Peer-to-peer Priority Signal Control Strategy in a Connected Vehicle Environment

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ABSTRACT

This paper presents a methodology that enhances the priority signal control model in the Multi-Modal Intelligent Traffic Signal System (MMITSS). To overcome the range limit of Vehicle to Infrastructure (V2I) and MAP distance limits, peer-to-peer intersection communications are utilized to send priority requests from adjacent intersections. Through the integrated communication, the peer priority control strategy can create a signal plan for prioritized vehicles that considers longer term (headway) arrival times. Transit vehicles are considered in this study. The longer-term signal plan provides a flexible signal schedule that allows local phase actuation. The peer priority strategy is effective in reducing the number of stops and delay for priority eligible vehicles, while minimizing the negative impact on regular vehicles. To validate the strategy, a simulation experiment was designed to compare: Fully actuated control, coordination, and MMITSS priority control using two different VISSIM simulation networks (Arizona and Utah). The result shows that the peer-to-peer long term planning strategy can improve transit service reliability while limiting adverse impact on other traffic.

INTRODUCTION

Policies and strategies have been conceived to attract people to use public transportation by improving transit service in terms of punctuality and regularity (1). Transit Signal Priority (TSP) has been one of the candidates that can improve transit service. TSP can reduce operation transit cost through less delay, travel time, fewer stops, and less vehicles required to cover the same route.

There are three major categories of signal priority: passive TSP, active TSP, and adaptive TSP. Passive TSP tries to improve performance of TSP operation by using pre-determined signal timing plans (2). Stevanovic et al. (3) presented a transit priority control strategy to adjust basic signal timing parameters, including cycle length, offset, splits, and phase sequences. The results showed that the adjustment of the signal settings can significantly improve transit operations. Estrada et al. (4) developed an optimization tool to determine the optimal set of offsets that minimize travel times of transit. Passive TSP may be beneficial only if transit frequency is relatively high (5). Active TSP accounts for these limitation by detecting and responding to transit vehicles in real time through green extension, red truncation, and phase skipping. Active TSP strategies may sacrifice the service of other traffic movements when serving requests. Active priority may be conditional based on lateness and occupancy criteria that determines when a request can be sent (or served) (1, 6, 7). To address limitations of active and passive TSP, Ma and Yang (5) integrated both active and passive strategies into one system, and showed that the integrated model can improve both variation and average bus delay. Adaptive TSP controls signal timing for transit vehicles with the goal of using phase time more effectively. Ling and Shalaby (8) used a Reinforcement Learning method to find the optimal phase duration for transit vehicles taking into consideration transit headway and elapsed green time for the requested phase. Lee et al. (9) developed a TSP operation model that selects the best plan among plans in a library according to a transit arrival prediction model.

Active and adaptive TSP requires a transit detection systems to generate priority requests. The detection system can be based on a number of technologies such as loop detectors, video cameras, radar (UDOT primarily uses wavetronics detectors), infrared transmitters, and radio. Recently, TSP detection systems have begun to use Global Positioning System (GPS). Koonce et al. (10) and Liao et al. (11) developed signal priority control models based on Automated Vehicle Location Systems (AVL) using GPS-based data. Through the emergence of connected vehicle technology, connected vehicle based signal priority control can provide significant benefit over traditional TSP strategies. Hu et al. (7) developed a person-delay-based optimization approach for an intelligent TSP strategy using connected vehicle technology, assuming that the connected vehicle market penetration rate was 0% except for transit. He et al. (12, 13) and Zamanipour et al. (14) developed multi modal priority control strategies that consider requests from transit as well as trucks and emergency vehicles.

