICM Decision Support System (DSS) Example**

The DSS:

- Takes the information gathered from monitoring systems
- Estimates current traffic conditions
- Identifies events, incidents, bottlenecks, etc.
- Develops strategies to respond to identified problems
- Uses estimation (or modeling and simulation – desirable but not required) to forecast near-future conditions under various scenarios and evaluate potential strategies
7.4. Alternative ICM Systems
Pros and cons are assessed for the following alternative ICM Systems:

1) Utilize and customize San Diego I-15 ICM system
2) Utilize and customize Dallas I-75 ICM system
3) Utilize and customize Caltrans I-110 DCCM system
4) Utilize and customize I-80 ICM system
5) Utilize and customize I-210 Connected Corridors system
6) Build From Scratch
7) Investigate use of other ICM systems from other locations

Table 2: Option 1 – Reuse San Diego I-15 ICM System

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Completed system based upon a product deployed to 25+ agencies</td>
<td>* Requires regional model to be created and maintained (can be very costly)</td>
</tr>
<tr>
<td>* Intelligent DSS</td>
<td></td>
</tr>
<tr>
<td>* Real-time Network Prediction Subsystem</td>
<td></td>
</tr>
<tr>
<td>* On-line micro simulation analysis</td>
<td></td>
</tr>
<tr>
<td>* Real-time response strategy assessment</td>
<td></td>
</tr>
<tr>
<td>* Congestion Event Finding</td>
<td></td>
</tr>
<tr>
<td>* Data Hub is build using TMDD standards</td>
<td></td>
</tr>
<tr>
<td>* Very flexible rules-based response plans</td>
<td></td>
</tr>
<tr>
<td>* Web-based low-cost ATMS software platform</td>
<td></td>
</tr>
<tr>
<td>* Works independently of legacy systems</td>
<td></td>
</tr>
<tr>
<td>* Ready to be used, no learning curve</td>
<td></td>
</tr>
<tr>
<td>* Well documented</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Option 2 – Reuse Dallas I-75 ICM System

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Includes a DSS System, which is more basic</td>
<td>* Requires regional model to be created and maintained (can be very costly)</td>
</tr>
<tr>
<td>* Very flexible rules-based response Plans</td>
<td></td>
</tr>
<tr>
<td>* Contains response plan assessment methodology</td>
<td></td>
</tr>
<tr>
<td>* Lower cost ATMS software platform</td>
<td></td>
</tr>
<tr>
<td>* Data Hub</td>
<td></td>
</tr>
<tr>
<td>* Works independently of legacy systems</td>
<td></td>
</tr>
<tr>
<td>* Ready to be used, no learning curve</td>
<td></td>
</tr>
<tr>
<td>* Documented</td>
<td></td>
</tr>
<tr>
<td>* Requires regional model to be created and maintained (can be very costly)</td>
<td></td>
</tr>
<tr>
<td>* Very basic tables-based DSS, difficult to maintain</td>
<td></td>
</tr>
<tr>
<td>* Simulation is not micro simulation and it is not integrated</td>
<td></td>
</tr>
<tr>
<td>* No traffic prediction</td>
<td></td>
</tr>
<tr>
<td>* Not widely used</td>
<td></td>
</tr>
</tbody>
</table>
### Table 4: Option 3 – Reuse (District 7) I-110 DCCM System

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likely based upon San Diego system with</td>
<td>System is still being designed and deployed</td>
</tr>
<tr>
<td>Congestion Event Finding</td>
<td></td>
</tr>
<tr>
<td>Data Hub</td>
<td></td>
</tr>
<tr>
<td>Very flexible rules-based response plans</td>
<td></td>
</tr>
<tr>
<td>Web-based low-cost ATMS software platform</td>
<td></td>
</tr>
<tr>
<td>Works independently of legacy systems</td>
<td></td>
</tr>
<tr>
<td>Ready to be used, no learning curve</td>
<td></td>
</tr>
<tr>
<td>Well documented</td>
<td></td>
</tr>
<tr>
<td>Built piecemeal, as funding became available</td>
<td></td>
</tr>
<tr>
<td>Lower cost</td>
<td></td>
</tr>
<tr>
<td>No modeling or microsimulation</td>
<td></td>
</tr>
</tbody>
</table>

### Table 5: Option 4 – Reuse (District 4) I-80 ICM System

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>System already developed</td>
<td>More basic system with less intelligent DSS (compared to San Diego)</td>
</tr>
<tr>
<td>Based on existing Caltrans ATMS solution</td>
<td></td>
</tr>
<tr>
<td>Flexible rules-based response plans</td>
<td></td>
</tr>
<tr>
<td>Ready to be used, no learning curve</td>
<td></td>
</tr>
<tr>
<td>Well documented</td>
<td>Functionality is embedded within ATMS, not external</td>
</tr>
<tr>
<td>Caltrans already owns the system and software</td>
<td></td>
</tr>
<tr>
<td>Lower cost compared to other options</td>
<td></td>
</tr>
<tr>
<td>No modeling or micro simulation</td>
<td></td>
</tr>
</tbody>
</table>

### Table 6: Option 5 – Reuse (District 7) I-210 Connected Corridors System

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Will use model driven DSS</td>
<td>System is still being designed and deployed</td>
</tr>
<tr>
<td>Based upon Caltrans driven statewide initiative</td>
<td></td>
</tr>
<tr>
<td>Could be the most cost-effective option with HQ support</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Has not been deployed anywhere else</td>
</tr>
</tbody>
</table>

### Table 7: Option 6 – Build from Scratch (or Customized Other Third Party Tool)

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility to build own custom solution any way desired</td>
<td>Likely to take a very long time and could be very costly</td>
</tr>
<tr>
<td></td>
<td>Does not take advantage by making reuse of other projects</td>
</tr>
</tbody>
</table>
7.5. Potential Strategy (*Utilize and customize California deployed system*)

The potential best fit from the existing options for the US 50 ICM include:

- I-15 ICM system
- I-80 ICM system
  - Both are mature ready systems, require lower cost, and less complicated. Both contain the features needed for US 50 Corridor.
- I-210 Connected Corridors system
  - If pilot is successful and Caltrans HQ supports deployment of the I-210 Connected Corridors statewide, this could be the most cost effective and easiest to implement.
  - It is unproven to date and much is still unknown.
  - Validity will depend on how it develops over the next couple of years.

If the STARNET system were to be used as part of the Data Hub, both of these systems would require modification to utilize the STARNET data hub, but would not require the interface work for data gathering from the agencies as that work has been completed as part of the STARNET implementation, which may result in a significant cost savings to the region. In addition, the STARNET system provides for the easy distribution of traveler Information though a proven system.
8. Performance Measurement

Many different technologies are utilized for collecting detection and surveillance information, including in-roadway and over-roadway sensors for measuring traffic flow parameters, vehicle probes for collecting data on travel times and origin-destination information, closed circuit television (CCTV) systems for viewing real time video images of the freeway, road weather information systems (RWIS) for monitoring pavement and weather conditions, and manual methods such as gathering information from drivers via their cellular telephones (e.g., crowdsourcing data). Companies such as Google, INRIX, and HERE are already collecting and utilizing crowdsourcing data, and offer them for purchase.

Travel time to a destination is a key piece of information that motorists want and need. It is vital for travelers to make good decisions about which route to take and whether to divert from their planned path. Technology now makes it feasible to provide drivers with real-time information about how long it will take to reach a given destination. While travel time information has traditionally been provided by transportation agencies only on major urban freeways, travel time messages are now being communicated on arterial roadways.

While PeMS can be used to assess the effectiveness of freeway operations in near-real time, no similar tool exists for assessing arterial performance. While third-party information tools such as Google Maps are increasingly being used to visualize traffic speeds on main arterials and locate congestion hotspots, these tools do not provide many of the performance metrics of interest to roadway managers, such as incurred delays, volume-to-capacity ratios, etc. Candidate arterial travel time data technology is presented in Table 8.

8.1. Potential Strategy (Use PeMS for freeway and implement arterial detection)

Caltrans currently maintains an extensive network of traffic detectors on freeways, using a combination of magnetic loop, microwave, and wireless vehicle detection systems. These report to the Caltrans performance measurement System (PeMS). Within the US 50 corridor Caltrans has plans to install Bluetooth devices to measure travel times and travel patterns between specific points. PeMS should be incorporated into the ICM system. Any expanded system detection and use of Bluetooth devices should also be incorporated.

Local Agencies along the US 50 corridor predominantly use loop detectors at few locations. At some locations the City of Sacramento uses video image processing in combination with loops – video at the stop bar and loops for mid- and advanced- detection. Sacramento County is starting to use Bluetooth devices and other agencies along the US 50 corridor are considering use. Additional system detection may need to be implemented to collect real-time performance data. Implementing additional system detection should be considered as part of the ICM development.

