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Procedia Computer Science 130 (2018) 82–89

Procedia Computer Science

www.elsevier.com/locate/procedia

The 9th International Conference on Ambient Systems, Networks and Technologies (ANT 2018)

Evaluation of Transit Signal Priority Implementation for Bus Transit along a Major Arterial Using Microsimulation

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Abstract

Transit Signal Priority (TSP) provides preferential treatment for public transit vehicles at signalized intersections when implemented. TSP is usually provided by interrupting the typical signal timings and extending the green or truncating the red for the signal phases that serve transits. This study investigates the impact of implementing a TSP treatment along a major arterial. A microsimulation approach was used to model, assess, and evaluate the potential benefits of implementing this treatment to bus transit vehicles. The network was built in a VISSIM multimodal microsimulation environment to test the traffic network performance with and without priority treatments. The study considered different peak hours for performance assessment. Three transit routes were considered in the microscopic modeling. The results showed a significant benefit of implementing TSP for the transit vehicles. The travel time was reduced by more than 40% in some cases, which can be translated into lower transit delay and more reliable transit service. The results also showed that TSP has a minimal negative effect on the general traffic. In fact, the general traffic along the studied transit routes benefited from the TSP implementation because of the better traffic progression and additional green times.

Keywords: signalized intersection; public transportation; VISSIM; transit operation

1. Introduction

Transit Signal Priority (TSP) has dragged the attention of many public and private transportation sectors, especially within the context of sustainable transportation systems and public transportation[1-3]. TSP provides

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Peer-review under responsibility of the Conference Program Chairs.
10.1016/j.procs.2018.04.015

preferential treatments to transit vehicles at signalized intersections. This action usually interferes with the typical signal timings by extending the green time or shortening the red time of the signal phases that accommodate transit vehicles. This treatment is expected to provide benefits to transit vehicles and promotes the use of public transportation [3-8].

Much research work has been done on the subject of optimizing signal timing for the purpose of achieving the best traffic performance, or optimum safety, or to facilitate a specific process of evacuation, etc. However, the focus of this review is on the specific topic of TSP. TSP is the control strategy of adjusting the signal timing of an upcoming intersection to afford a priority to transit vehicles. A transit vehicle is a large multi-passenger vehicle such as a bus or a light-rail transit vehicle. There are several publications that evaluated different TSP systems in the literature. However, there are very few studies that are done in the Gulf Council Countries (GCC) region.

One research was done to evaluate TSP implementation on an arterial corridor with four intersections within Michigan State University campus[9]. Microscopic simulation through VISSIM software was used to model the traffic and parameters specific to TSP such as maximum green time extension and red truncation were programmed using a vehicle actuated programming (VAP). Traffic volume was modeled for three peak periods; morning, midday, and evening. The study concluded that affording special treatment to transit vehicles, by extending green time on an upcoming signal, for example, minimizes the average delay with negligible or minimal adverse effects on non-transit vehicles. The study also concluded that the TSP system shows no impact on pedestrians. Transit vehicles usually have a routine schedule and can be detected by sensors.

In another study, TSP is implemented via the use of coordinated signals[10]. An optimization method that uses person-delay as an objective function, by enabling the communication between transit vehicles traffic signals controllers at consecutive signals. The TSP logic is shown to provide potential benefits over the traditional TSP along a specific corridor, by ensuring that the reduced delay gained by the transit vehicle on an earlier signal is not wasted on later signals. The problem is an optimization problem that aims to minimize person's delay. In this system, the algorithm did not grant priority requests unless the transit vehicle was behind schedule and granting TSP would not cause any additional total delay. The logic is analyzed using simulation. The study had a broad scope that includes conventional TSP, connected vehicles technology incorporated with TSP, and coordination between signals. Individual bus delay and the total travel time of all vehicles were used to compare the traffic performance of each solution. The paper found that TSP with vehicle communication and signal cooperation performed best, greatly reducing bus delay along signalized intersections.