Although TSP has been implemented for decades, challenges still exist. One of the shortcomings that has been observed in conventional TSP strategies is the difficulty in dealing with multiple conflicting priority requests. Most of the rule-based TSP strategies (15–17) are based on if-then structures that assume a first-come, first-serve priority logic. They have difficulties when multiple conflicting priority requests are received at the same time. Head et al. (18) presented an analytical model-based priority strategy based on a precedence graph structure. The paper showed that a rule-based first-come, first-served policy can lead to more delay than a model that considers multiple requests simultaneously. A similar result was found by Ma et al. (19), who formulated a dynamic programming model for multiple priority requests by optimizing phase sequence. Hu et al. (7) and Zamanipour et al. (14) used a mixed integer linear programming model to minimize vehicle delay for multiple priority requests and the result showed that vehicle delay was significantly improved. Instead of a model-based approach, Zlatkovic et al. (20) used a logic processor to resolve conflicting multiple requests and tested the model in a VISSIM simulation. The result showed that the first-come, first-served policy for conflicting TSP requests could result in worse performance than a policy that does not provide priority.

This paper presents an enhancement to the signal priority algorithm that is part of the Multi-Modal Intelligent Traffic Signal System (MMITSS) project. MMITSS is a USDOT Cooperative Transportation System Pooled Fund project that focuses on connected vehicle technology (21). Due to the limited range in the connected vehicle architecture, the signal priority algorithm in MMITSS can only accommodate priority requests received in the near-term (e.g. 10 ~ 20 seconds). Through this near-term priority planning, the signal controller has a limited time window to adapt for the priority request, which may lead to priority request delay or insufficient delay reduction for transit vehicle (22). A number of studies have already revealed that the active priority policy based on such short notice can have adverse effects on other traffic (1, 23). As the time between transit vehicle detection and actual arrival time at the signal increases, the flexibility in signal adjustments are significantly increased (24).

A peer priority control logic is presented to provide a long-term priority plan using peer-to-peer (P2P) communications. P2P is based on the backhaul network between adjacent traffic signals. The basic structure of the mathematical optimization in this paper follows the signal priority control model (14) in MMITSS. An improvement in the priority algorithm in (14) is created to integrate an implementation algorithm into the mathematical model. A platform is presented, which implements the peer priority control strategy based on the peer-to-peer priority request data from connected vehicles. Standard J2735 DSRC messages, including the Signal Request Messages (SRMs), Signal Status Messages (SSMs), Basic Safety Messages (BSMs), Signal Phasing and Timing Messages (SPaTs), and MAP Messages, defined by Society of Automotive Engineers (SAE) are used to manage multiple peer priority requests in the framework.

METHODOLOGY OF PEER-TO-PEER PRIORITY SIGNAL CONTROL

Peer Priority Control Framework

The peer priority control framework has been designed to address the limitation of the effective range of Vehicle to Infrastructure (V2I) communications (using DSRC) and the geographic extent of the MAP message. DSRC has a minimal range of 300 meters, but experience shows that signals can receive beyond 800 meters. However, a priority vehicle approaching an intersection won't be aware of the intersection until it receives a valid MAP message and is located within the extent of the MAP. The MAP message provides a description of the intersection geometry, including approaches, lanes, stop bar, cross walks, etc. The MAP description of each approach is based on GPS waypoints used to describe the lanes. Due to a limitation in the MAP message size, the extent – distance from stop bar, is limited. Experience has shown that this is about 300 meters for relatively straight approaches and shorter distances for curved approaches. Once the priority requesting vehicle determines that it is inside the MAP extent, it can form a valid Signal Request Message (SRM) that includes the in-lane (as defined in the MAP) and the time of desired service. Figure 1 illustrates the scenario when P2P priority control will be effective.

