

Project Title

Design and Evaluate Coordinated Ramp Metering Strategies for Utah Freeways

University

University of Utah

Principal Investigators

Xianfeng “Terry” Yang
Assistant Professor
University of Utah
Phone: (801) 585-1290
Email: x.yang@utah.edu
ORCID: 0000-0002-9416-6882

Research Needs

During the past decades, ramp metering (RM) control has been widely implemented in many states of the U.S., including Utah. In practice, it can reduce overall freeway congestion by managing the amount of traffic entering the freeway and by breaking up platoons that make it difficult to merge onto the freeway [1]. RM controllers can be implemented as coordinated or uncoordinated systems. When operating an uncoordinated RM, the metering rate and on/off statuses will be determined by local traffic conditions. Uncoordinated RM strategies include fixed, local, and corridor-responsive systems. Despite the improvements to the operational efficiency of mainline flows, RM will inevitably create additional delays to the ramp flows. As traffic demand for a freeway facility increases, mitigating mainline congestion could go beyond the capability of uncoordinated RMs [2-4]. Recognizing such limitations, the Utah Department of Transportation (UDOT) Traffic Management Division (TMD) is proposing to deploy coordinated RM systems in Utah, which will integrate several upstream RMs to alleviate one or several downstream bottlenecks.

The proposed research will be implemented to assist the on-going and future efforts to deploy coordinated RM systems and evaluate the performance of deployed systems. The research can benefit the transportation community by helping 1) understand potential ramp delays to achieve a target mainline congestion level; 2) identify the locations that would benefit from coordinated RMs; and 3) evaluate the system performance from both operational and safety aspects.

Hence, the proposed research is important to address the following issues:

1. What are the current practices on coordinated RM control and what lessons can be learned from them?
2. Where are the freeway bottlenecks that may warrant the implementation of coordinated RM?

3. What are the correlations among traffic flow level, target mainline congestion level, and ramp delays?
4. What is the safety performance of RM control on the risk of rear-end and merging crashes?
5. What is the overall system performance of coordinated RM after its first deployment in Utah?

Research Objectives

The research objectives of this project are summarized as follows:

1. Identifying the freeway bottleneck locations in Salt Lake County that are suitable for coordinated RM control.
2. Evaluating both the safety and operational performances of the placed coordinated RM control system.
3. Studying the additional delay created to the ramps by RM controls when a certain congestion level on freeway mainline is expected to be achieved.
4. Presenting the research outcomes at the national level.

By collecting the traffic sensor data and historical crash records on the I-15, I-80, and I-215 in Utah, this research will conduct preliminary data analysis and identify the potential locations that may need the coordinated RM. The results will be delivered to the UDOT TMD and be evaluated by their engineers. As UDOT TMD has already select one location to demonstrate the coordinated RM, additional data will be collected to compare the safety and operational performances of the freeway segment before-and-after the system implementation. Then grounded on the study of both field data and simulation data, this research will generate a guideline to quantify the additional delay created to the ramps by RM controls when a certain congestion level on freeway mainline is expected to be achieved. This guideline will be helpful to assist the decision-making process of UDOT in the near future.

Research Methods

The proposed research will include several key steps: literature review, data collection, data analysis, simulation establishment, model development, and performance evaluation. Therefore, appropriate research methods are essential to support the data analysis, simulation establishment, and model development.

For data analysis, this research will first adopt the Multi-Comparison with the Best (MCB) method to conduct data screening and eliminate the potential data errors by the traffic sensors. Then, an optimization model will be developed to determine the required number of coordinated RMs, with an objective of achieve the expected congestion level on the freeway. If the number is greater than one, then a coordinated RM is needed at the studied location. This research will develop simulation networks in VISSIM. Also, a curtail task is to conduct simulation calibrations. In this research, we propose to use a neuro network (NN) based calibration approach to minimize the difference between simulated and field collected traffic state (i.e., flow and speed). Considering the main purpose of the model development is to evaluate the safety and operational performance, this research will performance analysis at the microscopic (vehicle)

level. The vehicle trajectories from the VISSIM network and the safety performance measures such as rear-end and merging crash risks will be used.

Expected Outcomes

At the end of this project, the research outcomes are expected to provide transportation agencies such as state DOTs with a convenience tool to assess the need of placing coordinated RMs on their freeway networks. The developed model can also effectively predict the improvement of freeway efficiency and safety after the system implementation. More specifically, the following outcomes will be yielded by this research:

1. Report of literature review on the existing coordinated ramp metering control strategies and field applications.
2. A document to provide recommended bottleneck locations and associated ramp meters/rates to test coordinated ramp metering parameters.
3. A VISSIM simulation model to evaluate the additional delay created on the ramps with meters.
4. Report on the safety performance of ramp metering control.
5. Report on the operational and safety performance of coordinated ramp metering after the first deployment in Utah.
6. Final project report and final presentation which summarizes all findings.

Relevance to Strategic Goals

Many traffic crashes and congestions on the freeways are occurred by the traffic weavings of mainline and on-ramp flows. Based on the previous field experiments, RM has shown its great promise in improving freeway mainline operational efficiency and safety. This research will particularly examine the safety performance of the coordinated RM control in two ways: 1) study the vehicle trajectories generated by the VISSIM simulation to estimate the risks of two crash events, rear-end crash and merging crash; and 2) analysis the real-world crash data and compare the safety performance before and after the implementation of coordinated RM in Utah. The outcome of the research will provide state transportation agencies a better understanding on the potential safety benefit brought by coordinated RM. In addition, as the main objective of implementing coordinated RM is to limit the traffic flows entering to the freeway mainline and mitigation the congestions at the bottlenecks, this research will also comply with the strategic goal of “Livable Communities” by reducing the daily commute times of the community residents.