Another study uses microsimulation to create a model for TSP on an entire arterial with multiple intersections[11]. The paper focuses on proposing a control method for TSP that is summarized in four steps. The steps are: calculating the maximum green extension allowable based on the traffic demands, estimating the benefits to transit vehicles in terms of delay reduction, estimating the induced delays on general traffic, and optimizing the green extension to maximize potential benefits and reduces negative impacts. The objective function was to reduce the delay for transit vehicles while keeping the total person delay without an increase. The simulation is performed using VISSIM software. The arterial is a corridor of 6 km in length in includes 6 signalized intersection. However, TSP is provided only at two of intersections. Three scenarios are evaluated; no TSP, 15 sec green extension, and the proposed TSP control. The results show that the proposed TSP control performs better than the other control schemes in terms of traffic delay, passenger's waiting time, and network average delay.

Another paper presents a standalone integrated signal system for TSP[12]. CORSIM microsimulation model is used in this study. The study has a wide scope incorporating different objectives, such as managing recurrent and non-recurrent congestion, avoided downstream blockage conditions, and TSP implementation. A square grid made of intersections and connecting streets were used to lay out a total of 18 bus routes that are overlapping to test the proposed system. Although TSP reduced the transit delays, the total traffic delay has increased.

A novel real-time network-wide traffic signal control scheme that is able to work under the modern data technologies is proposed. It was expected that the proposed control would yield route-level flow information, also the scheme is flexible in response to the flow variation due to its non-cyclic feature[13]. The proposed control is designed to work in a real-time basis, and it is capable of conforming global Advanced Traveler Information Systems (ATIS) strategies. The logic behind the control scheme is to take the expected transit route in consideration and controls the signal systems of the routes to create an efficient signal timings plan. The paper gives a dynamic model for signal timing where it depends on traffic route's data at a given day and modifies the signal timings based on collected data.

Another study relied on developing an algorithm which takes the property of the bacteria foraging system[14]. The system is expected to operate at intersections with high demand and get the most optimal signal timing for these intersections. The study claims that the congestion in an intersection is one of the most faced problems in cities around the world, also that the signal timing optimization under high demand should be researched. The previously-created models are either fixed-time or controls that depend on sensors. Both of them are expected to works smoothly under low traffic demand conditions, but they do not function well for high-demand conditions. The study used the differential evolution bacteria foraging algorithm to create a proposed model for high-demand intersections. The model results showed improved traffic capacity intersection with reduced signals delay.

This study describes the impact of implementing TSP preferential treatment along a major arterial in the City of Doha, Qatar on both transit vehicles and general non-transit traffic. Qatar is a small country located in the GCC region. In Qatar, many residents prefer not to walk due to the hot weather[15-17], unsafe conditions for pedestrians[18-20], and aggressive driving[21-23]. Most of the residents are car-dependent and do not use public transportation on a regular basis[24-26]. Therefore, a solution such as TSP, if successful, can help promote the use of public transportation in the city. In this study, a microscopic simulation approach was used to model, assess, and evaluate the potential benefits of implementing this treatment to transit vehicles.

2. Methodology

2.1. Study Area

As shown in Fig. 1, the corridor selected for this study is a major arterial in the central business district, Al-Dafna district, in the Qatari capital Doha. The study corridor is surrounded by several ministries and public agencies in addition to a major mall. It has three public transportation routes and four signalized intersections.