In the near future (crowd sourced) WAZE or third party travel time source will emerge as a technology for consideration for both freeway and arterials. While not specific enough for signal timing calculations it does appear that it will be able to provide an effective estimation of travel time. The number of data sources (sample size) for some third party sources could be significantly higher than a given single technology source. While it may not be mature right now (getting close) it may be by the time ICM reaches design on US 50. Additionally, it can come at a much lower initial and O&M cost when compared to Bluetooth detection devices.
### Table 8: Candidate Arterial Travel Time Data Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>Spot Speed</th>
<th>Segment Travel Time</th>
<th>Track Real-time</th>
<th>Sensor Location</th>
<th>Coverage Per Sensor</th>
<th>% Vehicles Detected/Matched†</th>
<th>Implement Cost†</th>
<th>Non-traffic-info Functions†</th>
<th>Traffic Vols</th>
<th>Veh Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluetooth detection</td>
<td>X</td>
<td>Roadside/ above road</td>
<td>All lanes</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toll tag reader</td>
<td>X</td>
<td>Roadside/ above road</td>
<td>One or more lanes**</td>
<td>Low</td>
<td>Med</td>
<td>Med</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-pavement magnetic detectors</td>
<td>X</td>
<td>In pavement</td>
<td>One lane</td>
<td>High</td>
<td>Med</td>
<td>Low</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic license plate reader (ALPR)</td>
<td>X</td>
<td>Roadside/ above road</td>
<td>One or more lanes**</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video Image Processing</td>
<td>X</td>
<td>X*</td>
<td>Roadside/ above road</td>
<td>One or more lanes**</td>
<td>High</td>
<td>Med</td>
<td>High</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connected vehicle</td>
<td>X</td>
<td>X*</td>
<td>Roadside/ above road &amp; in vehicle</td>
<td>All lanes</td>
<td>???</td>
<td>Low</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radar, microwave, LiDAR</td>
<td>X</td>
<td>Roadside/ above road</td>
<td>One or more lanes**</td>
<td>High</td>
<td>Med</td>
<td>Med</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inductive loops</td>
<td>X</td>
<td>X*</td>
<td>In pavement</td>
<td>One lane</td>
<td>Low</td>
<td>Low</td>
<td>X</td>
<td>X*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crowdsourcing</td>
<td>X</td>
<td>None</td>
<td>All lanes</td>
<td>???</td>
<td>Low</td>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell phone monitoring</td>
<td>X</td>
<td>None</td>
<td>All lanes</td>
<td>???</td>
<td>Low</td>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Possible depending upon capabilities of technology  
** Multiple lanes possible depending upon capabilities of technology and sensor placement  
† Can vary substantially depending on a variety of factors; estimates are approximate based on user experience  
‡ Other functions can include tolling, traffic law enforcement, unregistered vehicle detection, cooperative safety, etc.  
??? Unknown/no basis for assessment

Source: Arterial Data Collection Technology, April 2013, FHWA-HOP-13-028

**Bluetooth Detection** - Wireless technology that allows electronic devices to communicate directly with one another; recently emerged as viable ATT collection tech; open standard, allows for off-the-shelf equipment; detection range limited to about 328 feet (100 meters); less expensive than many other options; flexible; some potential privacy concerns; detection technology relies on drivers’ use of Bluetooth-enabled devices.

**Toll Tag Reader** - Detect radio frequency ID of automated toll tags, mature technology, inconspicuous, detection accuracy can decrease with distance, limited to areas with adequate toll tag fleet penetration, some potential privacy concerns, electronic tolling becoming increasingly common.

**In-pavement Magnetic Detectors** - Arrays of magnetometers installed in pavement, can identify and match vehicles based on each vehicle’s unique magnetic signature, quick installation and self-calibrating, wireless sensors require access points and possibly repeaters, high vehicle detection rate, device life span of about 10 years, no privacy concerns. A commercially available magnetic detector capable of real-time data transmission is marketed by Sensys.
Automatic License Plate Readers - Optical cameras capture images of license plates and software “reads” the information; mature technology (over 30 years); installed above the roadway and requires direct line-of-sight; particularly sensitive to factors that reduce visibility; privacy issues are a concern.

Video Image Processing - Use of video cameras to monitor flow; installed above the roadway or on poles on the roadside; data bandwidth is a consideration; highly customizable set of features; privacy can be a concern for high-resolution systems; potential uses are likely to expand with advances in technology, processing power, and data transmission capabilities.

Connected Vehicle - Short range radio communications between vehicles and vehicles to infrastructure, technology is in very early stages of development, radio transceiver installed in host device within a vehicle, privacy protocols are being established, very inexpensive cost on a per unit basis, usefulness for travel time calculations uncertain, depends on implementation factors, potential for widespread use if initiative continues to develops. According to current estimates, some DSRC features are expected to become available to the public in or around 2017.

Radar, Microwave, and LIDAR - A sensor emits radio waves (radar), microwaves, or a laser beam (LIDAR), which reflects off of vehicles; mature and widely used technology, many products available with a variety of different implementation approaches, complete privacy to drivers. Use of these technologies for ATT calculations, however, is relatively uncommon.

Inductive Loops - Magnetic loops in pavement detect vehicle presence, and multiple loops can be used to calculate travel times; mature and widely used technology, though use for ATT data collection is rare; high detection rate; very inexpensive, but invasive installation and maintenance can increase costs; complete privacy to drivers.

Crowdsourcing - Drivers’ vehicles or mobile devices provide information to a public or private entity, and that information is used to generate traffic/travel time, early stage technology, critical mass of users is necessary for success, vehicle/motorist must have device capable of transmitting information, no roadway infrastructure needed, privacy issues are minimal or non-existent when data transmitted to agencies who purchase data, use likely to increase. Crowdsourcing data providers include INRIX, Google, and Waze. STARNET/Google and the “WAZE-Connected Citizen Program” could provide mechanisms for a low/no cost methodology to access large sample sized data. Additional development and partnering opportunities could greatly advance this option.

Cell Phone Signal Monitoring - Cell phone location information is automatically and anonymously downloaded from cellular network switching centers in real-time; relatively mature technology and cell phone use is almost ubiquitous; data provided by vendors, and data are anonymous when provided to agencies; shows adequately precise measurements of travel time.
9. Funding Alternatives

Successful implementation will require funding the ICM system. To accomplish this at a time when all funding programs are “oversubscribed” and “underfunded”, will require focusing on three key objectives, building a unified base for support of the concept, exploring and applying for all potential sources of funding, and leveraging all investments made by individual agencies and permit applicants. As noted earlier documenting the transportation system’s performance gains and air quality improvements generated by these investments will be key in securing the funding for future ICM capabilities.

As operations and planning personnel know the securing of “local matching funds” required for the use of Federal funding can generate cash flow problems internal to agencies, possibly delaying the use of Federal funding. As outlined below in the program funding alternatives (Section 9.2) many of the programs recommended for application, may be used for matching. The Program Manager should be careful in the use of matching funds and not expend the flexible funds too early in the process. Reserving and distributing these funds at the minimal level will allow for “over matching” or rapid use of special “Federal funding” if they were to become necessary or available.

9.1. Support of Concept

The importance of unified support for the project cannot be overstated. Support can come in many forms and will vary depending on the target audience. Support can take on many forms; being as simple as a letter of support, championing of the concept, lobbying for Agency support either fiscally or politically, or working with Community leaders to find new supporters of the ICM concept.

At the Regional level the impact of ICM will provide for congestion mitigation and a reduction in greenhouse gas generation. Gathering data to measure the improvements provided through the operational improvements will aid in insuring that the necessary funding for ICM and other regional projects continue to be available. The Benefit to Cost ratio (B/C) for “integration” and “operational” projects are typically much greater than other infrastructure increasing projects. At the regional level the “fix it first” projects will likely be considered a better investment so operational and planning groups will need to be diligent in lobbying for the inclusion of ICM components where applicable in “fix it first” projects.

The planning and operations departments in all agencies will have roles in securing funding for the ICM implementation. All partner agencies will need to remain involved in the ICM implementation to assure that all parallel projects, at a minimum consider inclusion of ICM components where applicable. Maintaining a “champion” for the ICM concept to keep the concept in front of management when appropriate will become a critical role for the engagement of other departments and divisions when necessary. Securing the ability to include ICM related features into encroachment permitted projects and other right of way activities will aid in furthering the ICM concepts.

As a partnership securing management support in the form of Memorandums of Understanding (MOU’s) for the coordinated development of the ICM concept and regional operational coordination will allow for the continuation of this effort. If the partnership can further this concept to include the identification of champions within large employer/tax/revenue generators for political support of ICM concept (major business, auto dealers, event centers, high profile projects, medical centers, government
agencies, colleges and schools) to be included in funding applications, it would set a new level of support not often seen in the funding application process. Gather a letters of support for the ICM concept from as many champions as can be identified for the safe an efficient arrival of workers or products/raw materials for manufacturing or retail sale as part of the ICM concept would be major accomplishments difficult to disregard in the application/award process.

9.2. Program Funding Alternatives

The partnership should explore and apply for all sources of potential funding and not limit themselves to only one or two programs. Through exposure as part of the funding application process, the ICM concept will gain a wider knowledge base. If funds are awarded from multiple applications for the same phase of the ICM project, it might be possible to accelerate a future phase to take advantage of the award.

A review of available funding programs has been completed and a review of each program, award agency and website links are provided for each. The minimal matching fund requirements has been provided for planning purposes or if applicable, the funds ability to be used as a match for Federal funds.

- Local Agency Transportation funds – This program is mostly oversubscribed; however, depending on the specific agency providing the funds some of the fund maybe ‘earmarked for transportation congestion mitigation. These fund sources are very flexible in there use and are eligible for use as matching funds for all other sources of funding.
  - Builder Development Fees / Major Street Construction Fund – call by different names depending on jurisdiction but the funds are secured though valuations of new construct of buildings.
  - Gas Tax Funds – Administered by State Board of Equalization, State Controller distributes funding
  - Measure A funds – These funds begin at City/Regional level and are administered by the Sacramento Transportation Authority (STA). Typical awards can be secured either directly or through the Sacramento Area Council of Governments (SACOG) Regional Funding Round process.