When a prioritized vehicle passes a stop bar at an upstream intersection (intersection #1), the local, or near-term, priority request is canceled since the vehicle has been served. A peer priority request is initiated when the cancel message is received from the vehicle. The peer control component monitors the vehicle position until it passes one of the defined exit Check Points, which is the first GPS waypoint on an egress approach lane after the stop-bar if there is no far-side bus stop. If there is a far-side bus stop (shown as BS in Figure 1), a GPS waypoint after the bus stop, which is denoted as '+' symbol in Figure 1, becomes the check point. When the vehicle passes the exit Check Point, a Peer Priority Request, including the requested signal phase, in-lane, and estimated arrival time to the stop bar at the downstream intersection, is sent to the designated intersection (intersection #2) through the backhaul network. The estimated arrival time is calculated based on an average travel time between the exit Check Point and the stop bar at the downstream intersection. In this paper, an average of free flow travel time for transit vehicles from VISSIM simulation was used. The peer request makes it possible for the traffic signal controller at the downstream intersection to have a long term priority planning horizon, which can reduce delay and number of stops for transit with more flexibility for other traffic. The system architecture of the P2P priority control system is shown in Figure 2.

The control system consists of several software components including the Priority Request Generator, Priority Request Server, Priority Solver, Vehicle Trajectory Awareness, Traffic Control Interface, and Long Term Planning, all of which are implemented in both simulation and real traffic networks. All of the components reside at roadside, either on a Road Side Unit (RSU) or on a co-processor at each intersection. When a priority vehicle enters in the V2I range of the intersection, the Signal Request Message (SRM) broadcast from the Priority Request Generator on the On Board Unit (OBU) is received by the Priority Request Server (PRS) through V2I communication. Once the PRS adds a new near-term priority request to the active requests table,

a unified MILP model, which resides in the Priority Solver, creates an optimal near-term signal priority plan. The signal plan is sent to the Traffic Signal Controller through the Traffic Controller Interface, using the NTCIP (25) commands, which include Vehicle Call, Force-off, and Hold.

When the prioritized vehicle passes the stop bar, the OBU broadcasts a cancel SRM message. The cancel SRM is received at the intersection and the PRS cancels the active signal request and checks to see if peer priority control is enabled for the downstream intersection. If it is enabled, the PRS sends a peer priority request to the Long Term Planning (LTP) component. The LTP component continues checking the vehicle position to see if it has passed one of the defined exit Check Points. When the vehicle passes the exit Check Point, the LTP sends a Peer Priority Request to the designated downstream intersection. Once a LTP at a downstream intersection receives a peer priority request, it adds the request to the active peer request table and sends it to Priority Solver. If there is no priority request in the V2I range of the downstream intersection, the Priority Solver solves the MILP only for the peer request and sends a feasible solution to the Traffic Controller Interface. If there are priority requests that are currently being served in the V2I range of the downstream intersection, the peer priority request is solved along with them in the same optimization process.

A detailed procedure of the peer priority control algorithm can be found in Figure 3. Figure 3(a) demonstrates how a peer priority request is initiated at an upstream intersection, while Figure 3(b) shows how the peer request is processed once received at the downstream intersection.

Figure 4 shows two examples using a time-phase diagram (26), which explain the necessity of P2P priority control strategies. A priority signal plan can be visualized in the diagram, which is a useful tool to analyze the optimized plan, verify if the schedule is feasible, and evaluate priority delay given the signal plan and priority request arrival times.

A priority request (box) with an arrival time interval is shown in Figure 4, where the x-axis is time and the left and right y-axes are showing phases in rings 1 and 2, respectively. The box with the letter 'L' represents a priority request that is out of V2I range and is not currently observed at the intersection. The box with the letter 'N' represents a near-term priority request that has already been detected at the intersection. The V2I range is shown at 17 seconds. Two black dotted lines starting from the origin, which denotes current time and current phase, represent the shortest path (minimum green times for each phase) and longest path (maximum green times) over the planning horizon. A signal control plan must reside in the cone-shaped area between the two lines. The solid arrow shows a phase-serving path that the controller may possibly take within the feasible area based on actuation logic. This could be based on coordination plan splits. As shown in Figure 4(a), the priority request may not be served in the current cycle because it is not observed by the local server (inside V2I range) before the signal completes the service phase (phase 2). Figure 4(b) shows, even with a near-term priority request being served, the long term priority request may not be served after the near term request passes the intersection. This may results in a significant delay to the priority eligible vehicle.

