Green Wave Speed Guidance on Signalized Road Networks

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Introduction

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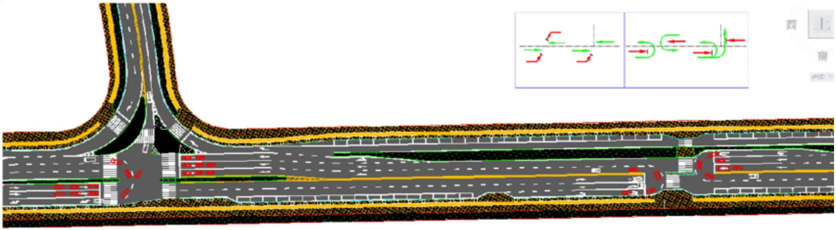

Figure: Green wave traffic phase diagram

Urban Traffic Challenges:

- Arterial roadways handle most urban traffic.
- Intersections act as bottlenecks, causing congestion and accidents due to insufficient traffic capacity.

Solution:

- Intelligent traffic control for urban arterial routes.

Introduction

Overview:

- **Optimize Flow:** Coordinate traffic signals to create a "green wave" for continuous movement.
- **Speed Guidance:** Provide optimal speed recommendations to match green light timings.
- **Reduce Stops:** Minimize stops, lowering travel time, fuel consumption, and emissions.
- **Enhance Traffic Efficiency:** Improve overall traffic flow and reduce congestion, especially during peak hours.

Introduction

Green Wave Strategy
Goal: Maximize green wave bandwidth.
Method: Coordinate signal timing across intersections.
Limitations:

- Requires synchronized signals.
- Needs bidirectional symmetry.

Introduction

Intelligent Vehicle Infrastructure Cooperation Systems

- Provides real-time traffic flow information.
- **Examples:** eSafety (EU), Smartway (Japan), IntellidriveSM (US).
- **Benefits**: Enhanced safety and situational awareness.

Introduction

Variable Speed Limit (VSL) Control for Urban Traffic
Inspiration: Highway VSL systems.
Method: Regulates average vehicle speed using real-time data.
Benefits:

- Optimizes road capacity.
- Reduces travel time.
- Enhances overall traffic flow

Related Work

Related Work

Overview of Variable Speed Algorithms for Urban Roads
Researchers have developed various speed guidance strategies to improve traffic flow, safety, and fuel efficiency.
Key Contributions:

- **Marchau and Jiménez:** Optimal speeds considering weather and road conditions.
- **Abu-Lebdeh:** Dynamic speed control to prevent congestion.
- **Yang and Mandava:** Speed advice to catch green lights.
- **Barth:** Minimize fuel consumption and emissions.
- **Rakha**: Compared fuel efficiency at signalized intersections.
- **Sun**: Speed guidance to reduce fuel consumption and emissions.

Related Work

Green Wave-based Speed Guidance Strategy (GWSGS):

- Helps vehicles pass through intersections without stopping.
- Calculates optimal speeds for high speed, acceleration, deceleration, and no guidance.

Emission-driven Speed Guidance Strategy (EDSGS) Modules:

- **Optimization Module:** Minimizes fuel consumption and CO2 emissions.
- **Ecological Index Calculation Module**: Adjusts speeds dynamically.

Process:

- Real-time speed recommendations based on vehicle's current speed, signal phase, and distance to intersection.

Related Work

Deep Q-Network (DQN) based Speed Guidance Algorithm

- Uses Reinforcement Learning (RL) to optimize driving decisions.
- Trains in SUMO traffic simulator.
- Agent learns from environment interactions to maximize rewards (minimize travel time).

Methodology

Methodology

Objective: Reduce travel time on main roads.
Approach: Control car movements, not traffic light timings.
Key Components:

- **Reduced Travel Time:** Efficient traffic flow.
- **Improved Traffic Flow:** Less congestion.
- **Enhanced Safety:** Smoother traffic movement.

Methodology

Flowchart:

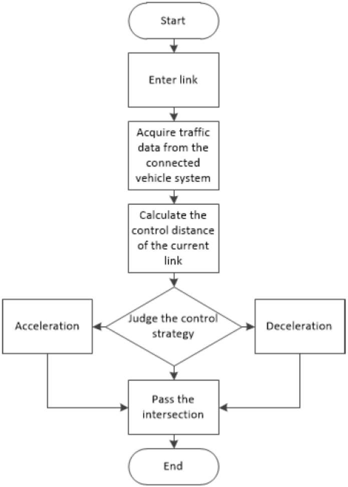

Figure: Flow chart of the distributed control strategy

Methodology

The optimization model and parameter explanations are as follows:

$$\text{Max } v_{\min}$$

$$s.t.$$

$$\begin{cases} x \geq \dfrac{(v^2 - v_{min}^2)v_{max}}{2a(v_{max} - v_{min})} + \dfrac{v_{min}v_{max}}{v_{max} - v_{min}}(R - \dfrac{v - v_{min}}{a}) & (1) \\ x \leq L & (2) \\ x \leq \dfrac{v_{\max}v}{v_{\max} - v}R & (3) \\ v \geq v_{\min} & (4) \\ G \geq \dfrac{x}{v_{\max}} & (5) \\ x, v, v_{max}, v_{min}, R, G, a \geq 0 \end{cases}$$

