Environment and Natural Resources Trust Fund

2027 Request for Proposal

General Information

Proposal ID: 2027-317

Proposal Title: Maximum Throughput Ramp Metering Algorithm with Field Testing

Project Manager Information

Name: Michael Levin

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: A new ramp metering control on freeways will reduce traffic congestion and its corresponding energy consumption and emissions. Implementation in MN's current control software will make it deployable on freeways.

ENRTF Funds Requested: $181,000

Proposed Project Completion: June 30, 2029

LCCMR Funding Category: Small Projects (G)

Secondary Category: Energy (E)

Project Location

What is the best scale for describing where your work will take place?

Region(s): Metro

What is the best scale to describe the area impacted by your work?

Region(s): Metro

When will the work impact occur?

In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Transportation causes around 27% of US energy consumption (78% of that from motor vehicles) and 29% of greenhouse gas emissions (80% of that from motor vehicles) (https://www.epa.gov/ghgemissions/transportation-sector-emissions, https://www.eia.gov/energyexplained/use-of-energy/transportation.php). Reduce energy consumption and emissions from transportation therefore has large potential benefits. Transportation-related energy use can be reduced by 1) reducing motor vehicle miles traveled, which requires reducing travel demand or providing alternative forms of transportation; or 2) improving the energy efficiency of travel. Energy consumption and emissions per mile traveled is highly dependent on traffic congestion. Energy is expended during acceleration and lost to braking, and traffic congestion causes acceleration and braking to occur much more frequently. Internal combustion engine powertrains are less efficient at lower speeds in traffic congestion.

To reduce congestion, Minneapolis/St. Paul metropolitan area freeways are controlled by ramp meters ("1 car on green" traffic signals on on-ramps), which limit the rate of vehicles entering the freeway. Fewer vehicles on the freeway reduces freeway traffic congestion and increases freeway travel speeds. However, the current ramp metering control algorithm, k-adaptive, is a suboptimal heuristic with limited performance in high or dynamic vehicle volume conditions.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

I developed a max-pressure ramp metering control that is mathematically proven to achieve maximum throughput for the entire freeway system under uncertainty in future traffic demand. My numerical results in simulation (see visual) show that max-pressure significantly reduces congestion compared to the current k-adaptive algorithm, with higher freeway travel speeds and higher throughput (more vehicles getting to their destination faster). Improved traffic congestion will reduce energy consumption and emissions per mile traveled.

I will implement max-pressure into IRIS, MnDOT's open-source ramp metering control software, using my experience with Java programming, and demonstrate the correctness and safety of the implementation by connecting IRIS to a SUMO simulation of the test corridor chosen by MnDOT (they previously indicated a preference for MN-610). Then, I will work with Garrett Schreiner at MnDOT to modify the production version of IRIS, activate max-pressure on the actual freeway corridor, and conduct a before/after experiment. Using loop detector data collected during the experiment, I will estimate the benefits to energy consumption and emissions using EPA's MOVES software.

Ultimately, these software changes could be permanently used by MnDOT to improve freeway traffic congestion across Minnesota. Garrett Schreiner is supportive of this possibility.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

The main project outcome will be a reduction in energy consumption and greenhouse gas emissions from motor vehicle travel on freeways in the Minneapolis/St. Paul metropolitan area. This directly reduces the use of fossil fuels by motor vehicles, conserves local air quality, and reduces the rate of climate change. I will achieve this outcome by modifying the IRIS software used to control MN ramp meters to reduce freeway traffic congestion. The magnitude of the benefit will be estimated using US EPA's MOVES software.

Activities and Milestones

Activity 1: Construct simulation model of the MN-610 corridor to validate IRIS modifications and performance benefits

Activity Budget: $20,000

Activity Description:
Garrett Schreiner indicated that MN-610 is a desirable location for initial experiments.

However, to validate the implementation of max-pressure within IRIS, I have developed an IRIS-in-the-loop simulation. Instead of testing IRIS on public roads, IRIS has been connected to the SUMO simulator to evaluate its control and performance. In the field, IRIS communicates with loop detectors and ramp meter controllers to compute the ramp metering rate and control the physical meters. IRIS's communication with these devices has been replaced by an internet connection to SUMO microsimulation. IRIS is therefore unaware that the detector data it is receiving is coming from a simulation, and its metering controls are only affecting a simulation.

The project team will construct an accurate SUMO model of the intended test corridor using road geometries from OpenStreetMaps or GIS software and historical loop detector counts for entering demand. The modified IRIS will be tested on this corridor in SUMO, comparing the new max-pressure algorithm to the existing K-adaptive algorithm. This will detect most, if not all, software bugs with the max-pressure implementation, and will also achieve a performance comparison of speeds, travel times, etc.