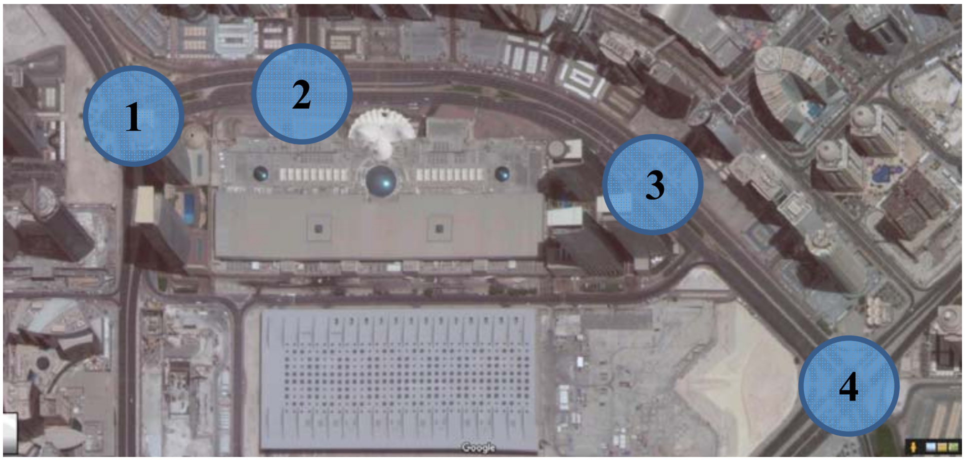


Fig. 1 Aerial imaging showing the study corridor and intersections

2.2. Transit Information

The transit schedules, along with route information and bus stop locations were obtained. There were three transit services that are using the corridor in this study. The first transit route, Route 57, connects the West Bay area to the Asian Town. It has a time headway of 30 min. The second transit route, Route 777, connects the West Bay area to Hamad International Airport. For the convenience of the riders, this bus is scheduled with a 20 min headway. The third route, West Bay Route, is a special route that serves the West Bay area exclusively, to promote public transportation usage. This route is scheduled with a 15 min headway. The study area has two bus stops. One of them is an off-street stop, and the other one is an on-street stop, as shown in Fig. 2.

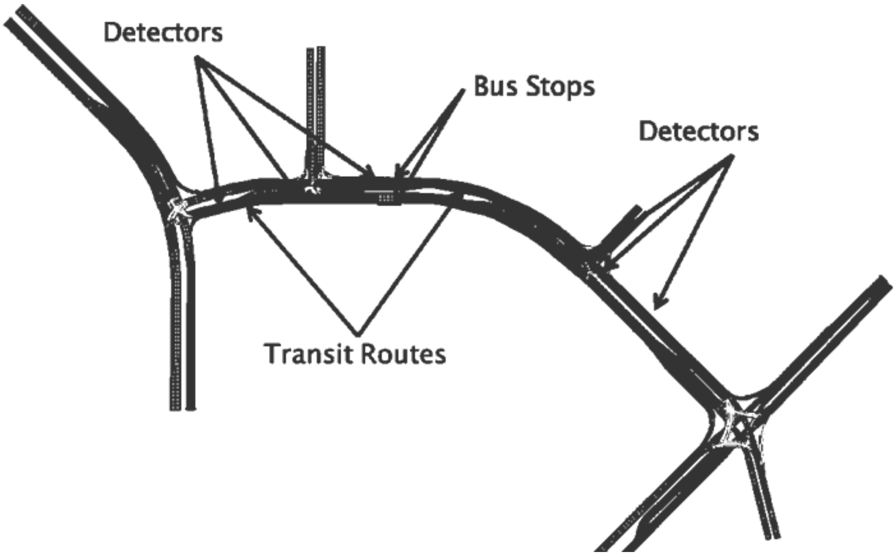


Fig. 2 Layout showing the location of the transit routes, bus stops, and detectors

2.3. Traffic Volumes

Traffic volumes and turning movements were obtained using the Qatar Strategic Transport Model 2016 (QSTM). The Ministry of Transportation and Communication was contacted to obtain the latest updated copy of this model. This model is used traffic flows during the morning (AM), mid-day (MD), and evening (PM) peak hours. Traffic flows during each of the studied peak hours are shown in Fig. 3.

2.4. Traffic Control

The signal timing and phasing scheme information were obtained for each of the three peak hours at the four intersections within the study area.

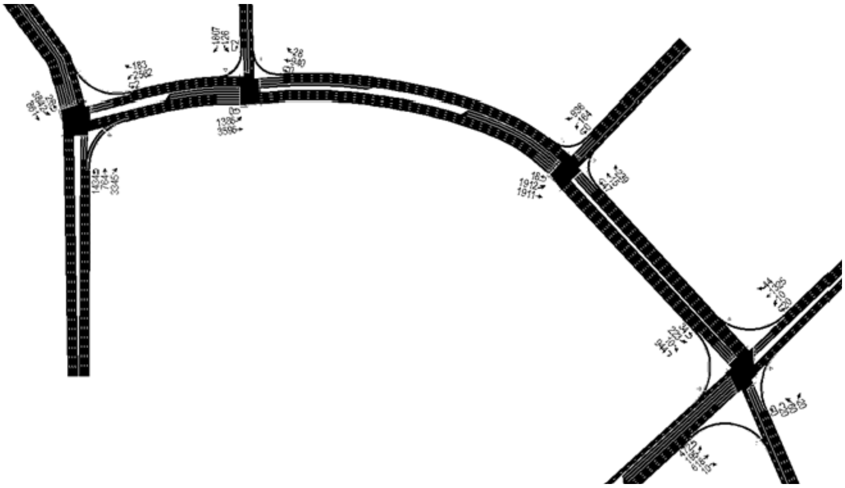
2.5. Network Modeling

VISSIM multimodal microscopic simulation software was used in this study. This software is used because of its powerful modeling performance in replicating real-life traffic networks. The study area was modeled in this simulation environment. Traffic flows and turning movements were entered for each of the peak hours. The corresponding traffic signal control timings were modeled using RBC module. The microscopic model was calibrated to assure reliable outcomes. The calibration process was done according to the Guidelines and Procedures for Transport Studies[27].

