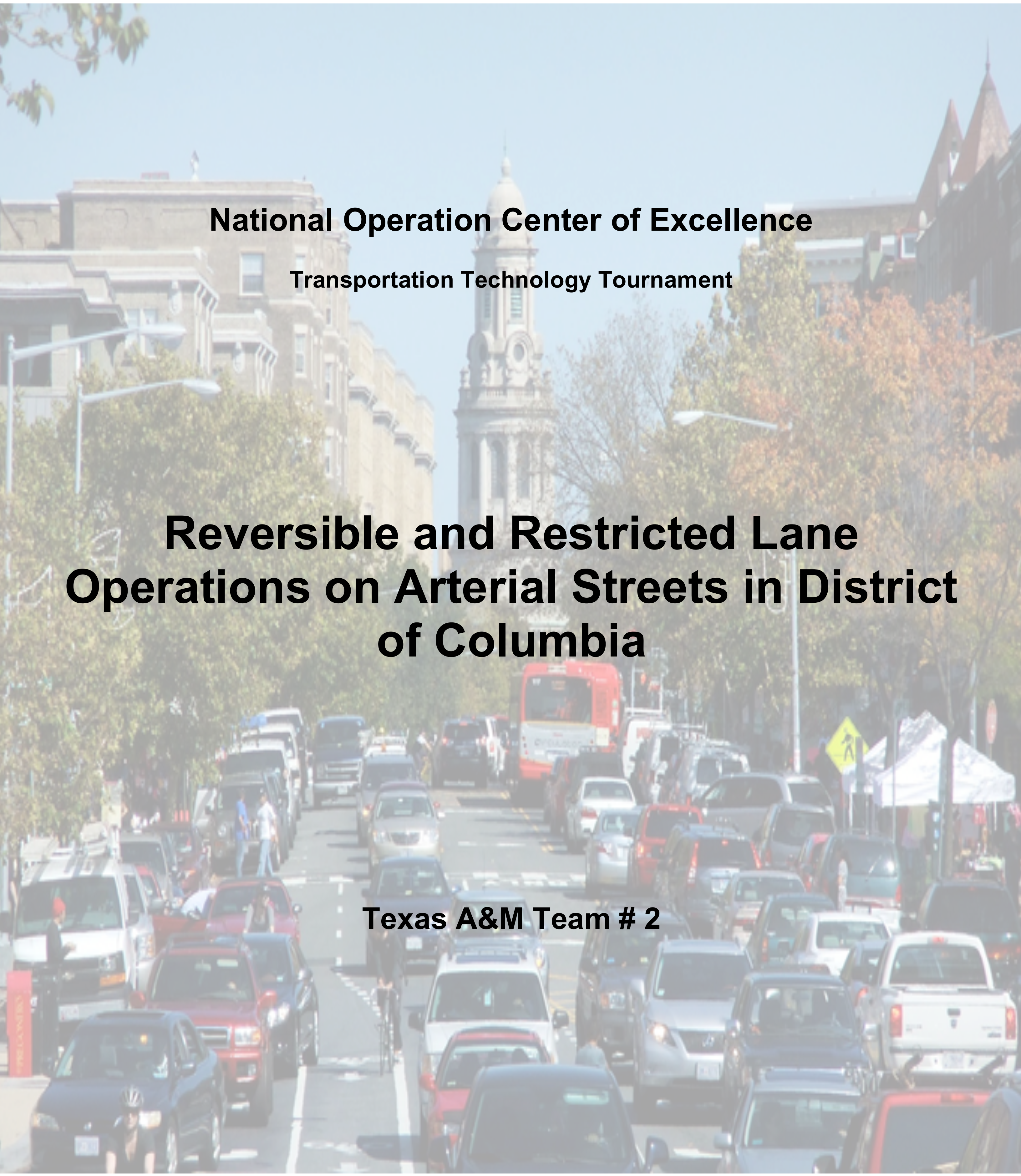

National Operation Center of Excellence

Transportation Technology Tournament

Reversible and Restricted Lane Operations on Arterial Streets in District of Columbia

