# Paper Review: Proactive Traffic Merging Strategies for Sensor-Enabled Cars

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# Objective

- Highway traffic throughput at a ramp merging section can be optimized when sensor-enabled cars are proactively coordinated. Vehicles plan the order in which they merge and where they will merge into traffic beforehand based on nearby sensor information, allowing vehicles in the target lane to adjust their flow so the merging vehicle can enter the lane with minimum perturbation, increasing the overall throughput and decreasing the delay at the section.

# Results

- A proactive merging algorithm can increase the traffic throughput by 200% and reduce delay by 30% when compared to a priority-based merging algorithm.

# Introduction

- Road traffic congestion is an ever increasing problem
- Increasing infrastructure can't be the only solution
- There is an increase in the development of automotive sensors and inter-vehicle communication systems
- Such vehicles can be utilized to improve road throughput and decrease congestion
- A fully decentralized system is proposed in which vehicles share information to coordinate themselves through the merge
- A proactive merging algorithm is found the be most effective

# Background

- System relies on sensor enabled cars and assumes sensor and communication capabilities based on currently available systems
- Current sensors are small and low cost and combine sensing, processing, and communications capabilities in a single package.
- Prior work used a hybrid of centralized and decentralized configuration to improve traffic flow. This system will use a fully decentralized system
- Simulated drivers will follow the intelligent driver model (IDM) which dictates a vehicle's acceleration and deceleration behavior for following a front vehicle.

# Proactive Merging Algorithms

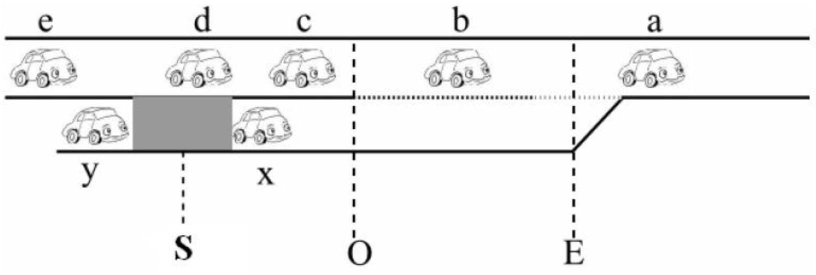
- Each algorithm uses position, velocity, and acceleration information from a few neighboring vehicles to make a merging decision.
- Assumptions:
  - We assume vehicles behave according to the IDM
  - Vehicles are capable of communicating with five to eight nearby vehicles using the Dedicated Short Range Communication (DSRC) protocol
  - All vehicles know the position and velocity of themselves and the vehicle ahead of them

# Proactive Merging Algorithms

- Cars are stored onto two lists: RampList and MainList.
- Algorithm decides the ordering of the two lists to form a combined OutList based on vehicle information.
- Distance-based, velocity-based, and platoon-velocity-based scheduling algorithms for merging order are proposed.

# Proactive Merging Algorithm: Two Phases

- :Three points on highway: Decision region (S), merge point (O), ramp end (E)
- At the decision region (S), the merging vehicle is chosen based on current traffic conditions instead of general lane conditions.
- Next it determines the spacing and velocity requirement to merge so that by the time the merging vehicle reaches its merging point (O), the target lane would have accommodated for the merging vehicle and the merging vehicle will have matched its velocity to the main road



# Evaluation (Performance Metrics)

- Delay: the time it takes for ramp cars to join the main road.
- Throughput: how many cars merge.
- Flow: product of density and velocity on main road

# Evaluation (Simulation)

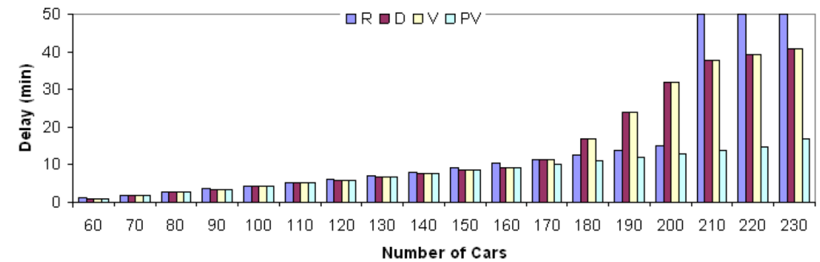
- Simulation performed in Java using an intelligent driver model (IDM).
- Less than ideal IDM parameters were used to better evaluate the effectiveness of the algorithm
- Each simulation begins with an initial density on a closed loop and allows the simulation to run with vehicles entering the loop through the ramp at a fixed rate.
- The initial densities chosen are 50, 100, 150 cars on the main road.