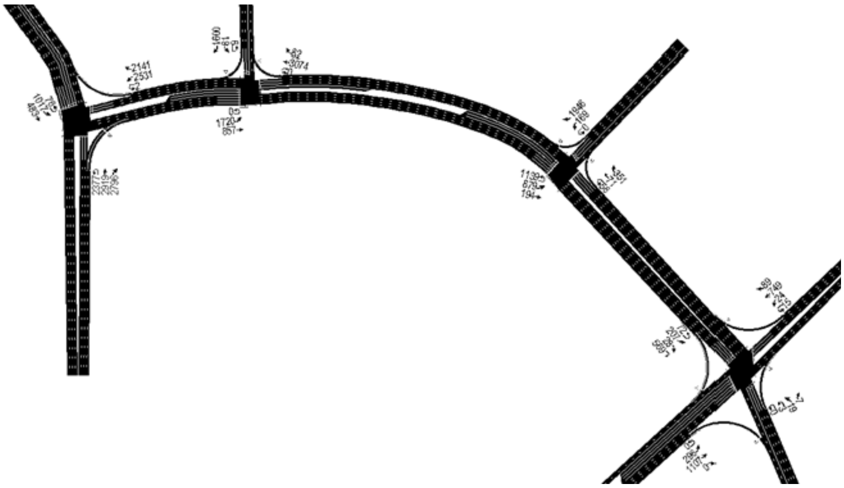
2.6. TSP Algorithm

In order to evaluate the impact of the TSP implementation on the study corridor, detectors were placed along transit routes in order to detect transit vehicles. To reduce the impact of TSP on the overall network, the detectors are placed so that the transit-free travel time between the detectors and stop line varies between 7.0 and 9.0 sec. This time will give the signal control system enough time to respond to the detection of transit vehicles, and provide the preferential treatment.

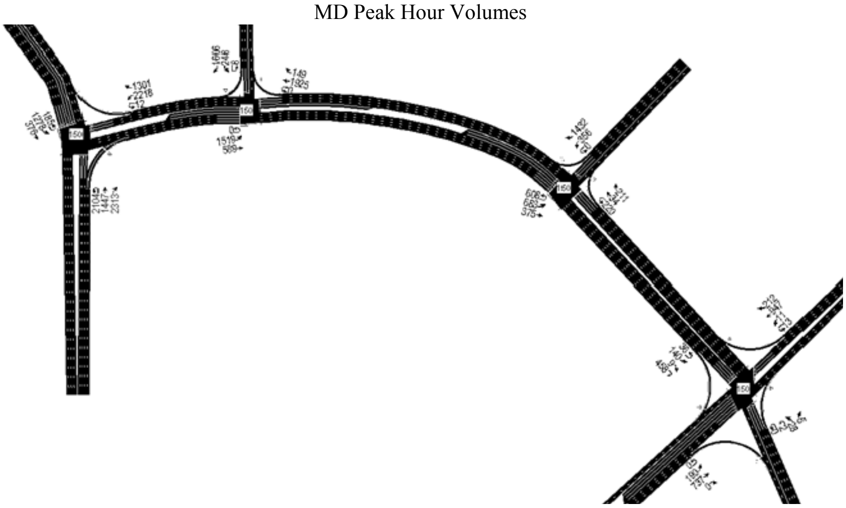
In this study, two TSP strategies were integrated within the traffic signal control logic. The TSP strategies are early green and green extension. For the early green strategy, the red time is being truncated and switched to green by the time the bus is expected to arrive. A minimum red time of 20.0 sec is imposed under this strategy. For the green extension strategy, if the bus is expected to arrive within a window of 10.0 sec beyond normal green time, then the green time is extended by 10.0 sec. The green extension preferential treatment is terminated once the bus is detected to leave the intersection.