- SHOPP (State Highway Operation and Protection Program) – This is a program administered by Caltrans for use on State only routes. The program can provide up to 100% project funding. These funds are eligible for use as matching funds to Federal Aid and could be used as part of a multi-agency project. Additional funding from SB-1 could be added if the bill is passed.
  - http://www.dot.ca.gov/hq/transprog/shopp.htm

- SAFE (Service Authority for Freeways and Expressways) – SACOG or the Capitol Valley Service Authority for Freeways and Expressways (CVR-SAFE) administer these funds, but the call for projects is likely to be administered separately from the Regional Funding Round process. Funding should be available to Sacramento and El Dorado County. For use on Freeways for driver aid projects, including congestion reduction, traveler information and re-routing improvements for which the nexus with ICM would be easily identified. The CVR-SAFE funds can
provide up to 100% project funding, but the program is very limited in available funding. These funds would be eligible for use as matching funds for all sources of Grant funding

- HSIP (Highway Safety Improvement Program) – This is considered a core Federal-Aid program, with specific goals and objective that projects must provide it be eligible for funding. The ICM Project as planned supports the safety goals and objectives of:
  - Intersection Safety
  - Roadway Safety Data and Analysis
  - Pedestrian and Bicycle Safety

  Typical funding of 90% of project costs ($100,000 to $10 million) apportionment dependent. The calls for projects are on one or two year cycles are typically. This program is administered by Caltrans: Office of Local Assistance

  - http://dot.ca.gov/hq/LocalPrograms/hsip.html or http://safety.fhwa.dot.gov/hsip/

- NHPP (National Highway Performance Program) – The federal FAST Act authorization was funding source. This program is currently administered by Caltrans, which may transfer up to 50% of NHPP funds, made available each fiscal year, to the National Highway Freight Program, Surface Transportation Block Grant Program, Transportation Alternatives, Highway Safety Improvement Program, and Congestion Mitigation and Air Quality Improvement Program. Caltrans appears to be focusing funds towards “bridges and their repair” per their website.

  Typical funding of 80% of project costs, but over matching of ‘Local Funds” could make a project appear more competitive.

  Federal Guidance reads: NHPP funds may be obligated only for a project on an "eligible facility"; that is a project, part of a program of projects, or an eligible activity supporting progress toward the achievement of national performance goals for improving infrastructure condition, safety, congestion reduction, system reliability, or freight movement on the NHS. Projects must be identified in the Statewide Transportation Improvement Program (STIP)/Transportation Improvement Program (TIP) and be consistent with the Long-Range Statewide Transportation Plan and the Metropolitan Transportation Plan(s).

  ICM Projects fall under the federal eligible activity of “j. Capital and operating costs for traffic and traveler information monitoring, management, and control facilities and programs. The project or activity must be associated with an NHS facility.” Most routes utilized on the US 50 ICM proposed project are located on the NHS.


- SACOG Regional Funding Round (Sacramento Area Council of Governments) – Regional Funding Round) Process continues to evolve, but to be competitive it is helpful if project is listed in a
Regional Planning document. Consideration should be for the US-50 ICM inclusion in the pending Regional ITS Master Plan update to satisfy this potential requirement.

The Funding program source is determined by SACOG as part of the award process. This is a very competitive program highly oversubscribed. Potential funding programs include:

- Congestion Mitigation and Air Quality (CMAQ)
- Regional Surface Transportation Program (RSTP)
- State Transportation Improvement Program (STIP)
- Active Transportation Program (ATP) funds

Typical funding level is a maximum of 80%, requesting less than 80% funding can make a project more competitive (over match). In the past Multi Agency project applications have proven to be very competitive. Letters of support and coordination can be very advantageous and typically have not included support from the larger employers or tax/revenue generators.

Project inclusion or being a component project directly working towards a regional project/goal can be advantageous. The regional goals of greenhouse gas reduction, congestion mitigation and multi-modal transportation coordination encouragement should occupy a leading position in this application.

- [http://www.sacog.org/regional-funding-programs](http://www.sacog.org/regional-funding-programs)

### 9.3. Potential Strategy (Start with Letters of Support and Charter)

Securing letters of support will be critical as the partners begin to seek funding for implementation of the ICM components. The development of a partnership MOU or the collection of letters of support as well as inclusion of the ICM components and communication needs in the upcoming ITS Master Plan should help.

As individual agencies continue to have their budgets reduced it is increasingly important for each agency to demonstrate how it is being a good steward of public funding while meeting the needs of their constituent base. All funding applications should include a statement on how the ICM project or phase is taking direct advantage of all previous investments, in recognition of this need. A direct siting of projects that the specific ICM project is working in coordination with should be included whether the previous project is completed in construction or not. As budgets and the funding of grant programs continue to become increasingly competitive the ability to demonstrate a projects use of past investments will continue to resonate with funding agencies. If a compounding of benefits is anticipated or can be verified through the past performance indicators it should be included as part of the application.

All agencies should take advantage of encroachment permit projects to increase investment in areas of need. All encroachment permit applications should be reviewed for potential inclusion of ICM components alone the appropriate corridors. If inclusion of ICM components is not possible through the permit process, consideration should be given to avoid future conflicts due to the improvements and potential conflicts with ICM components.
Appendix

- Caltrans District 7 Dynamic Corridor Congestion Management (DCCM) – Dynamic Corridor Ramp Metering System (DCRMS) Adaptive Ramp Metering Discussion Paper
- Caltrans District 7 Dynamic Corridor Congestion Management (DCCM) – Dynamic Corridor Ramp Metering System (DCRMS) Review of Existing Adaptive Ramp Metering Algorithms
California Department of Transportation
District 7

DYNAMIC CORRIDOR RAMP METERING SYSTEM (DCRMS)
P.O. 2660-0712000618-1

Adaptive Ramp Metering Discussion

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1 INTRODUCTION

1.1 DOCUMENT PURPOSE

The purpose of this document is to provide an overview of various state of the practice Ramp Metering algorithms used in North America and around the world. This document reviews deployed worldwide algorithms, provides a comparison and an evaluation of algorithm alternatives in North America, as well as presents Caltrans with recommendations on which algorithm to implement on its regional network. These recommendations will be focused on ways to improve operations within the current infrastructure’s capabilities.

1.2 WHY RAMP METERING

Ramp metering is a tool to manage traffic on approaching freeways. The most common objectives of ramp metering are improved mobility (reduced congestion, reduced travel time and improved travel time reliability) and improved safety (reduced collision rates).

Traditionally, ramp metering can be pre-timed or responsive to real-time conditions. Within the responsive approach, rates may be based on system-wide or local conditions. Several ramp meters can be coordinated to smooth flow at:

- A point;
- Along a stretch of freeway; or
- For several freeways within a regional network.

Ramp metering algorithms may take into account other conditions or situations such as HOV demand or queuing on the entrance ramp. Some algorithms adjust the calculated metering rates to account for these conditions and some incorporate consideration of these conditions as part of the basic calculations.

Adaptive ramp metering algorithms are designed to anticipate conditions and take action accordingly. Adaptive ramp metering algorithms typically either look upstream or downstream, or both in order to take action at a ramp before congestion occurs.
2 CATEGORIES OF ALGORITHMS

Typically there are two categories of ramp metering algorithms:

1. **Isolated**: Metering rates are decided solely by local traffic conditions; respond to conditions throughout a corridor including incidents; and requires little ongoing parameter maintenance.

2. **Coordinated**: Metering is done based on system-wide information.

2.1 COORDINATED

There are three types of algorithms: Cooperative, Competitive and Integral

2.1.1 Cooperative

- After computing the rate for each on-ramp, further adjustment is done based on system-wide information to avoid congestion and the spillback at critical ramps
- Examples: ALINEA, ZONE, Local Metering

2.1.2 Competitive

- Two sets of metering rates are computed based both on local and global conditions, and the more restrictive one will be selected and implemented
- Examples: Bottleneck, SWARM

2.1.3 Integral

- Local traffic and system-wide traffic conditions are both used to determine metering rates
- Examples: Fuzzy Logic, METALINE, Sperry Ramp, Dynamic Metering, etc.
3 RAMP METERING ALGORITHMS

Ramp metering algorithms can be categorized as local or system/corridor focused.

3.1 LOCAL ALGORITHMS

Local algorithms are based on conditions in vicinity of the ramp only. A local algorithm may also provide the basic concept that is used in a system algorithm. The most common local algorithm in the U.S. is an occupancy-based threshold approach that associates metering rates and occupancy levels at the detector station immediately upstream of the entrance ramp. The occupancy-metering rate relationship can be defined for each ramp. The rates can be determined from a simple lookup table or may be interpolated between the values defined (see the graph below). The metering rate is often adjusted for ramp queues, generally to keep ramp queues from affecting the surface street network or vehicles that are not destined to the freeway. Local algorithms are vastly deployed throughout Europe.