Unified Mathematical Optimization Model

Zamanipour et al. (14) developed a signal priority algorithm that includes two parts: a mathematical optimization model and a flexible implementation algorithm. Based on the standard North American NEMA dual-ring structure, the mathematical optimization model was formulated as a Mixed Integer Linear Programming (MILP) problem to minimize a weighted summation of multiple priority requests delay. In order to reduce the negative impacts on regular vehicles that may be caused by granting priority to priority-eligible vehicles, a flexible implementation algorithm was developed, which allows the non-priority phases to be actuated to cope with variation in traffic demand in real-time. This flexible optimized signal plan ensures that the signal controller can better serve non-prioritized vehicles on the phases that precede the requested phase, while minimizing the priority request delay. As shown in Figure 5, a feasible region is created by two piecewise lines starting from the origin to the priority request arrival time. The left dotted piecewise line represents a set of “HOLD” points for each phase, which denotes when the signal controller should hold a phase green. The right long-dashed piecewise line represents a set of “FORCE-OFF” points that provide less, or zero, delay to the priority request. Within the flexible region between the two lines, the controller is allowed to actuate the signal phase, which means that if there is no vehicle detection (call), the phase will gap out. Otherwise, the phase will extend until the “FORCE OFF” point.

The original flexible implementation algorithm was revised to directly address signal flexibility, considering two critical points as additional decision variables in the mathematical model. The revised model is:

$$\begin{aligned} & \text{Min}_{t_{left}, t_{right}} \sum_{m \in M} w^m d^m - \sum_{p \in P, k \in K} (t_{right}(k, p) - t_{left}(k, p)) \\ & \text{s.t} \\ & \quad \text{Precedence Constraints} \\ & \quad \text{Phase Duration \& Interval Constraints} \\ & \quad \text{Priority Request Delay Evaluation Constraints} \end{aligned}$$

where d^m is the total priority request delay of mode m , w^m is the mode m weight determined by the multi-modal policy. $t_{left}(k, p)$ is the left critical point of phase p in cycle k , while $t_{right}(k, p)$ is for the right critical point, as shown in Figure 5. To maximize the feasible region, a negative term is added to the objective function, which is the summation of time intervals between “FORCE-OFF” point and “HOLD” point. One set of precedence constraints are considered for each ring to find the left and right critical points. The *Phase Duration & Interval Constraints* and *Priority Request Delay Evaluation Constraints* also hold for both left and right points independently. The other variables defined in (14) remain the same.

Figure 6 shows several priority plans that the peer priority control model creates for multiple priority requests, including both near-term and peer requests, based on the revised optimization model. Each signal plan in Figure 6 was drawn based on actual log data from the Priority Solver component. As shown in Figure 6(a), the flexibility from current phase to the requested phase is possible when there is only one peer request. The delay for the peer request will be zero, and the signal controller has significant flexibility to serve for other traffic. Figure 6(b) shows the priority plan for the same request approximately 10 seconds later, which still maintains a large flexible region. Even with multiple peer requests, a flexible plan can exist as shown in Figure 6(c). Sometimes, the flexibility can be limited to serve multiple requests as demonstrated in Figure 6(d). According to the arrival interval of each peer request and traffic signal status, which includes current phases served and elapsed green times of the phases, peer requests can be served in one cycle (Figure 6(c)), or they can be served in different cycles (Figure 6(d)). Figures 6(e) and (f) illustrate the same case of Figures 6(c) and (d), when the first peer requests enter the V2I range. After the near-term request (N) passes the stop-bar, the signal controller can hold the signal green for phase 2 because a peer request (L) exists that can be served within the maximum green time of phase 2 (Figure 6(e)). On the other hand, if the peer request cannot be served in current cycle, the controller could force off the phase 2 right after the near-term request and follow the non-flexible line (a set of minimum green times for phases 4 and 1) up to the peer request (L) to have zero delay for the peer request (Figure 6(f)).