**Table 3: IDM parameters**

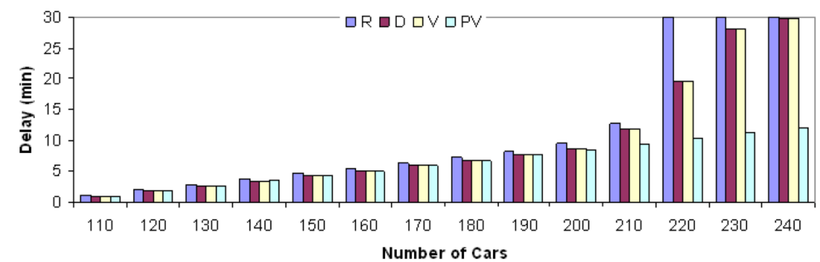
| Parameter | Value |
|---|---|
| Maximum velocity | $100\ km/h$ |
| Safe time headway | $1.5\ s$ |
| Maximum acceleration | $1\ m/s^2$ |
| Maximum deceleration | $3\ m/s^2$ |
| Minimum distance | $2\ m$ |

# Results (Delay)

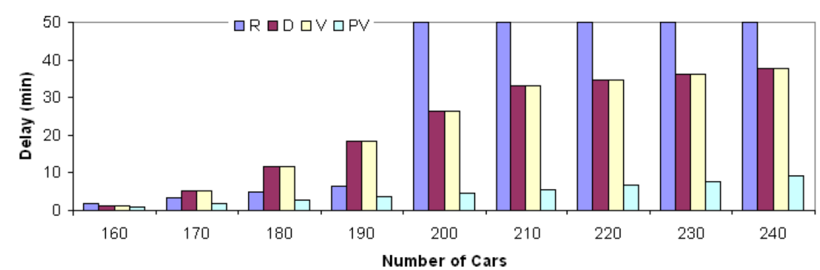
- Platoon-velocity based algorithm still allowed cars to merge when other algorithms had reach their capacities
- Priority-based merging will reach infinite delay.