Activity Milestones:

Description	Approximate Completion Date
Construct model of MN-610 in SUMO	July 31, 2027
Validate k-adaptive ramp metering behavior and connection to IRIS in SUMO model	August 31, 2027

Activity 2: Implement max-pressure ramp metering in IRIS and validate its implementation in SUMO

Activity Budget: $40,000

Activity Description:
The max-pressure control algorithm works by calculating a pressure term based on the density of traffic around each ramp. Intuitively, it wants to control ramp meters to move vehicles from long queues (on either the mainline or ramp) to areas of low traffic density. The mathematics have already been worked out, and numerical results suggest significant benefits over the current K-adaptive algorithm. This activity will implement max-pressure within IRIS for use on public roads.

IRIS is the MnDOT RTMC's open-source software for controlling its ramp meters. PI Levin has the IRIS source code compiled and running on his computer, and has already made modifications to it to work with SUMO. Using the object-oriented structure, max-pressure will be implemented as separate class files. Because the only detector information is from loop detectors at half-mile intervals, a cell transmission model of traffic flow will also be implemented to predict the movement of vehicles on the freeway around the ramp areas.

Using the MN-610 model from Activity 1, the implementation of max-pressure will be validated in SUMO simulation to ensure that it is safe and effective before attempting its use on public roads.

Activity Milestones:

Description	Approximate Completion Date
Software development of max-pressure in IRIS	October 31, 2027
Validation of max-pressure implementation in MN-610 model	December 31, 2027

Activity 3: Experimental deployment on MN-610

Activity Budget: $90,000

Activity Description:
The project team will work with the MnDOT RTMC to implement max-pressure within the production version of IRIS. Ideally, this will simply involve copying a few Java source files into the IRIS repository, and making a few changes to the IRIS PSQL database to register a new algorithm. However, they will undoubtedly require an extensive code review to verify the changes.

After that, Garrett Schreiner has agreed to activate max-pressure on the test corridor for experimental purposes. The project team will conduct a before/after study of traffic flow in the test corridor using occupancy times and counts from the loop detectors that are already installed at half-mile intervals. These counts are already publicly available. The project team will look at average speed and congestion patterns, using a combination of detector occupancies and a kinematic wave model of traffic flow calculated around the detector counts as boundary conditions. The objective is to verify that the simulation benefits of max-pressure hold up when it is used on public roads.

The project team will write a report on their findings to disseminate to MnDOT RTMC staff. If justified, the report will include evidence of benefits and a recommendation to continue using max-pressure.

Activity Milestones:

Description	Approximate Completion Date
Implement max-pressure in production version of IRIS: code review by RTMC staff	April 30, 2028
First activation of IRIS on MN freeways by RTMC	May 31, 2028
Conduct before/after comparison of max-pressure and k-adaptive using loop detector data	September 30, 2028
Analyze before/after comparison and make recommendations on permanent use	December 31, 2028

Activity 4: Estimate energy consumption and greenhouse gas emissions benefits of improved ramp metering

Activity Budget: $31,000

Activity Description:
In the vast literature on energy consumption and emissions from motor vehicles, traffic congestion consistently affects the efficiency per mile of travel. We expect that congestion reductions from max-pressure should result in significant energy consumption and emissions benefits. However, measuring those benefits directly is difficult. Instead, we will consider 2 options to obtain data about the traffic behavior, and use that as input to EPA's MOVES software, which is the standard tool for estimating energy consumption and emissions. 1) We will record data from the existing freeway loop detectors at 1/2 mile intervals, and use them to obtain estimates of the traffic flow behavior of the freeway that can be used within MOVES. It is possible that the detectors are too far apart to obtain sufficiently accurate estimates of traffic congestion in-between. 2) We will simulate max-pressure on 610 in SUMO, using loop detector counts for entering and exiting vehicles, and use the simulated vehicle trajectories in MOVES.

Activity Milestones:

Description	Approximate Completion Date
Estimate traffic flow behavior from freeway loop detectors, and attempt to use it in MOVES	December 31, 2028
(backup) Simulate entering/exiting traffic to obtain vehicle trajectories	March 31, 2029
Use MOVES to estimate energy and emissions benefits at different time-of-day periods	June 30, 2029

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
To enact useful change, this project requires MnDOT to use the new ramp metering control for freeways. Towards that goal, I have worked and will continue working with Garrett Schreiner during this project to conduct before/after experiments on MN-610 (or other freeway that MnDOT chooses) to obtain field results of the traffic congestion, energy, and emissions benefits from improved ramp metering. These results will be shared with Garrett Schreiner and his leadership at MnDOT to encourage future permanent use of the production software developed in this project. Furthermore, I will work with the University of Minnesota Center for Transportation Studies to share my results on their blog and newsletter so that Minnesota taxpayers are aware of the work that was accomplished.