EXPERIMENTAL DESIGN

The peer priority control strategy has been tested on two different VISSIM simulation networks: Daisy Mountain Drive in Anthem, Arizona and Redwood Road in Salt Lake City, Utah. As Figure 7 shows, the Daisy Mountain corridor has 6 intersections over 2.3 miles, while the Redwood corridor has 13 intersections over 5.12 miles. The main street in the Arizona network has three lanes in both directions, and the side streets have two lanes, while the main street in the Utah network has two or three lanes, and the side streets have one or two lanes. The intersection spacing of both networks varies, although the Utah network has, on average, wider spacing ranging from 150 m to 1400 m than the Arizona network, which has a range of 300 to 900 m. An eastbound movement from Gavilian Peak to Anthem on Daisy Mountain Dr. was simulated as a bus route, while a southbound movement from W 400 S to W 3800 S on Redwood Rd. was selected as a bus route. The Utah Transit Authority (UTA) actually runs bus service on Redwood Rd. at approximately 15 minute intervals, while there is no public transit service running in Anthem. For the test of the P2P priority control strategy, two far-side bus stops with bus bays and located within V2I range, shown as blue boxes in Figure 7(a), were simulated in the Arizona network model. As shown in Figure 7(b), the Utah network model has seven far-side bus stops without bus pullouts. The bus dwell time at each bus stop was distributed by normal distribution in the mean of 20 ~ 45 seconds with standard deviation of 5 seconds for both simulation network. The bus speed for both

network was simulated as 35 miles per hour, which was slightly lower than the actual speed limit of each road.

Both simulation models were run for two and half hours, which included a thirty minute warm-up period. The bus headway for the Arizona and Utah networks were set up as five minutes and ten minutes, respectively so the experiments would include a sufficient number of buses. Both simulation experiments were replicated with ten different random seeds. Traffic demand on the main street and side streets in Anthem were 900 vehicles per hour (vph) and 200 to 400 vph, respectively. Traffic demand on the main street in Salt Lake City is 1200 vph, and side streets have traffic volume ranging from 200 vph to 500 vph. An Econolite virtual controller (ASC/3), which can support the NTCIP interface, was used in the simulation.

EVALUATION RESULTS

Several measurements from VISSIM were evaluated including average vehicle delay, number of stops, and travel time. The peer priority control strategy was compared to three different signal control applications: fully actuated control (free mode), coordination control, and MMITSS priority control. The coordination parameters on the Arizona network, including phase splits, cycle length, and offsets, are determined by VISTRO (27) based on the vehicle demand, while the parameters for the Utah were provided by the Utah Department of Transportation.

Table 1 summarizes the performance of transit vehicles on a bus route for both networks in terms of average values of ten replications with different random seeds. The average vehicle delay represents average delay of each transit vehicle that travel along the bus route. Compared to fully actuated control in Arizona, the average vehicle delay, number of stops, and travel time from peer priority control were greatly improved by -48.35%, -94.94%, and -11.57%, respectively. Similar results were shown in the Utah network. When comparing the same measures with coordination control in both networks, peer control outperformed coordination by -41.39% ~ -42.92%, -59.85% ~ -94.03%, and -9.49% ~ -11.80%, respectively. The results show that the improvements were slightly reduced compared to fully actuated control. This is because signals were coordinated on the bus route, and buses benefit from the coordinated progression. However, as buses travel over a corridor, they cannot remain in the progression due to stopping and dwelling for passengers at bus stops. A comparison between peer priority control and MMITSS priority control also shows that all of the measures from the peer control were improved. In particular, the average number of stops for both networks were significantly decreased by -81.82% and -42.91%, respectively.

To show the reliability of the transit service under each signal control system, the standard deviation of travel time and vehicle delay were compared in Table 1. Compared to fully actuated control, the peer control model significantly improved the reliability of vehicle delay by -69.12% in Arizona and -53.01% in Utah. The reliability of travel time was also improved by -63.07% in Arizona and -50.66% in Utah. In comparison to coordination and MMITSS priority control, the

results show that the reliability of the peer control outperformed in both networks as shown in Table 1.