AM Peak Hour Volumes



MD Peak Hour Volumes



PM Peak Hour Volumes

Fig. 3 Traffic volumes for AM, MD, and PM peak hours

3. Results and Discussion

Three peak hours were evaluated under the two traffic control scenarios (i.e., with and without TSP). The simulation results are summarized to differentiate between transit vehicles and general traffic.

3.1. Impact of TSP Implementation on Transit Operations

TSP tends to benefit transit vehicles on their transit routes. This benefit can be measured in terms of reduction in the transit delay, travel time, and number of stops in addition to schedule adherence. In this study, transit vehicles observed a reduction of travel time that reaches 34%-43%, depending on non-transit traffic conditions. Fig. 4 summarizes the average transit travel time for transit routes 1 and 2. The figure clearly shows a significant reduction of transit travel time for both transit routes. The results also show the transit vehicles tend to benefit the most when traffic demand is less. This finding is consistent with the fact that fewer transit routes would experience disturbance under lower traffic condition.

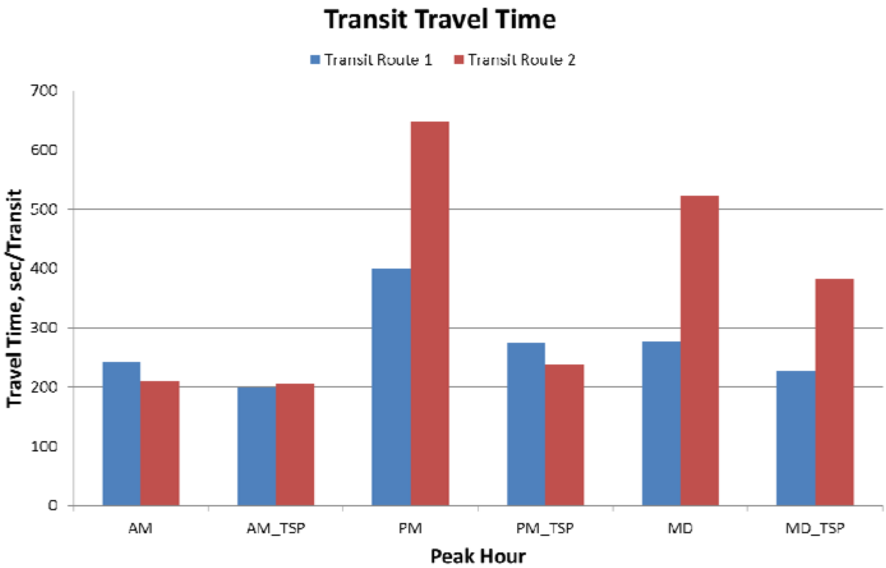


Fig. 4 Transit travel time of routes 1 and 2 under different peak hours and signal control schemes

3.2. Impact of TSP Implementation on General Traffic

With respect to general traffic (i.e., non-transit traffic), it is expected that TSP would have minimal-to-none negative impact on general traffic. This is associated with the fact that signal timings would go to the original timing plans once a priority request is granted. The minimum green time is also granted to the general traffic. Contrary to the expected, the general traffic actually benefited from TSP implementation. Fig. 5 compared the average delay per vehicle at each intersection, under different peak hours, and for different signal control plans. The figure shows a significant reduction delay reduction. This observation can be explained by the fact that general traffic along the mainstream runs along transit routes as well, and therefore, the mainstream will benefit from TSP implementation. TSP also will result in a better progress along the corridor. In some cases, the delay reduction exceeded 40%. Despite the significant delay reduction in most cases, there are some intersections that experienced a slightly higher delay of 5%. This delay resulted from the green time reduction on the crossing streets and the loss of progression of those streets. A similar conclusion can be made when the average number of stops per vehicle is analyzed, as shown in Fig. 6.