3.2 SYSTEM OR CORRIDOR ALGORITHMS

System or corridor algorithms use information on conditions throughout the corridor or facility to calculate metering rates. They may depend on the base local algorithm. They may also only kick in when an occupancy threshold is met.
4 RAMP METERING OPERATIONAL MODES

Ramp metering can be operated using several different modes. The three ramp meter operational modes are as follows:

1. Local Time of Day
2. Responsive Ramp Metering Control
3. Adaptive Ramp Metering Control

4.1 LOCAL TIME OF DAY

Local Time of Day (TOD) mode consists of using predetermined metering rates using a schedule of operation. It requires an off line determination based on mainline and ramp data history. This determination can be based on software, engineering judgment or a combination. TOD mode is typically used when real time traffic data is unavailable, and it used as a backup when higher level modes cannot operate due to equipment failures.

4.1.1 Technology Requirements

TOD requires a controller that can store tables of rates, dates, times, and holidays. All NTCIP compliant ramp metering firmware can operate TOD mode.

4.1.2 Pros

• When properly setup, reduces delay and congestion on mainline
• Simple form of control
• Serves as an effective backup mode when more complex modes cannot operate

4.1.3 Cons

• Not responsive to real time conditions including congestion and incidents
• May meter when not necessary
• May not meter when necessary
• Requires continual metering rate evaluations including seasonal variations

4.2 RESPONSIVE RAMP METERING CONTROL

Responsive Ramp Metering Control (RRMC) is a mode where a single meter uses traffic data from the set of vehicle detectors on freeway mainline adjacent to the on-ramp. RRMC can be performed within a local controller or at a central location.

Typically, RRMC is based on a simple algorithm that uses the local mainline’s volume, occupancy and/or speed data to lookup in a table the desired metering rate. This mode is included in all NTCIP compliant ramp metering firmware. When RRMC is operated from central it can be configured in many ways including using multiple mainline stations and using a more complex method to compute metering rates.

4.2.1 Technology Requirements

Local RRMC requires a controller that can access the local mainline traffic data.
4.2.2 Pros

- When properly tuned, can improve reductions in delay and congestion on mainline over TOD mode
- Can be set to turn on/off meters based on conditions if there is an algorithm present in the controller for Local RRMC
- Responds to local mainline conditions
- Requires little ongoing parameter maintenance

4.2.3 Cons

- Requires mainline detectors
- Not responsive to downstream conditions including congestion and incidents

4.3 Adaptive Ramp Metering Control

Adaptive Ramp Metering Control (ARMC) is a mode that controls a set of ramp meters assigned to a specified corridor adapting to traffic conditions derived from multiple sets of freeway mainline detectors. Typically the corridor is segregated based on its bottlenecks and the set of meters upstream from each bottleneck work together to regulate traffic flow into the bottleneck. Adaptive algorithms also feature dynamic on/off strategies.

4.3.1 Technology Requirements

ARMC require a central system, an adaptive algorithm, mainline detectors, and controllers that can accept metering rates in real time.

4.3.2 Pros

- When properly tuned, can significantly reduce delay and congestion on mainline
- Respond to conditions throughout a corridor including incidents
- Requires little ongoing parameter maintenance

4.3.3 Cons

- Requires mainline detectors, a central system, and a controller that can accept real time rates
- Complexity often not understood
5 ADAPTIVE RAMP METERING

This section highlights the key features of the most common used adaptive algorithms in the US and internationally.

5.1 SWARM

The System Wide Adaptive Ramp Metering (SWARM) algorithm was initially developed in 1994 as part of a demonstration project in Caltrans District 12. It has subsequently undergone several improvements and is currently operating in several North American jurisdictions.

SWARM:

- Makes continuous forecasts of traffic conditions in real time based traffic data at dynamically determined bottleneck locations
- Creates metering rates based on the forecasts, ramp capacities, and allowable metering rates using a propagation methodology
- Has many subsystems that determine allowable metering rates

5.1.1 SWARM – Network

- Looks at the complete system
- Forecasts traffic conditions x minutes into the future
- Changes metering rates now to avoid predicted future problems

5.1.2 SWARM – Local

- Looks at local traffic conditions near ramp
- Based on current data

![Figure 5-1. SWARM Concept](image-url)
• SWARM 2a - Headway (time between vehicles)
• SWARM 2b - Storage
• SWARM 2C – Two-station algorithm

**Deployments**: Los Angeles, CA; Portland, OR; Atlanta, Georgia

### 5.2 CARMA

Corridor Adaptive Ramp Metering Algorithm (CARMA) computes metering rates based on mainline speeds and prevailing local controller conditions then optimizes them over each freeway direction.

CARMA computes a metering rate at each mainline station regardless of whether there is an associated metered ramp or not. VDSs are ordered by geography and are processed starting with the furthest downstream location. The concept is based on the assumption that a ramp can allow maximum vehicles when the speed is high and should theoretically allow no vehicles when the speed is at a jam condition.

CARMA features include:

- Smoothed mainline speed
- Computes rates at each mainline Vehicle Detector Station (VDS)
- Tempers rates based on downstream conditions
- Bounds rates based on local maximum and minimum rates
- Adapts to ramps in queued states
- Adapts to ramps operating in non-CARMA modes
- Controls hours of operation
- Given the Mainline Speeds at which:
  - A Maximum Rate would be applied
  - No vehicles should be allowed entry
  - A linear relationship is established

- Current Smoothed Mainline Speeds are input to this linear relationship to compute the desired Local Raw Rate
- Note: Local Raw Rates can be greater than Absolute Maximum and even less than zero
5.3 FUZZY LOGIC

The fuzzy logic algorithm was developed by WSDOT under a research project with the University of Washington. It addresses multiple objectives and weighs rules that implement those objectives. It has a user-friendly tuning process that uses linguistic variables, not numerical variables.

- The rule groups used by the WSDOT algorithm include:
  - Local mainline speed and occupancy
  - Downstream speed and occupancy
  - Ramp queue occupancy

- A process known as “fuzzification” translates each numerical input into a set of fuzzy classes: very small (VS), small (S), medium (M), big (B), and very big (VB). Each has a scale from 0 to 1 to describe the probability that the parameter fits in that class. The charts below show the fuzzification for local occupancy and for downstream occupancy that were developed for the WSDOT algorithm.
After the fuzzy states are determined, weighted rules determine the metering rate. The numerical metering rate is based on the rule weight and the degree of activation of each rule outcome. The final meter rate determination combines the contributions from all the weighted rules.

Key features of the Fuzzy Logic algorithm include:

- The overall framework allows rules can be changed or added. Weights can be modified to tune to local conditions.
- The parameters are robust and do not need extensive or frequent tuning.
- The fuzzy logic algorithm can be used to turn metering on and off.
- Ramp queues are integral to algorithm, not an adjustment to the outcome.

**Deployments:** Seattle, WA; Miami, FL

### 5.4 MN Zone Algorithm

The zone algorithm was developed by MnDOT and put in use in the early 1970’s. In the zone algorithm, the freeways are divided into multiple zones, generally 3 to 6 miles long and defined by an upstream typically free flow location and a downstream bottleneck. The zone is comprised of distinct elements, including the mainline, metered ramps, freeway to freeway connectors, unmetered ramps, and exit ramps. The zone algorithm establishes a total allowable metering rate for the ramps in the zone that would maintain mainline flow, then allocates the flow to each ramp based on preset rates at the ramp. The preset rates are based on typical demands at the ramp with high volume ramps in the zone getting higher allocations allowed entrance volume. The rates are continually adjusted to maintain consistent traffic flow on the mainline. For each zone the algorithm attempts to maintain the mainline condition below critical density levels by allocating inputs into the zone from ramps with the exiting volume at
ramps and at the bottleneck. It selects metering rates, ranging from no metering to a cycle length of 15 seconds. The zone algorithm requires detection at the ramp merge and exit points and on the mainline.

**Deployments:** Minnesota

5.4.1 Stratified Zone Algorithm

The objective of the stratified zone remains the same as that of the Zone algorithm, which is to regulate zones through metering so that the total volume exiting a zone exceeds the volume entering. SZM, though, incorporates the more dynamic nature of a freeway by allowing multiple zone bottleneck locations by assigning a ramp to a series of zones then optimizing the ramp meter rate based on the most critical zone at the time, rather than pre-established fixed zone locations.

Stratified zone metering also addresses the need to manage queue wait times by having a separate function for monitoring and managing queues. The separate queue wait calculation runs parallel to the stratified zone algorithm in setting ramp flow rates. The queue wait system only overrides calculated zone rates with a less restrictive rate whenever the queue wait threshold is reached. The current threshold is four minutes on local ramps and two minutes on freeway to freeway connectors. When the queue wait rate is in effect and increasing the flow rate on a given ramp in a zone, the SZM attempts to rebalance the remainder of the zone by making other meter rates for ramps in the active zone more restrictive.

**Deployments:** Minneapolis/St. Paul, MN

The key features of the Zone and Stratified Zone algorithms include:

- The zone algorithm limits total number of vehicles entering a zone to total number leaving the zone. It distributes the spare capacity among the meters in a zone based on current demands at the ramps.
- Capacity is considered a constant relative to the number of lanes at the bottleneck, during all times at all bottlenecks.
- Stratified zone algorithm allows for dynamic bottleneck locations to adjust to changing traffic conditions based on incidents, weather, or other factors.
- Queue detectors are used to calculate queues. Queue waiting time is limited generally to about four minutes. The metering rate at a ramp can be raised to assure wait time is limited.
- “Spare” capacity is calculated from volume and speed and utilized to increase ramp flow rates, and reduce queues, when mainline conditions can handle additional vehicles.