Texas A&M Team # 2

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1. Overview

1.1 Reversible Lane Operation Objective

Traffic is dynamic during the day and on some arterials the proportion of traffic is quite different in each direction especially during the peak hours. The unbalanced directional traffic results in overutilization of lanes in one direction and underutilization in the other direction. Reversible lanes are implemented in District of Columbia with the goal of improving traffic flow during the peak periods. The total length of reversible lanes in DC is approximately 10.6 miles which is less than the 1% of the total length of roadways in DC. One of the main concerns in the operation of reversible lanes is proper communication of the lane assignment to travelers. Currently, the information of the operation of these segments is communicated with travelers using the pole- and post-mounted static signs and illuminated signs on signals. The opposition of using mast arms and overhead lane control signs stems from opposition by the Fine Arts Commission; the commission is concerned that such solutions will hinder "views of government building(s) and monument(s)." This limitation diminishes the efficient operation of the reversible lanes." On the other hand, crash studies of these reversible lanes demonstrate a dependency of some types of crashes to the operation of the reversible lanes.

Therefore, an efficient management of reversible lanes is required to improve the performance of the network from different aspects such as mobility, environmental and traffic operation while providing a safe environment for travelers. To this end, a communication system is required to exchange information with travelers by informing drivers of the direction of the reversible lanes at each period of time and alerting the drivers if a wrong-way driving is recognized. A more efficient management of reversible lane operation can result in more throughput in the system, reducing the travel time and improving the safety.

While the solution techniques, which will be outlined in the next few sections, can be used for all reversible lanes located in District of Columbia, in this study, our focus is on a segment of 16th Street between Arkansas Avenue and Irving Street. 16th Street is one of the major corridors in DC which moves travelers into and out of downtown while also connecting various neighborhoods. This corridor experiences high demands especially during the peak hours resulting in high delay for transit and other travelers.

This document was created upon the discussion performed with the professionals from District of Columbia Department of Transportation (DDOT) on April 9, 2018 on the issues regarding the operation of the reversible lane in the DC area which was limited for further expansion due to communication, efficiency and safety problems. To this end, the present document will focus on:

- Providing several solutions on informing drivers of the existence of reversible lane and direction of it,
- Modeling proposed solutions using a driving simulator and assessing drivers' decisions and behavior under each scenario, and
- Evaluating proposed solutions based on different criteria, including safety, operation, limitations and improvement capability

1.2 Reversible Lane Operation Preparation

This document was organized to address the objectives defined in the previous section. Given the time, the project will focus on the identified objectives by providing an overview of the problem, solution approach, developing a driver simulator to test travelers' behavior in response to the suggested solutions and scenarios and test the defined scenarios using a few numbers of drivers. At the end, the summary of the impacts of the solution approach will be discussed and some opportunities for insight into the problem will be suggested.

2. Concept of Operation

2.1 Background, Objectives and Scope

This Concept of Operation (ConOps) generally defines the characteristics of a system. The purpose of the ConOps for this project is to understand the current issues in the reversible lane operation, the user's needs and to explain how system improvement can be performed to fulfill these needs. The team members worked with DDOT to identify the main issues on the reversible lane operations on the corridors in DC. The first issue is how to inform the drivers of the existence of the reversible lane, which is critical to encourage drivers to use the reversible lane. In fact, informing the drivers of the possibility of using reversible lane is required to distribute the flows over the main lane and reversible lane for a more efficient transportation system. The second issue which is essential to resolve is figuring out an efficient way to communicate the direction of travel on the reversible lane to travelers.

The main objective of this study is to build a system for communicating with travelers in order to achieve the expected efficiency from the reversible lanes and also improve the current system specifically from the safety perspective. To this end, the current traffic operation data from existing reports and studies were used to establish new functional methodologies for improving the performance of the reversible lane.

