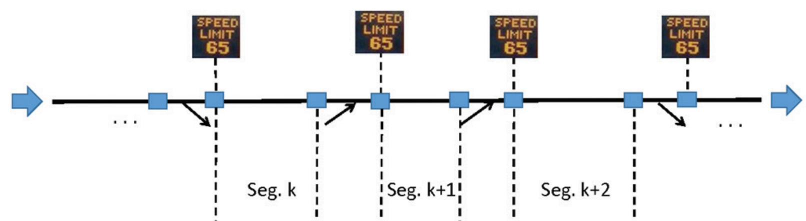
Distributed Traffic Control for Reduced Fuel Consumption and Travel Time in Transportation Networks

tech transfer summary

New techniques generate traffic control strategies that realize real-time, macroscopic-level traffic regulation with high precision.

Problem Statement

Current technology in traffic control is limited to a centralized approach that has not paid appropriate attention to efficiency of fuel consumption and is subject to the scale of transportation networks. A transformative approach is needed to reduce fuel consumption and travel time through the management of dynamic speed limit signs.



Sample traffic control scenario using dynamic speed limit signs

Background

Large-scale, complex transportation systems are some of the most indispensable infrastructures in urban and rural areas. The dramatically increasing demands of transportation service have led to traffic congestion, energy waste, pollution, and safety issues. To address these issues, researchers are developing intelligent traffic management strategies that rely on advanced sensing, communication, and high-performance computation techniques.

Project Objectives

- Generate a traffic control model that is computationally efficient and facilitates searching for an optimal control command
- Formulate the optimization of the model's performance index and dynamic traffic flow via convex functions, which will generate optimal speed profiles within polynomial computational times
- Construct a distributed framework based on dual decomposition and the subgradient method via networked road infrastructures

Research Methodology

Inspired by the Barron-Jensen/Frankowska (B-J/F) solution for Hamilton-Jacobi (HJ) partial differential equations (PDEs), the researchers adopted the B-J/F solution to Moskowitz HJ PDEs to obtain exact solutions without approximation.

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The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC). Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.

MTC's research focus area is State of Good Repair, a key program under the 2012 federal transportation bill, the Moving Ahead for Progress in the 21st Century Act (MAP-21). MTC research focuses on data-driven performance measures of transportation infrastructure, traffic safety, and project construction.

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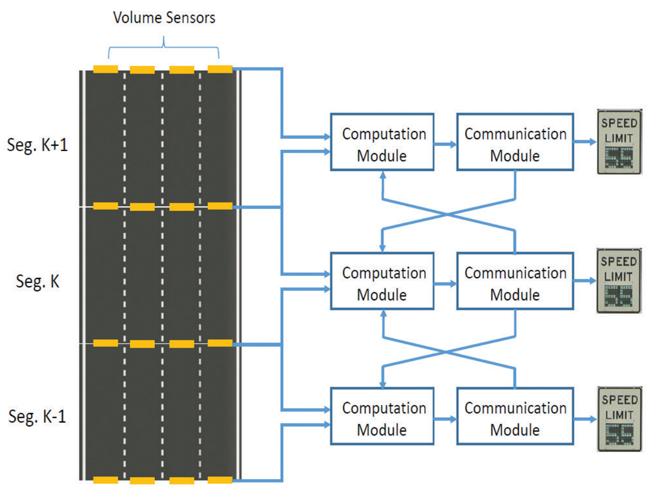
Combing the simplified solution to Mozkowitz HJ PDEs with the quadratic formulation of the Computer Programme to calculate Emissions from Road Transport (COPERT) fuel consumption model, the researchers formulated the energy-efficient traffic control problem as a convex quadratic optimization problem (CQOP).

A distributed framework was constructed to circumvent the utilization of global information in a centralized network. Dual decomposition and the subgradient method were implemented so that each decomposed subproblem could be solved individually in an iterative manner.



Road infrastructure components and information flow in the distributed framework

The feasibility of the proposed optimization method was verified through Vissim simulations that used real-world traffic flow data on segments of I-235 in Iowa. Road infrastructures (RIs) that integrate the functions of measurement, display, communication, and computation were installed at each decomposed road segment to guide drivers to travel at an optimal desired speed.

Key Findings

- The researchers developed an explicit solution to Moskowitz HJ PDEs and model constraints using a parabolic-shaped fundamental diagram. Moreover, a simplified model with linear constraints was developed.
- The energy-efficient traffic control problem formulated as a CQOP was computationally efficient.
- The distributed framework significantly reduced computational complexity by decomposing a centralized optimization problem into a set of small-scale subproblems. The distributed method was therefore more efficient and easier to implement than the centralized method. Moreover, each subproblem could be solved in parallel, which reduced the overall calculation time.
- Local information transmission in the distributed framework effectively avoided issues concerning missing data or redundancy.
- Experimental verification in Vissim confirmed that the proposed control strategy led to lower average vehicle density and the avoidance of severe congestion. The framework of data and control flow is applicable to real-time implementation.

Conclusions

- An efficient distributed optimization method would minimize fuel consumption in traffic flows modeled by the Lighthill-Whitham-Richard partial differential equation.
- The real-time, fuel-efficient traffic control problem was successfully formulated as a CQOP.
- Simulation results demonstrated reduced fuel consumption and alleviated traffic congestion. The feasibility of the proposed optimization method was verified through Vissim simulations that considered different traffic volumes and random seed parameters.

Implementation Readiness and Benefits

The proposed real-time highway control strategy can be implemented on highway sections using dynamic speed limit signs. The researchers plan to extend the one-dimensional control strategy to a highway network control strategy in the future.

The objective can be not only fuel consumption minimization, but also travel time minimization, throughput maximization, or multiple objectives. Moreover, the researchers expect to use hybrid highway infrastructures to design even more efficient control strategies, such as dynamic speed limit signs, ramp meters, and highway information signs.