Table 2 demonstrates how the peer priority control affects the performance of regular vehicles in the entire system. It was observed that in both networks the peer priority control does not have a negative impact on regular vehicles in terms of average vehicle delay, number of stop, and travel time, compared to fully actuated and MMITSS priority control. However, the average number of stops under coordination control in both networks was better than peer control, although vehicle delay and travel time from the peer control were better than under coordination. It turned out that the coordination plans from VISTRO and the UDOT were effective at minimizing the number of stops for regular vehicles, although it did not improve the number of stops for transit because the coordination cannot differentiate vehicle modes, as shown in Table 1.

A statistical analysis was performed to determine the significance of the simulation results. Using a paired-sample t-test at the confidence level of 95%, the mean value of ten replications were examined for each signal control's comparison. The null hypothesis of the test was that the mean values of each signal control were insignificant compared to peer priority control. According to p-values for all measures of transit, all of the null hypothesis are rejected at the 5% significance level, which indicates that the improvement of peer priority control on transit is significant. For the same measures of regular vehicles, the test fails to reject all of the null hypothesis except for the comparison of peer and coordination control, indicating that the mean values are insignificant. Accordingly, the results indicate that the peer priority control model does not have adverse impact on the performance of regular vehicles.

CONCLUSIONS AND FUTURE RESEARCH

This paper presents a methodology that enhanced the MMITSS priority control strategy based on P2P and V2I communications in a connected vehicle environment. The peer priority control strategy makes it possible for a signal controller to have a flexible long-term plan for prioritized vehicles. They can benefit from the long-term plan within a secured flexible region and it can prevent the near-term priority actions from having a negative impact on other traffic by providing more flexibility for phase actuation. In addition, the strategy can be applied to all different modes of prioritized vehicles such as transit, freight, and emergency vehicle without consideration of bus stop.

In this paper, peer priority control was implemented without a consideration of coordination or pedestrians in the optimization. Future research focuses on an integration of peer priority-coordination signal control, which creates an optimal solution that considers multiple peer requests and periodic virtual coordination requests in the same optimization framework. Inclusion of pedestrians is a complex research topic that needs to be addressed – since pedestrians are transit customers. It is understood that pedestrian service intervals create significant constraints on the

priority control, but it is believed that the longer optimization horizon of peer-to-peer priority will afford some additional benefits.

In addition, the estimation of arrival time for each peer request to the downstream intersection is critical. If the arrival time of the peer request are not accurate, the performance of the prioritized vehicles and other traffic could be negatively impacted. For example, if the arrival time to the downstream intersection was forecasted too early, it could force off competing phases too early, causing unnecessary delay or cycle failure for other traffic. On the other hand, if the arrival time was estimated too late, the peer priority may not take advantage of the long term planning. Thus, for future improvement, statistical methods can be used to estimate more accurately instead of using the average travel time on the link.

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AUTHOR CONTRIBUTION STATEMENT

Study conception and design: Byungho Beak, Mehdi Zamanipour, Larry Head, Blaine Leonard; Data collection: Byungho Beak, Mehdi Zamanipour, Larry Head; Analysis and interpretation of results: Byungho Beak, Mehdi Zamanipour, Larry Head; Draft manuscript preparation: Byungho Beak, Mehdi Zamanipour, Larry Head, Blaine Leonard. All authors reviewed the results and approved the final version of the manuscript.

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FIGURE 1 Illustration of peer priority request initiation.

FIGURE 2 Architecture of peer-to-peer priority control system.

FIGURE 3 Flow chart of peer-to-peer priority control model: (a) upstream, (b) downstream.

FIGURE 4 Two long term priority request scenarios: (a) without near-term request, (b) with near-term request.

FIGURE 5 Flexible feasible signal plan in time-phase diagram.