Based on the identified problem, a list of alternatives for improving the communication among vehicles and infrastructure was prepared to inform unfamiliar drivers of the existence of a reversible lane on the corridor and also to warn them about the direction of travel on the reversible lane during each specific time periods. Proper communication of the direction of reversible lanes is quite critical to prevent confusion of travelers and to promote safe operation of reversible lanes. Conventionally the reversible lane on 16th Street is controlled using broken double yellow lines and overhead lane-use control signals. However, for the case of arterials in District of Columbia, the use of overhead signals is restricted. As a result, this study proposes the use of dynamic message signs, in-pavement LED lightings and warning messages on navigation applications to communicate the reversible lane's direction. In selecting these alternatives, one consideration was to identify the solution approaches that have the deployment potential in near future. Therefore, we did not consider the connected vehicles technology at this point in the project. However, further studies can be done to investigate the effectiveness of the potential alternatives in a connected environment.

2.2 Justification and Nature of Changes

The project team worked closely with DDOT to understand the key issues and potential improvements to be gained in reversible lane operation. Two main issues of the operation of reversible lanes in District of Columbia were identified. The first issue stems from the fact that unfamiliar travelers rarely use reversible lanes which results in having congestion on the regular lanes, and thus the expected operational benefits of reversible lanes cannot be achieved. This proves that there is a need for an efficient communication system to inform drivers of the existence of a reversible lane and its direction. The second issue is based on the previous studies on the number of crashes in the sections with and without the reversible lanes. These studies demonstrate some relations between the crashes and the reversible lane operation. For instance, the 6-year crash history of the reversible section on Connecticut Avenue indicates that the number of crashes is slightly higher in the sections with reversible lanes. Two types of crashes were reported to have an association with reversible lane operations: sideswipes and head-on collisions. Moreover, the data collected using video cameras demonstrates some violations of when using the reversible lanes; this contributes to the crashes on these segments. Two main reasons were proposed for these violations. Firstly, the violation occurred because the driver did not obey the traffic regulations. The second reason for violation was reported to be due to the deficiencies of communication that results in the usage of reversible lane operation unclear for travelers. Based on the outlined reasons for the need of better communication, this study was done to evaluate new alternatives and methodologies for improving the performance of the reversible lane operation. The developed solution is expected to improve the communication with travelers considering the defined regulations for control devices proposed by Fine Arts Commission.

2.3 Concepts for the Proposed System

This study addresses the identified issues through an interconnected communication and alerting system. The communication component of the proposed system disseminates the lane assignments, and the alerting component of the proposed system utilizes the vehicle detection technologies in addition to the communication means. The alerting component identifies possible vehicles traveling in a wrong lane assignment and disseminates a warning message to these vehicles as well as to the vehicles approaching in the opposite direction. The proposed system relies on a combination of three candidate communication means that include dynamic message signs, in-pavement LED lightings and navigation applications used in vehicles or on smartphone. The alerting component of the proposed system also incorporates video cameras and loop detectors to monitor the traveling vehicles and to detect any vehicle that might be travelling in a wrong direction. Figure 1 demonstrates the ITS technologies used for this problem.

2.3.1 High-level Functional Architecture

Figures 2 illustrates the functional architecture of the proposed reversible lane operation system. The successful operation of this system requires the following actions to be accomplished in traffic control center (TMC) as well as in the field control units.

The supported actions in TMC are:

- Monitor traffic performance
- Check reversible lane time plan
- Reversible lane assignment
- Communicate with field control unit
- Update online portal
- Communicate with transit services

The supported actions in field control unit are:

- Communication with TMC
- Update the traffic control devices including dynamic message signs and the in- pavements LED light.
- Continuously monitoring reversible lane by processing the data from loop detectors and video cameras.