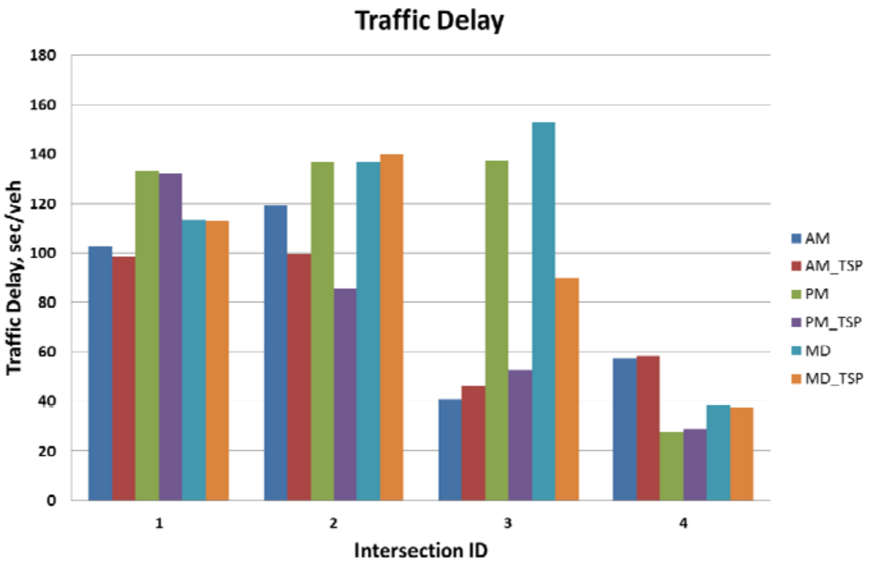


Fig. 5 Average traffic delay under different peak hours and signal control schemes

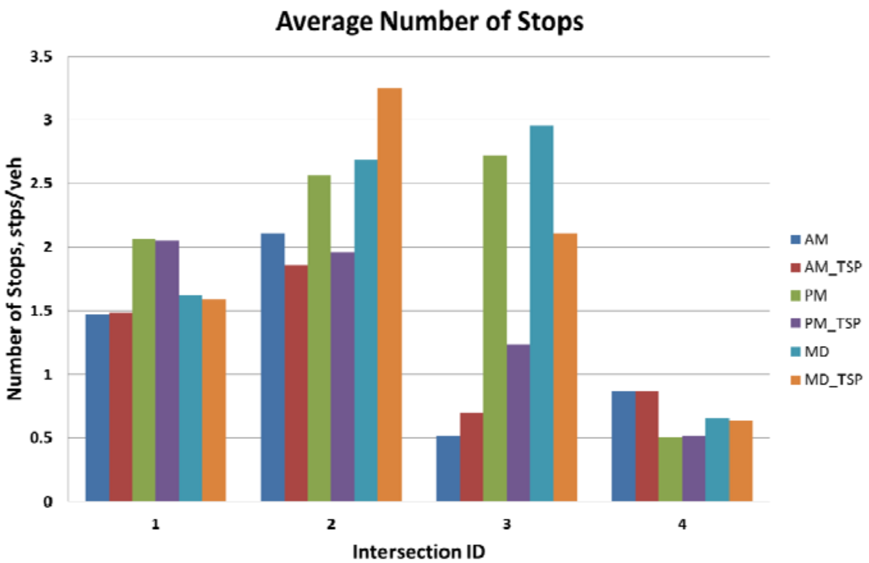


Fig. 6 Average stops under different peak hours and signal control schemes

4. Conclusions and Recommendations

This study evaluates the potential benefits of implementing TSP along a major corridor in the City of Doha, near Doha City Center. The corridor which is classified as urban arterial is located in a vital location near offices and shopping centers. Two differential treatments were considered; early green and green extension. The network was built in VISSIM multimodal microsimulation environment to test the traffic network performance with and without priority treatments. The study also considered different peak hours for performance assessment as well. Three transit routes were considered in the microscopic modeling.

The results have shown a significant benefit of implementing signal priority for transit vehicles, where travel time was reduced up to 43% in some cases. This can be translated into lower transit delay and more reliable transit service. The results also show that TSP has a minimal negative effect on general traffic. In fact, general traffic benefited from TSP implementation, especially general traffic along transit routes, because of the better traffic progression and more green times.

While the study shows that preferential treatment to transit vehicles could benefit both transit and general traffic, there are several actions that can be performed in the future to provide a comprehensive assessment of TSP implementation. Some of the actions are the consideration of TSP impact on pedestrians and the assessment of TSP implementation with real-time traffic controls.

Acknowledgments

This report was made possible by UREP award (UREP18-054-2-020) from the Qatar National Research Fund (a member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors.

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