5.5 Bottleneck

BOTTLENECK has been applied in Washington State for a number of years. It provides local- and system-level control on a selected freeway section. Bottleneck computes two metering rates for each on-ramp, one based on local conditions and the other based on system-wide condition, and selects whichever is more restrictive. It has three components:

1. Local metering algorithm (occupancy control);
2. Coordination algorithm is the unique aspect of BOTTLENECK; and
3. Adjustment to meter rates.
It incorporates occupancy control as their local controllers to account for localized congestion. It can work with dynamic bottlenecks.

**Deployments:** Washington State

### 5.6 HERO

The **HEuristic Ramp metering coOrdination (HERO)** estimates queue lengths and calculates the desired meter rate based on critical occupancy, the queue estimate, and ramp demand. It is based on readily available real-time data without the need for real-time model calculations or external disturbance prediction.

HERO uses an extended version of ALINEA at a local level.

- Dynamic, coordinated algorithm
- It has two aspects:
  - Uses ALINEA algorithm for local control
  - Uses the HERO algorithm to provide coordination between ramps. HERO distributes rate restrictions upstream to nearby ramps. The figure at right shows the components of the HERO algorithm

![HERO Algorithm Components](image)

**Figure 5-4. HERO Algorithm Components**

The characteristics of HERO are as follows:

- Coordinates local ramp metering actions in a suitable way so as to avoid the pitfalls of uncoordinated application
- Algorithm is feedback-based to reduce sensitivity to unexpected disturbances.
- Simple and transparent, e.g., rule-based
• Reactive so that no real-time model involvement and no external disturbance prediction are needed
• Approaches the efficiency of sophisticated optimal control schemes
• It is generic (i.e., directly applicable to any freeway network) without a need for cumbersome parameter calibration or fine-tuning

The basic philosophy for HERO is:

i. HERO identifies potentially active mainstream bottlenecks

ii. To retard or avoid ramp queue control of the concerned on-ramp (master) and the resulting mainstream congestion, HERO activates increasingly storage space via recruitment of upstream located slave-ramps

iii. The formed cluster of ramps is dissolved when the mainstream occupancy at the bottleneck or the master-ramp queue become sufficiently low

Notice that, while HERO is recruiting increasingly slave ramps with corresponding minimum queues, the master-ramp’s ALINEA continues to operate normally so as to continue to maximize the mainstream throughput at the potential bottleneck location.¹

5.7 RIJKSWATERSTAAT (RWS)

It is a capacity-demand feed-forward control algorithm, its goal is to prevent or postpone congestion from forming. Currently, RWS is the only algorithm implemented in Dutch ramp metering systems. This type of metering algorithm calculates the metering rate by subtracting the motorway traffic demand from the motorway capacity.²

Once congestion in the motorway has form and the speed drops below the congestion threshold, the performance of the ramp meter will be mostly determined by the motorway congestion detection and the on-ramp queue detection. When congestion on the motorway is detected the flow on the on-ramp is restricted, my implementing the maximum cycle time (approximately 4.5 secs).³

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¹ HERO Coordinated Ramp Metering Implemented at the Monash Freeway white paper
² Adaptive Ramp Metering – ITS EDU Lab, Marc Stanescu – May 2008
³ Coordination of Ramp Metering - ITS EDU Lab, Yufei Yuan – July 2008
5.8 Traffic Introduction Metering

The overall system overview can be divided into two segments, the Central level and the Local one. The Central level consists of a central computer; the Local one is the Omnivue system that can be used for monitor the system by the operators. The Central system, called Traffic Introduction Metering (TIME) system, handles the centralized control of when to allow green periods to the ramps, basing on all the traffic data.

The control actions are calculated on the basis of a two-level strategy which takes into account the data received from the local computing units (MFO - multifunctional out stations). At the central level, the overall control strategy is computed every 60 seconds, so as to be able to optimize traffic distribution and prevent a buildup of queues on any single ramp. The central server can exchange data with other traffic management systems, including variable message signs, video surveillance, and traffic monitoring and enforcement systems. TIME can also take into account traffic predictions received from other systems.4

![Figure 5-5. Local Control Overview](http://www.largevents.eu/wp/wp-content/uploads/2012/10/ramp_metering.pdf)
5.9 **RAMP METER DESIGN SYSTEM**

The SCATS Ramp Metering System (SRMS) chosen for this trial was an “off the shelf” product developed by the Roads and Traffic Authority, NSW (RTA). This software requires detector loops for its operation.

- Software requires detector ops for its operation
- The ramp meter timings are fully controlled by freeway mainline flow conditions, but can be adjusted to reflect surface arterial road conditions
- Ramp meter timings can also be adjusted to balance flow rates between competing on-ramps based on detected queues, by considering the relative requirements of all ramps within a “bottleneck sub-system”
- Designed to operate groups of ramps, and can “balance” the competing demands between the ramps within the sub-system in a manner that can enable the sub-system to avoid flow breakdown
6 LOCAL RAMP METERING

6.1 HELPER

The Helper algorithm is comprised of a local traffic-responsive algorithm with the added feature of central override control. Within a freeway corridor, controlled on-ramps are divided into six location groups, with each group containing one to seven controlled on-ramps. With local traffic-responsive component, one of six pre-set metering rates is selected at each on-ramp, based on local conditions near the ramp. (The local conditions are measured by mainline occupancy reported from the detector station upstream of the on-ramp.)

The algorithm also monitors on-ramp queues by keeping track of occupancies on queue detectors and adjusts metering rates in case of any excess queue development. If an on-ramp is operating at the minimum metering rate, and occupancy on the queue detector exceeds a pre-determined threshold value, the on-ramp is categorized as “critical” and the central override feature becomes active. The centralized algorithm increases the rate at the critical on-ramp by one level and reduces the rate for the upstream on-ramp by one level. The distribution continues one level at a time to other upstream on-ramps, until no on-ramp is categorized as critical.5

Deployments: Denver, CO

6.2 ANCONA

ANCONA was developed by Boris Kerner. The theory states that there are three stages of traffic: free flow, synchronized flow and the wide moving jam. Breakdown at a bottleneck such as an on-ramp is associated with a transition from free-flow to a synchronized flow state. ANCONA is based on the transition. After congestion has begun on the motorway, synchronized flow should be maintained around the on-ramp by switching between a high and a low metering rate.6

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5 Using Archived ITS DATA to Measure the Operational Benefits of a System-Wide Adaptive Ramp Metering System - Robert L Bertini & Soyoungh Ahn, Portland State University

6 Adaptive Ramp Metering – ITS EDU Lab, Marc Stanescu May 2008
6.3 ALINEA

ALINEA (Asservissement Linéaire d’Entré Autoroutière) was developed by Markos Papageorgiou and it is an occupancy-based feedback control strategy. It lets the inflow be determined as proportional to the difference between the ideal occupancy and the observed occupancy⁷.

ALINEA algorithm is a local traffic responsive (adaptive) algorithm and it is not system wide. Its key factors are the location of mainline detectors, occupancy estimate and the regulator parameter. It has a feedback method and it attempts to maintain the mainline throughput by maintaining a desired occupancy on a downstream mainline freeway station. ALINEA:

- Considers conditions last time period (feedback)
- Targets optimal mainline occupancy downstream of ramp
- Queue override can be incorporated
- Additional module can dynamically estimate optimal occupancy

Currently, ALINEA is being used in most European ramp metering sites. The EURAMP partners reported that there have been modifications to ALINEA to cover additional needs.

**Deployments:** UK, France, Germany, Belgium, Shanghai (China), Turkey, Israel

6.3.1 Variable ALINEA

The Variable-ALINEA (V-ALINEA) algorithm, or EDA (simple metering algorithm), is a version of the ALINEA algorithm designed at RWS by Frans Middelham et al. [18]. The difference from the ALINEA algorithm is the use of speed measurements instead of occupancy for the metering rate calculation. Also, the V-ALINEA algorithm is not a closed loop feedback controller. The advantage of using the speed instead of the flow is the same as with the occupancy, the observation is unique for both congested and free flowing traffic.⁸

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⁷ Adaptive Ramp Metering – ITS EDU Lab, Marc Stanescu May 2008
⁸ Adaptive Ramp Metering – ITS EDU Lab, Marc Stanescu May 2008
6.3.2 AD-ALINEA
Although occupancy has shown less sensitivity to external circumstances than motorway capacity, it is still difficult to estimate and maintain a correct value for the critical occupancy. To fix this problem Kosmatopoulos et al. have developed the AD-ALINEA metering algorithm, an adaptive version of the original ALINEA algorithm. The ALINEA metering algorithm itself remains unchanged.

For AD-ALINEA only an estimation module has been added to it.9

6.3.3 UP-ALINEA
Upstream measurements are used by this variation of ALINEA

6.3.4 Variable Cycle ALINEA
Variable Cycle ALINEA (VC-ALINEA) computes long metering cycles instead of not metering when the traffic is fluid, as opposed to ALINEA which does not start metering in this case. VC ALINEA also releases the control more quickly than ALINEA, which explains a higher number of activations. Coordinated metering switches on less often at upstream ramps because metering remains on longer, which is due to the fact that they serve as slaves for the downstream ramps10.