- Detection of wrong way driving vehicles.
- Action or response formulation.
    - Issuing warning message on dynamic message signs
    - Communicate with TMC

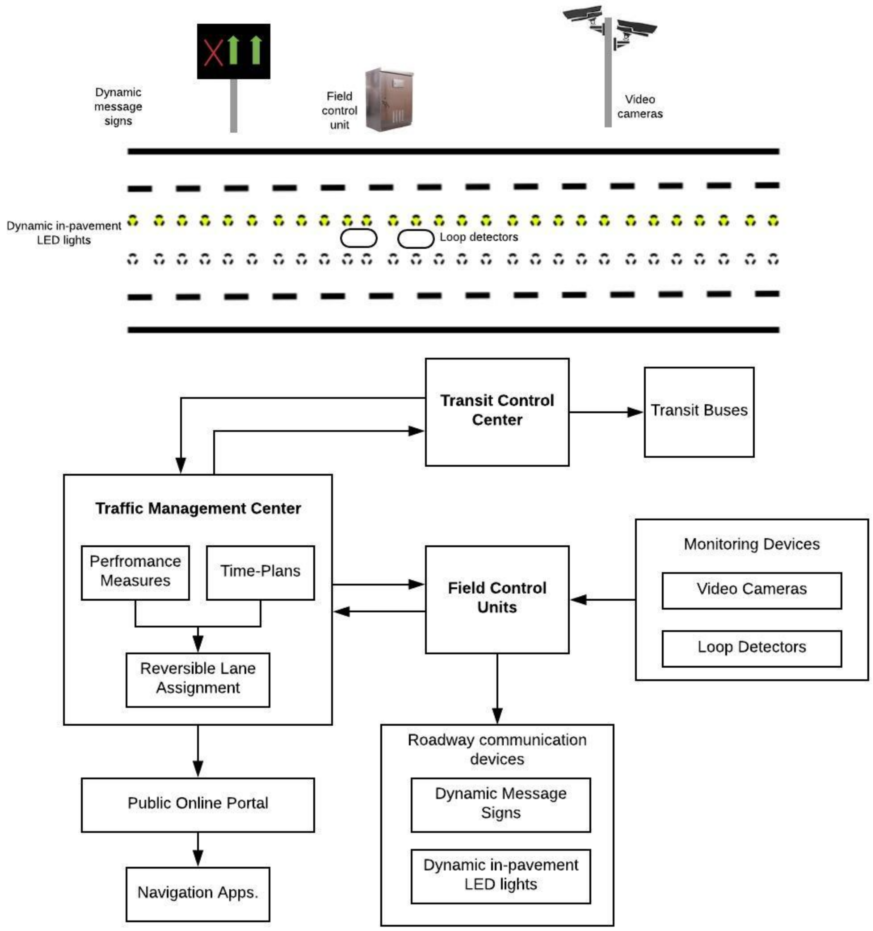

Figure 1. Illustration of ITS Tools that support the reversible lane operation

2.3.1.1 Communication components of the systems

Dynamic message signs: Stationary dynamic message signs (DMS) are proposed to display real-time traffic-related messages to travelers. For this project, two types of messages are communicated to travelers covering the lane assignment as a regulatory message and a warning message for the case of potential wrong-way drivers. There is a need for the continuous communication of the lane assignment to promote the use of reversible lanes. Still one of the limitations of the DMS is that their messages are available to drivers at limited locations and there is a need for other devices to complement DMS.