Methodology

Variable	Definition
V_{min}	he minimal velocity that the vehicle is required to decelerate, which is also the optimize goal
X	length from the control point to the intersections

Table: Definition of the Variables

- Among these variables, Vmin and x are not fixed.
- The optimization solution can be easily found using software like LINGO

Methodology

Parameter	Definition
V_{max}	the maximal velocity that a vehicle can attain under the legal speed limits
V	the desire velocity the vehicle is willing to attain without control
R	the red light time of the timing model of current link
G	the green light time of the timing model of current link
a	the equivalent deceleration of the vehicle

Table: Table: Definition of the parameters

Methodology

Optimization Model Constraints

Constraint (1):

- Based on Newton ' s laws of motion.
- Vehicle must slow down to avoid red light.

Constraint (2):

- Geographical limitation.
- Control distance must not exceed road length between intersections.

Constraints (3) and (4):

- Ensure vehicles slow down to avoid red lights.
- Controlled vehicles must be slower than their previous speed.

Timing Constraint:

- Controlled time should not exceed one signal cycle duration.

Results

Results

-Simulates urban traffic and public transit operations.

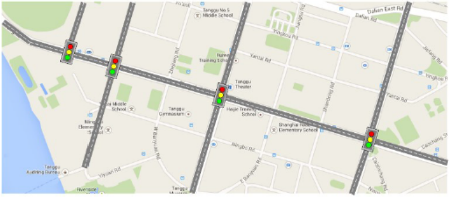

Figure: Map of the simulation network

-Static Timing Plan: Fixed intervals for traffic light changes at four intersections.

Intersection No	Red-time(Sec)	Green-light(Sec)	Yellow-light(Sec)
1	30	27	3
2	40	22	2
3	65	22	3
4	20	42	3

Table: Signal Time Model of The Intersections

Results

Analysis:

- Compare controlled vs. uncontrolled traffic.
- Analyze data from the last 100 vehicles.
- Plot vehicle paths and measure travel time reduction.

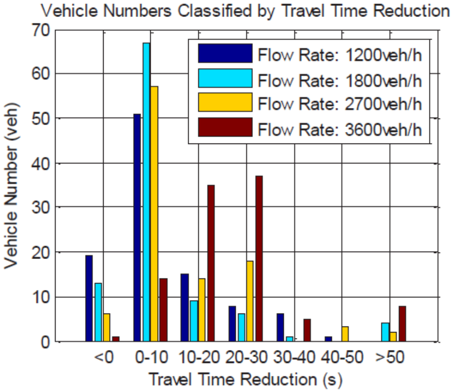

Figure: Distribution of TTR under different flow rates

Results

- Traffic control algorithm optimizes flow rates and reduces travel times.
- Controlling all vehicles from the start maximizes time savings.
- Even during heavy traffic, the algorithm prevents queues.

Traffic flow rate(Vehicle/h)	Average TTR(Sec)
1000	7.310
1200	6.778
1800	5.506
2700	10.216
3000	10.194
3600	18.942

Table: The TTR different traffic flow rate

Results

- More vehicles lead to congestion without control, causing longer stays in the link.
- The algorithm adjusts vehicle trajectories to avoid red light time, as shown in the plotted signal time plan and vehicle trajectories.

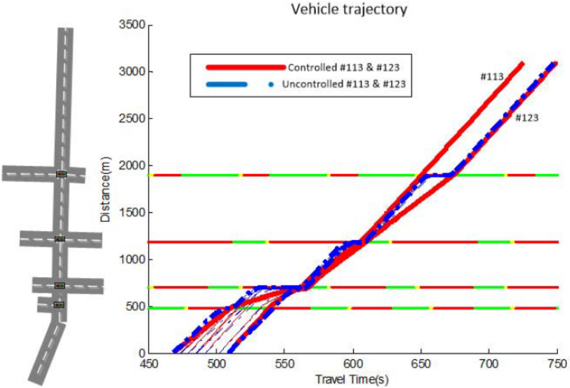

Figure: Trajectories of two specified vehicles

Comparison

Comparison

- **DQN-based:** Uses RL (DQN) to optimize travel time by training vehicles to make optimal speed decisions.
- **EDSGS:** Minimizes emissions by adjusting speeds based on real-time data and predefined constraints
- **GWSGS:** Coordinates vehicle speeds to match green waves, ensuring continuous flow through intersections.
- **Each approach offers unique advantages for optimizing signalized road networks**.

Conclusion

Conclusion

- Greatly reduces travel time according to simulation results.
- Minimizes braking and acceleration, potentially extending vehicle lifespan and benefiting the environment.
- Cost-effective option for road maintenance as it doesn't require major infrastructure investment.
- Shows promise in reducing queues and congestion, particularly during peak traffic.
- Alternative to traditional green wave strategies.
- Can optimize signal timing plans in real-time when combined with actuated controllers.

Acknowledgement

Acknowledgement

- Appreciation extended to Yang Bowen and Hu Jianming for their significant contributions.
- Inspired by their pioneering research, my study builds upon their foundation.
- Their insightful findings and innovative approaches shaped my research direction and methodology.

Any Questions?

Thank you!

Figure: Full paper link