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9 Adaptive Ramp Metering – ITS EDU Lab, Marc Stanescu May 2008
10 EURAMP – IST2002-23110 European Ramp Metering Project Contract No 507645
6.3.5 METALINE

METALINE is an extension of the ALINEA algorithm, and its control logic is Proportional-Integral state feedback. The metering rate of each ramp is computed based on the change in measure occupancy of each freeway segment under METALINE control, and the deviation of occupancy from critical occupancy of each segment that has a controlled on-ramp. With METALINE there is no direct consideration of queue overflow, HOV/bus priority, and bottleneck effects.

It has been implemented in freeways in France, the Netherlands and the United States.
7 ALGORITHM ASSESSMENT

The assessment of the algorithms is based on Caltrans applicable requirements and needs, as well as the algorithms deployed in North America. The following are the characteristics that were used in the algorithm assessment.

7.1.1 Operator Interaction

- In order to keep staffing levels reasonable, the algorithm should be fully automated with minimal operator interaction. This includes the ability to turn metering on and off automatically. The algorithm should respond appropriately and effectively to non-recurring congestion scenarios, such as incidents, without operator input.
- The algorithm should require minimal and infrequent adjustment or calibration.
- The algorithm should be easy to understand and tune. There should be a reasonable number of parameters that are easy to change or modify. A tool to help in calibration would be helpful.
- The operator should be able to override metering rates and be able to turn meters on and off manually.

7.1.2 Ramp queue management

- The algorithm should be able to equitably spread wait times throughout the corridor. This is important so the travelers closer in do not have a time disadvantage compared to those who live further out in the corridor.
- The algorithm should take quick action when congestion is detected. It should also quickly propagate reduced metering rates upstream to balance ramp queuing.
- The algorithm should minimize the likelihood of queue override conditions that “flush” the ramp. The algorithm needs a more sophisticated way to mitigate queues than simple queue override or queue adjustment. It should have the functionality to treat ramp queues differently, preferably with ramp queues inherently balanced against mainline conditions in the basic formulation of the algorithm.

7.1.3 Other operational characteristics

- The algorithm must function meaningfully if one or more ramps go offline. There may be communication problems or controller failures that would take certain ramps out of the algorithm. The algorithm must effectively respond to those conditions.
- The algorithm must work in concert with the Caltrans local algorithm. The local controller firmware will control the ramp meter signals. The central algorithm must work with the local controller firmware in order to be effective.
- The ramp metering system needs to respond quickly to congestion at multiple locations in the corridor, not just pre-determined bottlenecks. Each ramp needs to be able to respond to congestion at multiple locations in the corridor.
- The algorithm has to respond to downstream conditions before congestion reaches the mainline in the vicinity of the ramp.
- The algorithm should be able to incorporate preferential metering for HOVs.
- The algorithm should support the existing field configuration for ramp meters, particularly mainline detector placement.

Table 7-1 presents the characteristics mentioned above along with the weighting factor (1-5), where 5 is the highest possible score for each feature.

Table 7-1. Algorithm Comparison

<table>
<thead>
<tr>
<th>Desired Functionality</th>
<th>Candidate Algorithm Rankings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MN Zone</td>
</tr>
<tr>
<td><strong>Operator Interaction</strong></td>
<td></td>
</tr>
<tr>
<td>Fully automated with minimal operator interaction</td>
<td>5</td>
</tr>
<tr>
<td>Minimal and infrequent adjustment/calibration needed</td>
<td>5</td>
</tr>
<tr>
<td>Easy to understand and tune. Reasonable number of parameters that are easy to change or modify</td>
<td>4</td>
</tr>
<tr>
<td>Can override metering rates and turn meters on and off</td>
<td>5</td>
</tr>
<tr>
<td><strong>Ramp Queue Management</strong></td>
<td></td>
</tr>
<tr>
<td>Impacts of congestion stay localized</td>
<td>3</td>
</tr>
<tr>
<td>Equitably spread wait times throughout the corridor</td>
<td>3</td>
</tr>
<tr>
<td>Quick action and quick propagation of ramp queues upstream</td>
<td>5</td>
</tr>
<tr>
<td>Minimizes the likelihood of queue override conditions that “flush” the ramp</td>
<td>5</td>
</tr>
<tr>
<td>Ability to function meaningfully if one or more ramps go offline</td>
<td>4</td>
</tr>
<tr>
<td>Respond quickly to congestion at multiple locations in the corridor, not just pre-determined bottlenecks</td>
<td>5</td>
</tr>
<tr>
<td>Ability to respond before congestion occurs</td>
<td>4</td>
</tr>
<tr>
<td>Can incorporate preferential metering for HOVs</td>
<td>4</td>
</tr>
<tr>
<td>Algorithm should support existing field configuration for ramp meters, particularly mainline detector placement</td>
<td>5</td>
</tr>
<tr>
<td>Ease of implementation</td>
<td>2</td>
</tr>
<tr>
<td><strong>Weighted Score</strong></td>
<td><strong>4.2</strong></td>
</tr>
</tbody>
</table>

The rule based coordinated ramp metering strategies make their real-time decisions by checking appropriate heuristic rules and activating specific regulators or actions at individual on-ramps. Since no
common general method is used, rule-based strategies may be quite different in approach and complexity, required calibration effort, and, most importantly, efficiency.\textsuperscript{11}

In addition, Table 7-2 provides a list of different rule-based strategies along with a brief description.

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ACCEZZ algorithm</td>
<td>The method is based on fuzzy logic. The rule base, defined as the set of rules in the fuzzy logic algorithm, incorporates human expertise.</td>
</tr>
<tr>
<td>2</td>
<td>Zone algorithm</td>
<td>The motorway network is divided into zones which end at a bottleneck. The algorithm aims at balancing the entering and exiting traffic volumes of each zone.</td>
</tr>
<tr>
<td>3</td>
<td>Helper algorithm</td>
<td>It performs a form of hierarchical coordinated control where decisions with respect to local ramp metering are taken on a higher level.</td>
</tr>
<tr>
<td>4</td>
<td>Bottleneck algorithm</td>
<td>Demand-capacity strategy is used at local level. At a network-wide level, the formation of congestion at various bottleneck locations is identified and a decision is made with respect to the required volume reduction.</td>
</tr>
<tr>
<td>5</td>
<td>Fuzzy logic algorithm</td>
<td>The fuzzy logic approach requires the use of a number of inference rules, which provide the guidelines for the system's behaviour.</td>
</tr>
<tr>
<td>6</td>
<td>Linked-ramp metering system</td>
<td>The coordination aspect of this system rests on a heuristic logic, similar with that of the Helper Algorithm.</td>
</tr>
<tr>
<td>7</td>
<td>Sperry ramp metering algorithm</td>
<td>The strategy operates at two distinct modes, the restrictive and the non-restrictive with respect to a predefined threshold.</td>
</tr>
<tr>
<td>8</td>
<td>SWARM strategy</td>
<td>It uses a linear regression and Kalman filter applied to detector data for the forecast of the future traffic demands.</td>
</tr>
<tr>
<td>9</td>
<td>HERO algorithm</td>
<td>HERO (HEuristic Ramp metering coOdition) incorporates local ALINEA regulators. When the queue of an on-ramp becomes larger than a predetermined threshold, then the burden of decreasing this queue is assigned to upstream on-ramps.</td>
</tr>
</tbody>
</table>
8 DEPLOYMENTS

The following section provides a snapshot of the countries and cities (in the US) that have implemented ramp metering.

Figure 8-1 provides a list a cities/counties where ramp metering has been implemented, as well as the type of algorithm deployed.

Figure 8-1. Who Meters?

8.1 US DEPLOYMENTS

The following section highlights US deployments, the range of their implementation and the central algorithms used throughout the country.

Table 8-1 provides a list of the central algorithm used by different agencies.

<table>
<thead>
<tr>
<th>Large Systems (&gt; 50 metered ramps)</th>
<th>Small Systems (&lt; 50 metered ramps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago, IL</td>
<td>Columbus, OH</td>
</tr>
<tr>
<td>Los Angeles, CA (&gt;1000)</td>
<td>Cincinnati, OH</td>
</tr>
<tr>
<td>Minneapolis/St Paul, MN (~420)</td>
<td>Denver, CO</td>
</tr>
<tr>
<td>New York, NY</td>
<td>Detroit, MI (on hold)</td>
</tr>
<tr>
<td>Orange County, CA (~300)</td>
<td>Northern Virginia, VA</td>
</tr>
</tbody>
</table>
### Large Systems (> 50 metered ramps) vs. Small Systems (< 50 metered ramps)

<table>
<thead>
<tr>
<th>Large Systems (&gt; 50 metered ramps)</th>
<th>Small Systems (&lt; 50 metered ramps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland, OR (~150)</td>
<td>Houston &amp; San Antonio, TX</td>
</tr>
<tr>
<td>San Diego, CA (~290)</td>
<td>Milwaukee, WI</td>
</tr>
<tr>
<td>CA Bay Area (~250)</td>
<td>Kansas City, KS/MO</td>
</tr>
<tr>
<td>Seattle, WA (&gt;200)</td>
<td>Riverside &amp; San Bernardino, CA</td>
</tr>
<tr>
<td>Arizona (~200)</td>
<td>Las Vegas, NV</td>
</tr>
<tr>
<td>Miami, FL</td>
<td>Louisiana</td>
</tr>
<tr>
<td>Atlanta, GA (~160)</td>
<td>Fresno, CA</td>
</tr>
<tr>
<td></td>
<td>Sacramento, CA</td>
</tr>
</tbody>
</table>

### North America Deployments

<table>
<thead>
<tr>
<th>North America Deployments</th>
<th>Central Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seattle, WA</td>
<td>Fuzzy Logic Algorithm</td>
</tr>
<tr>
<td>Washington</td>
<td>Bottleneck</td>
</tr>
<tr>
<td>Portland, OR</td>
<td>System Wide Adaptive Ramp Metering (SWARM)</td>
</tr>
<tr>
<td>Los Angeles, CA</td>
<td>System Wide Adaptive Ramp Metering (SWARM)</td>
</tr>
<tr>
<td>Denver, Colorado</td>
<td>Helper</td>
</tr>
<tr>
<td>Minneapolis/St Paul, MN</td>
<td>The Stratified Zone Algorithm</td>
</tr>
<tr>
<td>Kansas City, MO/KS</td>
<td>Corridor Adaptive Ramp Metering Algorithm (CARMA)</td>
</tr>
</tbody>
</table>

### International Deployments

The following section highlights international deployments and the central algorithms used in the various countries. Counties that have implemented ramp metering include: UK, Germany, Netherlands, Italy, Australia, Taiwan, Canada, South Africa, New Zealand, and Japan.