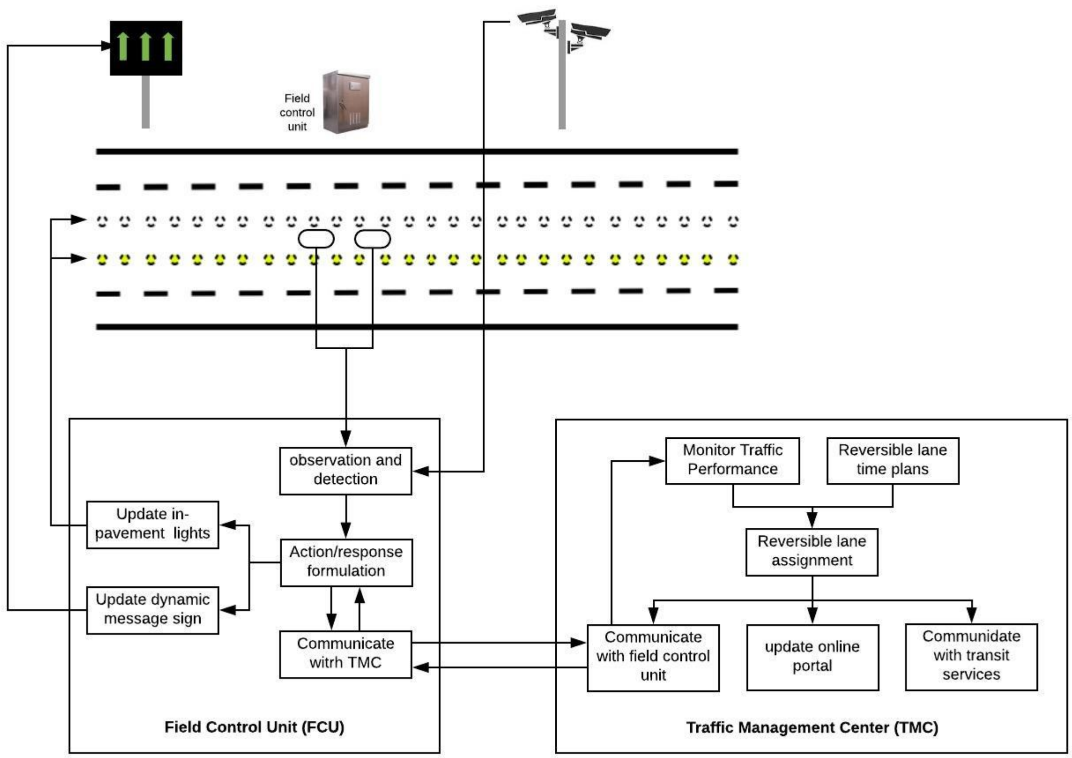

Figure 2. High level summary of reversible lane operation

In-pavement LED lightings: In-pavement lightings are a particular type of traffic signal installed on the surface of roadway usually used to warn travelers in situations involving pedestrian crossings. Furthermore, steadily illuminated in-pavement lightings can be used as illuminated raised pavement markers. Moreover, this technology has been used as lane guidance for bikes, curves, HOV and reversible lanes. The in-pavement LED lights provide the opportunity to use illuminated dynamic lane markings and to continue communicating the reversible lane assignment to the travelers.

Navigation Applications: The advancement in the communication technology and availability of the navigation applications in vehicles and on smartphones provides a new opportunity to communicate the dynamic changes in the road network with travelers. There exist some programs such as the “Connected Citizen Program” by Waze that communicate the publicly available data such as incidents and road closures to the users. The DDOT traffic management center can embrace the opportunity to share the reversible lane assignment plans using an online portal providing a foundation for navigation applications to communicate this information to their users. The unfamiliar travelers are the ones who are in need for more communication regarding the reversible lane assignment. These travelers most probably will use navigation apps for route suggestions. Transferring the information of reversible lane operation to the users by the apps have the potential to improve the efficiency of network and reduce the probability of wrong-way driving.

2.3.1.2 Monitoring components of the systems

The monitoring components of the proposed system help identifying potential vehicles driving in a wrong direction of the reversible lane. This system utilizes inductive loop detectors as in roadway sensors and video camera as over the roadway sensors to monitor the driving direction of vehicles on the reversible lane. At each detection location, two loop detectors with slight overlapping configuration are used to detect the direction of travel. Besides, video cameras are mounted on poles on the side of the roadway to complement the loop detectors. Video image processing technology is used to detect the travel direction of vehicles. Moreover, the video cameras provide the opportunity to verify the presence of the wrong-way driving vehicles by the TMC.

2.3.1.3 Controlling and operating components of the systems

The field control units control both the communication and the monitoring components of the system. The field control unit keeps continuous communication with the traffic management center (TMC) and controls the dynamic message signs and in-pavement LED lights accordingly. Moreover, the field control unit process the data collected by loop detectors and the video cameras. In case of detection of wrong-way driving vehicles, the field control unit communicates the detection to TMC.