Light initial density of the main road



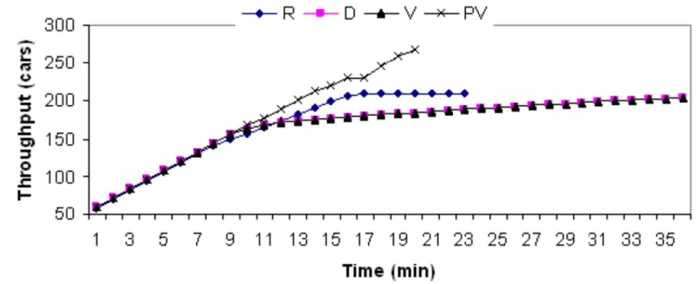
Medium initial density of the main road



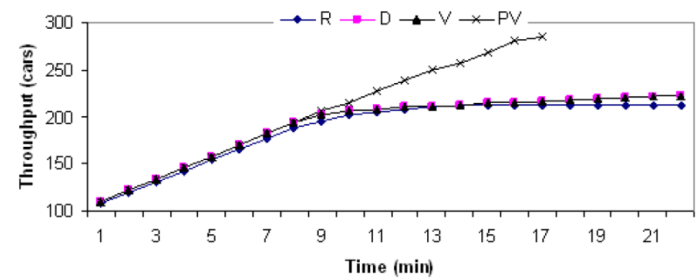
Heavy initial density of the main road

# Results (Throughput)

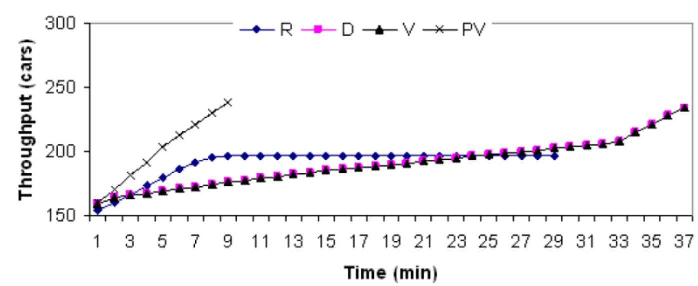
- Platoon-velocity based algorithm continuously increases throughput until capacity is met
- Other methods level off at a lower threshold, so fewer cars are able to merge.




Light initial density of the main road



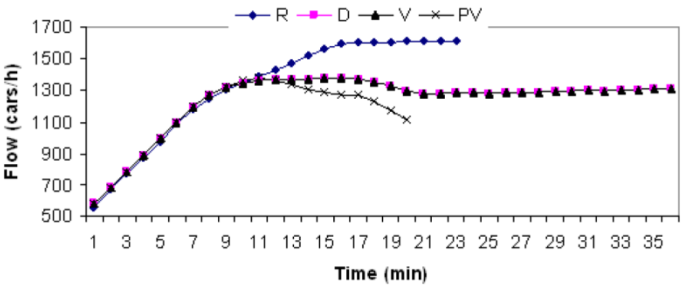

Medium initial density of the main road



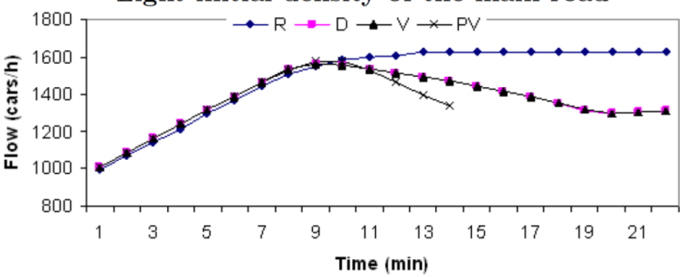

Heavy initial density of the main road

# Results (Flow)

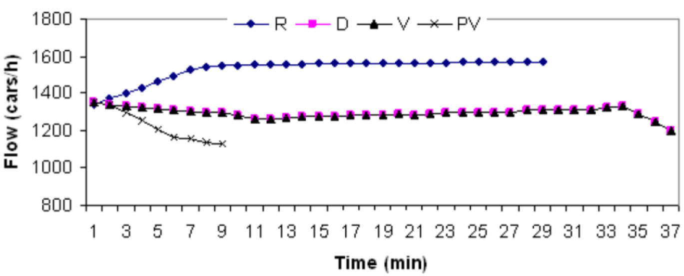
- Platoon-velocity based first to show signs of decrease flow due to reaching capacity
- Priority-based merging has all cars traveling at desired speed with desired spacing
- Proactive merging algorithms increase occupancy at the cost of speed, resulting in lower observed flow