FIGURE 6 Time-phase diagram with peer priority requests and feasible plan.

FIGURE 7 Simulation test bed layout: (a) Anthem, Arizona, (b) Salt Lake City, Utah.

TABLE 1 Performance Measure of Transit Vehicle

TABLE 2 Performance Measure (Average) of Regular Vehicle on Entire Network

FIGURE 1 Illustration of peer priority request initiation.

FIGURE 2 Architecture of peer-to-peer priority control system.

FIGURE 3 Flow chart of peer-to-peer priority control model: (a) upstream, (b) downstream.

FIGURE 4 Two long term priority request scenarios: (a) without near-term request, (b) with near-term request.

FIGURE 5 Flexible feasible signal plan in time-phase diagram.

FIGURE 6 Time-phase diagram with peer priority requests and feasible plan.

FIGURE 7 Simulation test bed layout: (a) Anthem, Arizona, (b) Salt Lake City, Utah.

TABLE 1 Performance Measure of Transit Vehicle

Simulation network		Measurement	Average			Standard deviation	
			Vehicle delay	Number of stop	Travel time	Vehicle delay	Travel time
Arizona	Bus Route (eastbound)	Fully actuated control	79.67	1.32	334.74	27.32	28.00
		Coordination control	72.10	1.12	327.04	24.32	24.32
		Priority control	51.40	0.37	306.42	13.01	13.89
		Peer Priority control	41.15	0.07	296.00	8.44	10.34
	Comparison	<i>Peer VS Fully actuated</i>	-48.35%	-94.94%	-11.57%	-69.12%	-63.07%
		<i>Peer VS Coordination</i>	-42.92%	-94.03%	-9.49%	-65.30%	-57.47%
		<i>Peer VS Priority control</i>	-19.95%	-81.82%	-3.40%	-35.14%	-25.52%
Utah	Bus Route (eastbound)	Fully actuated control	298.42	5.15	998.80	50.39	49.53
		Coordination control	279.80	3.26	980.50	32.82	32.76
		Priority control	197.72	2.30	898.36	31.32	32.99
		Peer Priority control	163.99	1.31	864.75	23.68	24.44
	Comparison	<i>Peer VS Fully actuated</i>	-45.05%	-74.60%	-13.42%	-53.01%	-50.66%
		<i>Peer VS Coordination</i>	-41.39%	-59.85%	-11.80%	-27.85%	-25.40%
		<i>Peer VS Priority control</i>	-17.06%	-42.91%	-3.74%	-24.41%	-25.92%

TABLE 2 Performance Measure (Average) of Regular Vehicle on Entire Network

Simulation network		Measurement	Average vehicle delay	Average number of stop	Average travel time
Arizona	Entire network	Fully actuated control	40.68	1.57	158.22
		Coordination control	48.60	1.29	165.93
		Priority control	40.58	1.57	158.14
		Peer Priority control	40.45	1.55	157.96
	Comparison	<i>Peer VS Fully actuated</i>	<i>-0.57%</i>	<i>-1.03%</i>	<i>-0.16%</i>
		<i>Peer VS Coordination</i>	<i>-16.78%</i>	<i>20.07%</i>	<i>-4.80%</i>
		<i>Peer VS Priority control</i>	<i>-0.33%</i>	<i>-1.06%</i>	<i>-0.11%</i>
Utah	Entire network	Fully actuated control	45.59	1.57	135.59
		Coordination control	61.62	1.42	151.56
		Priority control	45.82	1.58	135.84
		Peer Priority control	45.97	1.58	136.09
	Comparison	<i>Peer VS Fully actuated</i>	<i>0.84%</i>	<i>0.24%</i>	<i>0.37%</i>
		<i>Peer VS Coordination</i>	<i>-25.24%</i>	<i>11.32%</i>	<i>-10.21%</i>
		<i>Peer VS Priority control</i>	<i>0.32%</i>	<i>0.03%</i>	<i>0.18%</i>