2.4 User Classes and Other Involved personnel

The main players of this solution are the road users, in particular, the drivers traveling on the 16th Street, Washington DC. Indeed, the solution seeks way to better communicate with road users about the direction of the reversible lane, targeting a safer and more effective reversible lane operations on the arterials. The District Department of Transportation (DDOT) is the other main player in the proposed solution. The DDOT transportation operation and safety, transportation planning, ITS program management, and transit teams will be all involved in analyzing, evaluation, and potential applications of the proposed solutions. Moreover, considering the historical context of the city and associated signage and signal design considerations, the DC Historic Preservation Office and the Commission of the Art and Humanities will also play a determining role in evaluating the solutions.

3. Summary of Impacts

To have safe and efficient operations in reversible lanes, there should be a clear implementation planning and traffic rules. As discussed, the present study proposes three main alternatives as potential tools that can be used to efficiently communicate with drivers and provide them with information on the presence as well as the direction of the reversible lane. Potential impacts of each solution along with the associated evaluation criteria are investigated using a driving simulator which will be discussed in more details in the following section.

3.1 Driving Simulator

The simulator is created within the Unity game engine. The environment contains a recreation of a segment of 16th Street between Arkansas Avenue and Irving Street at the north and southern boundaries respectively; short extensions beyond these borders are also included. All intersections and lane configurations within the segment's boundaries are created within the simulator as well. For all intersections which are signalized in the real-world, traffic signals are also included within the simulator and are set to operate on a preset timing plan. The environment also allows for placement of additional signs as well as pavement markings. Spawn points are present at the road extensions beyond the northern and southern boundaries of the segment. An overall view of the developed environment for testing is shown in Figure 3. The dynamic message sign, markings and navigation apps are three communication tools developed in the model. Vehicles are generated within the simulator after a time interval equivalent to the headway which in turn is obtained as the inverse of the flow rate of the lane groups. The equation is as follows:

$$h = \frac{3600}{q} \qquad (1)$$

where h is headway in seconds and q is flow rate in vehicles per hour. Vehicles in the simulator move along the segment according to the rules established by the Intelligent Driver Model. The model states that the acceleration of a vehicle is given by equation (2).

Figure 3. Simulated environment of 16th street in District of Columbia

$$a = a_{max}[1 - (\frac{v}{v_o})^{\delta} - (\frac{s^*(v,\Delta v)}{s})^2\,] \qquad (2)$$

where a_{max} is the vehicle's maximum acceleration, v is the vehicle's current speed, v_o is the vehicle's desired speed, δ is an acceleration exponent, $s^*(v, \Delta v)$ is the vehicle's desired dynamical distance, s is the current gap between the vehicle and the vehicle ahead of it (set to a value of 1000 meters if no leader is present). The desired dynamical distance is calculated by:

$$s^*(v, \Delta v) = s_o + vT + \frac{v\Delta v}{2\sqrt{a_{max} b}} \quad (3)$$

where s^* is the minimum desired distance, T is the time headway value, and b is the vehicle's comfortable deceleration rate. Table 1 presents the values used for each parameter within the simulator.

Table 1. Initial parameter values for simulation

Parameter	Value
a_{max}	1.0 m/s^2
v_o	120 km/hr
δ	4
s_o	2 m
T	1.5 sec
b	1.5 m/s^2

In addition to these rules, all vehicles respond to the status of signals at approaching intersections.

Beyond the simulation of volumes, the simulator also allows for a human to take control of a vehicle and drive within the segment. The driver controls the vehicle via a steering wheel controller and pedals in order to recreate the feeling of driving a real car. Figure 4 demonstrate the driving simulator for this study. Other vehicles will continue to move based on the IDM's rules while the driver traverses through the segment as they would in a real-world setting. In addition to this, the simulator can also present on-screen warning messages to the driver regarding the status of the reversible lane within the segment.