Table 8-2 provides a list of the central algorithm used by different countries.

#### Table 8-2. International - Central Algorithm

<table>
<thead>
<tr>
<th>International Deployments</th>
<th>Central Algorithm</th>
<th>Type of Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>ALINEA</td>
<td>Isolated</td>
</tr>
</tbody>
</table>

8.2 **INTERNATIONAL DEPLOYMENTS**

The following section highlights international deployments and the central algorithms used in the various countries. Counties that have implemented ramp metering include: UK, Germany, Netherlands, Italy, Australia, Taiwan, Canada, South Africa, New Zealand, and Japan.

Table 8-2 provides a list of the central algorithm used by different countries.
9 SOFTWARE SELECTION IMPLICATIONS

There are some features of the software that will be required that regardless of the algorithm.

- The algorithm will be able to be set to automatically turn on and off within a possible ramp metering window. That window could be 24 hours per day, 7 days a week. It will also be able to turn on and off based solely on time of day.

<table>
<thead>
<tr>
<th>Country</th>
<th>Software</th>
<th>Coordination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>COMPASS</td>
<td>Coordinated</td>
</tr>
<tr>
<td>Israel (Ayalon Hwy, Tel Avis)</td>
<td>ALINEA</td>
<td>Isolated</td>
</tr>
<tr>
<td>Istanbul, Turkey</td>
<td>ALINEA</td>
<td>Isolated</td>
</tr>
<tr>
<td>Italy (Mestre Ring Road)</td>
<td>TIME</td>
<td>Coordinated</td>
</tr>
<tr>
<td>France</td>
<td>METALINE (based on ALINEA)</td>
<td>Coordinated</td>
</tr>
<tr>
<td>France</td>
<td>V-C ALINEA</td>
<td>Isolated</td>
</tr>
<tr>
<td>France (A6 south of Paris)</td>
<td>ALINEA</td>
<td>Isolated</td>
</tr>
<tr>
<td>Germany (A94 Munich)</td>
<td>ALINEA</td>
<td>Isolated</td>
</tr>
<tr>
<td>Germany</td>
<td>ACCEZZ (based on Fuzzy Logic)</td>
<td>Coordinated</td>
</tr>
<tr>
<td>Japan (Tokyo Metropolitan Fwy)</td>
<td>ALINEA</td>
<td>Isolated</td>
</tr>
<tr>
<td>Melbourne, Australia (VicRoads)</td>
<td>Heuristic Ramp metering coOrdination (HERO)</td>
<td>Coordinated</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Rijkswaterstaat (RWS)</td>
<td>Coordinated</td>
</tr>
<tr>
<td>Netherlands</td>
<td>METALINE</td>
<td>Isolated</td>
</tr>
<tr>
<td>New Zealand (SH20)</td>
<td>Easy Merge Ramp Signal</td>
<td>Coordinated</td>
</tr>
<tr>
<td>UK (M6)</td>
<td>ALINEA</td>
<td>Isolated</td>
</tr>
<tr>
<td>UK (M8, Glasgow)</td>
<td>ALINEA</td>
<td>Isolated</td>
</tr>
<tr>
<td>Shangai (Urban Expressway)</td>
<td>ALINEA</td>
<td>Isolated</td>
</tr>
<tr>
<td>Stockholm, Sweden</td>
<td>TIME</td>
<td>Coordinated</td>
</tr>
<tr>
<td>Taiwan (Fwy no. 5)</td>
<td>Fuzzy Logic</td>
<td>Coordinated</td>
</tr>
</tbody>
</table>
• The algorithm will have parameters that can be tuned from the graphical user interface by those with the authority to make adjustments. The algorithm should be easily tuned or a tool should be available to allow for easy tuning or adjustment of parameters to optimize ramp metering performance.

• Operators will have the authority to turn meters on and off and to override metering rates in situations that warrant that degree of intervention.

• The systems will be able to assign detector stations or individual detectors to individual ramps for rate calculations.

• The algorithm will have a more sophisticated way to mitigate queues than simple queue override or queue adjustment features.

• The algorithm will need to be able to operate even if some ramps have failed communication.
## Resource List

The documents listed below were reviewed and used as references in developing this report.

<table>
<thead>
<tr>
<th></th>
<th>Source</th>
<th>Overview</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>National Cooperative Highway Research Program (NCHRP) – Proactive Ramp Management Under the Threat of Freeway-Flow Breakdown</td>
<td>A study was conducted with the objective to develop procedures for ramp metering implementation at freeway sections that frequently experience breakdowns and congestion.</td>
</tr>
<tr>
<td>2</td>
<td>University of California, Berkley for the California PATH Program – Design, Field Implementation and Evaluation of Adaptive Ramp Metering Algorithms <a href="http://www.me.berkeley.edu/~horowitz/Publications_files/All_papers_numbered/horowitz_TO4136_PATH_report05.pdf">http://www.me.berkeley.edu/~horowitz/Publications_files/All_papers_numbered/horowitz_TO4136_PATH_report05.pdf</a></td>
<td>The objective of the research is to develop, validate and implement strategies for new-traffic responsive ramp metering in order to reduce congestion in California highways. Microsimulation and Macrosimulation traffic models were used as part of the research.</td>
</tr>
<tr>
<td>4</td>
<td>Caltrans District 7 – Ramp Metering <a href="http://www.topslab.wisc.edu/its/rampmetering/other/CA_Dist7RM.doc">www.topslab.wisc.edu/its/rampmetering/other/CA_Dist7RM.doc</a></td>
<td>Overview of the different types of ramp metering.</td>
</tr>
<tr>
<td>Source</td>
<td>Overview</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Texas Transportation Institute - Ramp Metering Algorithms and Approaches for Texas</td>
<td>Comparison of ramp metering algorithms in order to develop guidelines from implementation in Texas.</td>
<td></td>
</tr>
<tr>
<td>Highways Agency, UK - Ramp Metering and Integrated Traffic Management</td>
<td>Presentation on the ramp metering, current deployments and Integrated Traffic Management (ITM)</td>
<td></td>
</tr>
<tr>
<td>US Department of Transportation – Ramp Metering Status in North America, 1995</td>
<td>Overview of the ramp metering systems deployed in the USA. Case studies for entrance ramp metering, connector metering, mainline metering, ramp metering considerations, and guidelines for ramp metering.</td>
<td></td>
</tr>
</tbody>
</table>
Review of Existing Ramp Metering Algorithms

- SWARM
- CARMA*
- Fuzzy Logic*
- MN Zone*
- Stratified Zone
- Bottleneck*
- Helper
- ANCONA
- ALINEA*
- Variable ALINEA
- AD ALINEA
- METALINE
- HERO
- Rukswaterstaat (RWS)
<table>
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<tr>
<th>North America Deployments</th>
<th>Central Algorithm</th>
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</tr>
<tr>
<td>Kansas City, MO/KS</td>
<td>Corridor Adaptive Ramp Metering Algorithm (CARMA)</td>
</tr>
</tbody>
</table>
### Who meters in the US?