Light initial density of the main road



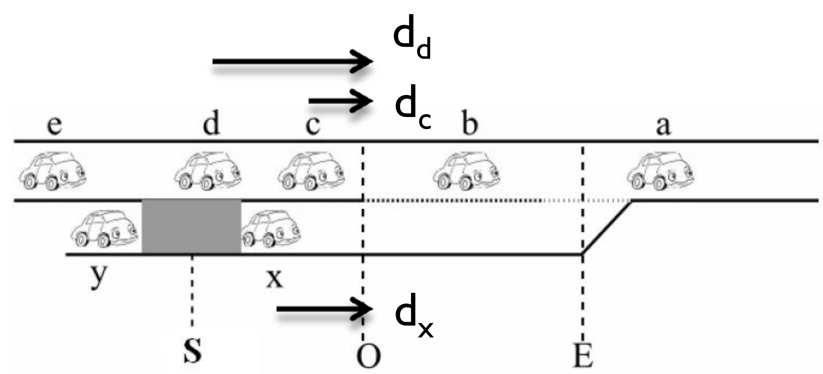

Medium initial density of the main road




Heavy initial density of the main road

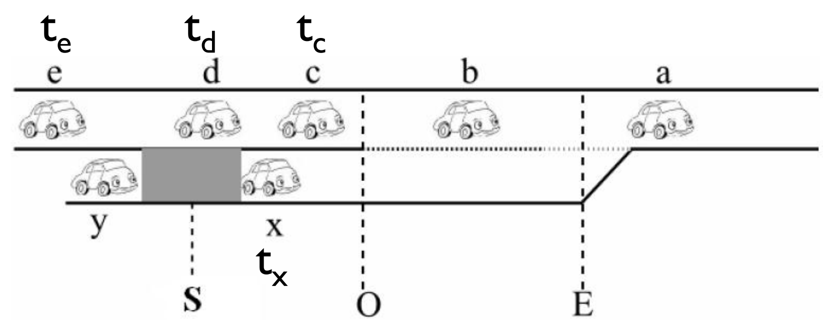
# Proactive Merging Algorithm: Distance-Based

- Compares the distance between the decision point and start of merging area with how far a car on the main road is from the start of the merging area.
- If the main road car is further from the merge point than merging car, then the ramp road car merges first.
- Otherwise, the algorithm finds the distance of the next main road car to the merge road until it finds a vehicle further from the merge point than it.
- Merging car will merge in front of first vehicle further from merging area than it



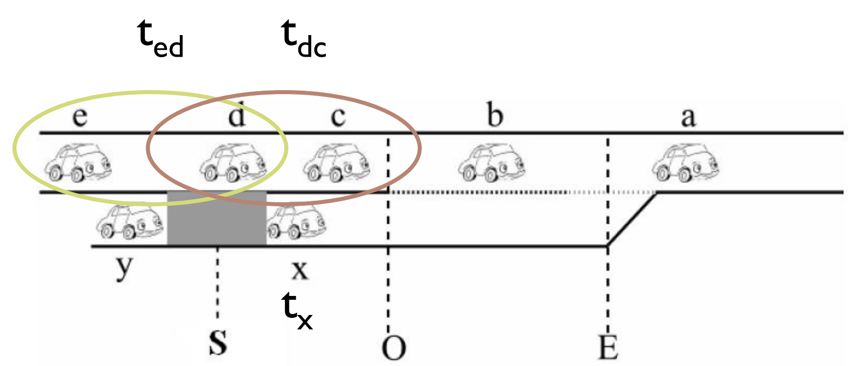
# Proactive Merging Algorithm: Velocity-Based

- Compares the time it takes for a vehicle on ramp road and main road to reach the merge point
- The vehicle with the shortest arrival time is prioritized and has the right of way
- Comparison is also done iteratively until the merging vehicle can have the right of way



# Proactive Merging Algorithm: Platoon-Velocity-Based

- Uses the same algorithm as velocity-based merging algorithm
- Instead of targeting a vehicle, the merging vehicle targets a slot between main road cars.
- A merge will be initiated if the vehicle can reach the merge point before the slot.
- Merge car can enter that slot without too much deceleration of cars on the main road.
- Minimizes perturbation of traffic flow.



# Conclusions

- When studying the impact of ramp rate, the platoon-velocity based algorithm best handled the different densities in arriving vehicles
- Proactive algorithms can significantly reduce the delay to merge onto a road by up to a third compared to a priority based algorithm.
- Proactive merging algorithms are able to better saturate the main road to support higher merge throughput until cars can no longer merge. As a trade-off, vehicles will tend to have a lower velocity with proactive algorithms.
- Platoon-velocity based algorithm provides the best performance.

# References

Ziyuan Wang, Lars Kulik, and Kotagiri Ramamohanarao. 2007. Proactive traffic merging strategies for sensor-enabled cars. In *Proceedings of the fourth ACM international workshop on Vehicular ad hoc networks* (VANET '07). ACM, New York, NY, USA, 39-48. DOI=10.1145/1287748.1287755 http://doi.acm.org/10.1145/1287748.1287755