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?
This project will produce a product - an improved version of the IRIS software used by Minnesota Department of Transportation (MnDOT) to control ramp meters. After this project, MnDOT should implement this product by activating it on individual ramp meters. Since 2025, I have been working with Garrett Schreiner, the traffic engineer at the MnDOT Regional Traffic Management Center who controls the ramp meters, to develop a software product that he is interested in using.

Project Manager and Organization Qualifications

Project Manager Name: Michael Levin

Job Title: Associate Professor

Provide description of the project manager's qualifications to manage the proposed project.
I have received over $3.4 million in 16 projects sponsored by state and federal governments. I have been supervising a team of graduate student research assistants since 2017 and collaborating with professor and industry partners on these projects. My successful projects include 1) Using stated preference surveys and mobile-sourced data to determine that early school start times do not have a noticeable impact on elementary school students walking or biking to school. 2) Developing an in-vehicle system that warns drivers to brake to avoid running red lights (like a forward collision warning), with the severity of the warning customized based on the future traffic signal timing and the driver's position and speed. This was demonstrated in Shakopee to Minnesota Department of Transportation. 3) Using mobile-sourced data to create estimates of pedestrian and cyclist volumes (travelers per day) for the Minnesota Department of Transportation. 4) Fundamental research on developing an adaptive traffic signal timing algorithm that guarantees maximum throughput for the US National Science Foundation. In collaboration with Hennepin County, simulation results predicted over 50% reductions in delay at some intersections.

Many project reports are publicly available, e.g.
https://mdl.mndot.gov/items/202521
https://mdl.mndot.gov/items/202433
https://mdl.mndot.gov/items/202419

Organization: U of MN - College of Science and Engineering

Organization Description:

The Department of Civil, Environmental, and Geo- Engineering at the University of Minnesota-Twin Cities is ranked in the top 20 among US civil engineering programs. This Department regularly conducts sponsored projects on fundamental and applied research for local, state, and federal governments.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Michael Levin, Principle Investigator		Technical supervision and project management. Lead software developer for IRIS modifications.			36.6%	0.2		$59,917
Graduate research assistant, 1 person		Graduate student who will lead simulation work and experimental analyses			24.2%	2		$121,083
							Sub Total	**$181,000**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
							Sub Total	-
Capital Equipment								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-
Travel In Minnesota								
							Sub Total	-
Travel Outside Minnesota								

							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$181,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**-**

Total Project Cost: $181,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: 3b7d91cc-e9e.pdf

Alternate Text for Visual Component

Max-pressure ramp metering significantly reduces traffic congestion vs. k-adaptive on a simulation model of I-94. This will reduce emissions per mile; data shows motor vehicles are most efficient around 50-60 mph. 80% of transportation emissions are from motor vehicles. Software implementation and experimental deployment will activate these benefits in MN...

Supplemental Attachments

Capital Project Questionnaire, Budget Supplements, Support Letter, Photos, Media, Other

Title	File
SPA letter of approval	dbddb187-a4c.pdf
Letter of support from Garrett Schreiner	ec7eddc9-37f.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Do you understand that travel expenses are only approved if they follow the "Commissioner's Plan" promulgated by the Commissioner of Management of Budget or, for University of Minnesota projects, the University of Minnesota plan?

N/A

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

No

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

N/A

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

N/A

Does your project include original, hypothesis-driven research?

No

Does the organization have a fiscal agent for this project?

No

Does your project include the pre-design, design, construction, or renovation of a building, trail, campground, or other fixed capital asset costing $10,000 or more or large-scale stream or wetland restoration?

No

Do you propose using an appropriation from the Environment and Natural Resources Trust Fund to conduct a project that provides children's services (as defined in Minnesota Statutes section 299C.61 Subd.7 as "the provision of care,

treatment, education, training, instruction, or recreation to children")?

No

Provide the name(s) and organization(s) of additional individuals assisting in the completion of this proposal:

Enoch Pan, Christina Doherty, University of Minnesota

Do you understand that a named service contract does not constitute a funder-designated subrecipient or approval of a sole-source contract? In other words, a service contract entity is only approved if it has been selected according to the contracting rules identified in state law and policy for organizations that receive ENRTF funds through direct appropriations, or in the DNR's reimbursement manual for non-state organizations. These rules may include competitive bidding and prevailing wage requirements

N/A