Educational Benefits

This project will directly fund two Ph.D. students from the Department of Civil and Environmental Engineering at the University of Utah. Females and students from underrepresented groups will also be encouraged to participate in the project. The student will be responsible for conducting the research activities under the supervision of the PI. He or she will also lead the writing of peer-reviewed journal and conference articles resulting from this project. The research outcomes will directly support his/her dissertation work as well. In addition, we will foster the integration of research and teaching in transportation engineering. Students enrolled in the following courses will directly benefit from this research: Transportation Engineering (CMSEEN 3520), Quantitative Methods in Transportation (CMSEEN 6530),

Highway Designs (CMSEEN 5620), Optimization in Transportation (CMSEEN 5920/6920), Traffic Network Modeling (CMSEEN 7545), and Transportation Planning (CMSEEN 5560).

Technology Transfer

As shown in Table 1, there are at four levels of RM control strategies and three of them are deployed in Utah.

Table 1 Summary of RM strategies in the state of Utah

Ramp Control Strategy	Description	Deployment in Utah
Fixed	Fixed time-of-day schedule and rate, no adjustments from mainline detection, queue detectors can modify rate in response to queues.	73%
Local	Fixed time-of-day window of metering operations, responsive to mainline detection to begin metering period. Metering rate fluctuates within 6 occupancy levels from mainline detection. Ramp queue detectors can modify the rate in response to queues.	5%
Corridor-responsive	Fixed time-of-day window of metering operations, responsive to mainline detection to begin and end metering operations. Metering rate fluctuates within 6 occupancy levels from mainline detection. Additionally, downstream bottleneck will create additional metering commands for overall segment volume reduction from on-ramps. Ramp queue detectors can modify the rate in response to queues.	22%
Coordinated	Ramp rates adjust based on adjacent and downstream mainline detectors. Ramp controllers communicate to balance queues and delays. Queue detectors on ramp <u>cannot</u> increase rate.	None

The proposed research will be implemented to assist UDOT TMD’s on-going and future efforts to deploy coordinated ramp metering systems and evaluate the performance of deployed systems. The research can benefit Utah by helping UDOT 1) understand potential ramp delays to achieve a target mainline congestion level; 2) identify the locations that would benefit from coordinated ramp meters; and 3) evaluate the system performance from both operational and safety aspects. The research is also expected to help UDOT provide better transportation services to Utah residents and will be aligned with UDOT’s strategic directions “Optimize Mobility” and “Zero Fatalities.”

The potential audiences of this research would include traffic engineers, traffic safety agencies, transportation asset managers, transportation planners, and policy decision-makers. The following agencies, offices, and committees are those most likely to implement the research results:

- Utah Department of Transportation
- Utah Department of Public Safety
- FHWA Office of Safety and Office of Planning
- TRB Standing Committee on Safety Data, Analysis, and Evaluation, Highway Safety Performance, Freeway Operations.

The research outcomes will also be published in peer-reviewed journals and conferences such as traffic injury prevention, accident analysis and prevention, ASCE journal of urban planning and development, and Transportation Research Board Annual Meeting. The PI of this project has been actively participated in the activities in TRB committees and is serving as member and friend of several standing committees. The PI is also serving as the Associate Editor of several transportation-related journals such as ASCE Journal of Urban Planning and Development and IEEE Open Journal of Intelligent Transportation Systems. Research findings will be shared with those communities the PI involved at the end of this project.

Work Plan

The work plan includes the following major activities:

1. Literature review
2. System-wide analysis to determine RM implementation locations
3. VISSIM simulation model development
4. Safety model development
5. System performance evaluation
6. Final project report preparation

The proposed research work will take one and a half year to complete. Research tasks with associated work schedules are listed as follows:

1. Conduct a literature review on coordinated ramp metering control methods and field applications (3 months).
2. Provide a system-wide analysis to identify existing freeway bottlenecks using current UDOT datasets (e.g., iPeMS and PeMS) and determine the locations of freeway-intersection interchanges that may benefit from coordinated ramp metering control (3 months).
3. Develop a generic VISSIM simulation model to evaluate the coordinated ramp metering system under different traffic flow patterns and answer the key question “To achieve a certain freeway congestion level, how many additional delays will be created to those ramps?” (3 months)
4. Develop models to evaluate the safety performance of coordinated ramp metering control in terms of quantifying the potential rear-end and merging crash risks, using the simulation data from task 3 (3 months).
5. Evaluate the system performance, from both operational and safety aspects, with the field data after UDOT deploys the first coordinated ramp metering system in Utah (3 months).
6. Prepare the final project report, the final presentation, and other conference/journal publications (3 months).

Project Cost

Total Project Costs: \$170,000
MPC Funds Requested: \$ 70,000
Matching Funds: \$100,000
Source of Matching Funds: Utah Department of Transportation (\$40,000)
University of Utah (\$60,000)

References

- [1] Papageorgiou, M., & Kotsialos, A. (2002). Freeway ramp metering: An overview. *IEEE transactions on intelligent transportation systems*, 3(4), 271-281.
- [2] Papamichail, I., Kotsialos, A., Margonis, I., & Papageorgiou, M. (2010). Coordinated ramp metering for freeway networks—a model-predictive hierarchical control approach. *Transportation Research Part C: Emerging Technologies*, 18(3), 311-331.
- [3] Kotsialos, A., Papageorgiou, M., & Middelham, F. (2001). Optimal coordinated ramp metering with advanced motorway optimal control. *Transportation Research Record*, 1748(1), 55-65.
- [4] Kotsialos, A., & Papageorgiou, M. (2004). Nonlinear optimal control applied to coordinated ramp metering. *IEEE Transactions on control systems technology*, 12(6), 920-933.