<table>
<thead>
<tr>
<th>Large Systems ((&gt;\ 50) metered ramps)</th>
<th>Small Systems ((&lt;\ 50) metered ramps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago, IL</td>
<td>Columbus, OH</td>
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<tr>
<td>Los Angeles, CA ((&gt;1000))</td>
<td>Cincinnati, OH</td>
</tr>
<tr>
<td>Minneapolis/St Paul, MN ((~420))</td>
<td>Denver, CO</td>
</tr>
<tr>
<td>New York, NY</td>
<td>Detroit, MI (on hold)</td>
</tr>
<tr>
<td>Orange County, CA ((~300))</td>
<td>Northern Virginia, VA</td>
</tr>
<tr>
<td>Portland, OR ((~150))</td>
<td>Houston &amp; San Antonio, TX</td>
</tr>
<tr>
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<td>Milwaukee, WI</td>
</tr>
<tr>
<td>CA Bay Area ((~250))</td>
<td>Kansas City, KS/MO</td>
</tr>
<tr>
<td>Seattle, WA ((&gt;200))</td>
<td>Riverside &amp; San Bernardino, CA</td>
</tr>
<tr>
<td>Arizona ((~200))</td>
<td>Las Vegas, NV</td>
</tr>
<tr>
<td>Miami, FL</td>
<td>Louisiana</td>
</tr>
<tr>
<td>Atlanta, GA ((~160))</td>
<td>Fresno, CA</td>
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The System Wide Adaptive Ramp Metering (SWARM) algorithm:

- Makes continuous forecasts of traffic conditions in real-time based traffic data at dynamically determined bottleneck locations
- Creates metering rates based on the forecasts, ramp capacities, and allowable metering rates using a propagation methodology
- Has many subsystems that determine allowable metering rates
- Forecasts traffic conditions x minutes into the future
- Changes metering rates now to avoid predicted future problems
CARMA

- Corridor Adaptive Ramp Metering Algorithm (CARMA)
- Based on Smoothed Mainline Speed
- Computes Rates at each Mainline Vehicle Detector Station (VDS)
- Tempers Rates based on Downstream Conditions
- Bounds Rates based on Local Maximum and Minimum Rates
- Adapts to Ramps in Queued States
- Adapts to Ramps operating in Non-CARMA modes
- Controls Hours of Operation
- Current Smoothed Mainlines Speeds are input to this linear relationship to compute the desired Local Raw Rate
Fuzzy Logic

- Developed by WSDOT with the University of Washington.
- It addresses multiple objectives and weighs rules that implement those objectives.
- The rule groups include:
  - Local mainline speed and occupancy
  - Downstream speed and occupancy
  - Ramp queue occupancy
- A process known as “fuzzification” translates each numerical input into a set of fuzzy classes: very small (VS), small (S), medium (M), big (B), and very big (VB).
MN Zone

- It divides Freeways into multiple zones, generally 3 to 6 m long
- Zones (upstream free flow location/downstream bottleneck)
- Balances volumes entering/exiting fixed freeway r/m zones
- Distributes the spare capacity among the meters in a zone based on current demands at the ramps
- Capacity is considered a constant relative to the number of lanes at the bottleneck, during all times at all bottlenecks
- Dynamic bottleneck locations to adjust to changing traffic conditions based on incidents, weather, or other factors.
- Queue detectors are used to calculate queues. Queue waiting time is limited generally to about four minutes. The metering rate at a ramp can be raised to assure wait time is limited.
- “Spare” capacity is calculated from volume and speed and utilized to increase ramp flow rates, and reduce queues, when mainline conditions can handle additional vehicles.
Stratified Zone

- Incorporates the more dynamic nature of a freeway by allowing multiple zone bottleneck locations by assigning a ramp to a series of zones then optimizing the ramp meter rate based on the most critical zone at the time, rather than pre-established fixed zone locations.

- Addresses the need to manage queue wait times by having a separate function for monitoring and managing queues.
**Bottleneck**

- Bottleneck has been applied in Washington State for years. It has three components:
  - Local metering algorithm (occupancy control);
  - Coordination algorithm is the unique aspect of Bottleneck; and
  - Adjustment to meter rates.
- It incorporates occupancy control as their local controllers to account for localized congestion. It can work with dynamic bottlenecks.
Helper

- It is comprised of a local traffic-responsive algorithm with the added feature of central override control.
- Within a freeway corridor, controlled on-ramps are divided into six location groups, with each group containing one to seven controlled on-ramps.
- Helper monitors on-ramp queues by keeping track of occupancies on queue detectors and adjusts metering rates in case of any excess queue development.
ANCONA

- The theory states that there are three stages of traffic: free flow, synchronized flow and the wide moving jam.
- Breakdown at a bottleneck such as an on-ramp is associated with a transition from free-flow to a synchronized flow state.
- ANCONA is based on the transition. After congestion has begun on the motorway, synchronized flow should be maintained around the on-ramp by switching between a high and a low metering rate.
ALINEA

- ALINEA is a **local traffic responsive algorithm** with feedback structure (not adaptive), but it is the basis of HERO (adaptive algorithm):
  - Considers conditions last time period (feedback)
  - Targets optimal mainline occupancy downstream of ramp
  - Queue override can be incorporated
  - Additional module can dynamically estimate optimal occupancy
Variable ALINEA

- The V-ALINEA or EDA (simple metering algorithm), is a version of the ALINEA. The difference is the use of speed measurements instead of occupancy for the metering rate calculation.
- V-ALINEA is not a closed loop feedback controller.
- The advantage of using the speed instead of the flow is the same as with the occupancy, the observation is unique for both congested and free flowing traffic.
AD-ALINEA

- Although occupancy has shown less sensitivity to external circumstances than motorway capacity, it is still difficult to estimate and maintain a correct value for the critical occupancy. To fix this problem Kosmatopoulos et al. have developed the AD-ALINEA metering algorithm, an adaptive version of the original ALINEA algorithm. The ALINEA metering algorithm itself remains unchanged.

- For AD-ALINEA only an estimation module has been added to the original ALINEA.
METALINE

- METALINE is an extension of the ALINEA algorithm
- Its control logic is Proportional-Integral state feedback
- The metering rate of each ramp is computed based on the change in measure occupancy of each freeway segment under METALINE control, and the deviation of occupancy from critical occupancy of each segment that has a controlled on-ramp.
- No direct consideration of queue overflow, HOV/bus priority, and bottleneck effects.
HERO

- The HEuristic Ramp metering coOrdination (HERO) estimates queue lengths and calculates the desired meter rate based on critical occupancy, the queue estimate, and ramp demand.
- Based on readily available real-time data without the need for real-time model calculations or external disturbance prediction.
- HERO uses an extended version of ALINEA at a local level.
  - ALINEA algorithm for local control
  - HERO algorithm to provide coordination between ramps.

The basic philosophy for HERO is:
- HERO identifies potentially active mainstream bottlenecks
- To retard or avoid ramp queue control of the concerned on-ramp (master) and the resulting mainstream congestion, HERO activates increasingly storage space via recruitment of upstream located slave-ramps
- The formed cluster of ramps is dissolved when the mainstream occupancy at the bottleneck or the master-ramp queue become sufficiently low
Rukswaterstaat (RWS)

- It is a capacity-demand feed-forward control algorithm, its goal is to prevent or postpone congestion from forming.
- Only algorithm implemented in Dutch ramp metering systems.
- Calculates the metering rate by subtracting the motorway traffic demand from the motorway capacity.
- Performance of the ramp meter will be mostly determined by the motorway congestion detection and the on-ramp queue detection. When congestion on the motorway is detected the flow on the on-ramp is restricted.
Traffic Induction Metering

- Overall system overview can be divided into Central and Local level
- The Central level consists of a central computer; the Local one is the Omnivue system that can be used for monitor the system by the operators
- The Central system, called Traffic Introduction Metering (TIME) system, handles the centralized control of when to allow green periods to the ramps, basing on all the traffic data
- At the central level, the overall control strategy is computed every 60 seconds, so as to be able to optimize traffic distribution and prevent a buildup of queues on any single ramp
- TIME can also take into account traffic predictions received from other systems
Key Differentiators

- Instrumentation
- Rate range
- Rate selection
- Rate stability
- HOV/Transit Vehicle Priority
Instrumentation

- Algorithms must accurately measure occupancy and speed using stations at ramps and at regular spatial intervals along the freeway. They need to accurately measure state of ramp queues. Different algorithms rely on different detector configurations. Isolated algorithms consider local conditions at the ramp only. Coordinated algorithms also consider conditions elsewhere on the freeway.

- We need a coordinated algorithm for the DCCM application. Metering rates will depend on local conditions at the ramp and conditions downstream on the freeway.
Rate Range

- Algorithms must determine minimum and maximum rates at each ramp. Some algorithms use predefined ranges that are either fixed or can vary by time of day. Other algorithms collect ramp volumes in real time, and choose a minimum rate consistent with the historical demand and the ramp storage capacity.
- A fixed predefined range is sufficient for the DCCM application.
Rate Selection

- Algorithms must select the rate to apply at each meter. Responsive algorithms select metering rates deterministically according to current traffic conditions and predefined thresholds (e.g., saturation density or critical speed).

- Adaptive algorithms are able to dynamically update these thresholds based on collected traffic data, and can therefore adapt to construction and incidents. Adaptive algorithms sometimes use prediction to avoid congestion rather than simply responding to it.

- A responsive algorithm is sufficient for DCCM. Dynamic updating of thresholds and the use of prediction requires additional effort to configure and troubleshoot, and is not considered to be of high value for this project.
Rate Stability

- Algorithms must avoid excessive fluctuation in the ramp metering rates from one minute to the next; balancing this with the need to respond quickly to changing traffic conditions. Some algorithms use a smoothed rate (based on a weighted average of the current and past values). Other algorithms apply a maximum differential between successive rates.

- Smoothing can mask issues and adds latency. A maximum differential between successive metering rates will be used for DCCM.
HOV/Transit Vehicle Priority

- Algorithms may support a bypass lane for HOVs and transit vehicles at each ramp. Some algorithms measure the volume of HOV and transit vehicles using the bypass lane and subtract from the metering rate for the general purpose lanes at the same ramp. Other algorithms separately meter the HOV/transit lanes.
- Separate metering of HOV/transit lanes will be used.