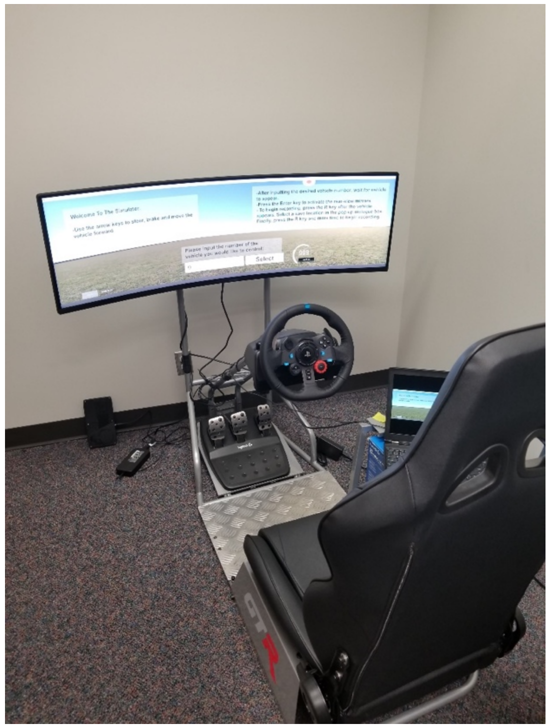

Figure 4. The driving simulator

3.2 Evaluating the proposed solutions

As discussed, the evaluation criteria for the proposed solutions distinguish between two main tasks: (1) informing drivers of the presence and direction of the reversible lane (communication systems), and (2) warning drivers if a wrong-way driving has been detected along the segment (warning system). Each solution alternative needs to be evaluated considering its performance on each of these two tasks, and the best alternative can then be determined accordingly.

16th Street NW is one of the vital corridors in Washington, DC operating as a major arterial and also an evacuation route. Near-capacity traffic volume on the corridor has led to extensive vehicle queues, delay, and congestion, particularly in peak hours, causing serious mobility, safety, and environmental challenges. The reversible lane solution is already developed along the section to address the aforementioned problems. These facilities are used to mitigate the congestion stemmed from unbalanced directional traffic while optimizing utilization of the existing infrastructure. The middle lane of 16th Street NW is a reversible lane which operates at both directions based on time of the day, i.e. morning and evening peak hours. Accordingly, the through traffic on peak direction can be distributed between three, instead of two, lanes by temporarily borrowing a traffic lane from off-peak direction. The new alignment therefore can increase the roadway capacity in the peak direction, and in turn, efficiently improve traffic mobility on this heavily-traveled arterial.

Lane-use monitoring results of 16th Street, however, indicate significantly low utilization of the reversible lane compared to other traditional lanes, limiting its functionality in reducing peak-hour congestion and the resulted mobility improvement. This can be due to the inadequate and/or vague reversible lane signage along the section, leading to driver's limitations of understanding reversible lane operation and failure to follow its associated traffic rules. Besides, a high proportion of visitors and non-local travelers in areas like DC highlights the problem even more as they are usually not familiar with the existence or daily operation of the reversible lanes in the city. Targeting the aforementioned communication phase, the present study has introduced two main alternatives to improve the existing reversible lane signage on 16th Street NW. Given the traffic volume data provided by DDOT and the geometric features of the segment, the traffic condition of the 16th Street NW is simulated under existing and proposed signage solutions.

Beyond mobility and operational points of view, safety has always been one of the major challenges associated with reversible lane implementations. Collected data on crashes in one of these facilities in DC indicates that even after normalizing traffic volume, reversible lanes still have high crash rates due to wrong-way driving. In addition, the reversible lane had significantly low utilization particularly in segments where there is a high propensity for encroachments, as drivers tend to stay away from that third lane because of the safety concerns. The attempts made to address these challenges are two-fold:

- To improve the existing communication system: As discussed, the present study suggests using a combination of three candidate communication means including dynamic message signs, in-pavement LED lightings, and navigation applications, to improve traveler information. The idea is that providing drivers with sufficient information on the operation direction of the existing reversible lane through an efficient communication system can mitigate wrong-way driving, and in turn, ensure higher levels of safety along the segment.
- To implement a warning system: In addition to improving communication task, a warning system is also suggested to address the current safety concerns of the 16th Street NW. Accordingly, in case of a detecting a wrong-way driving on the existing reversible lane, drivers will be informed through the proposed communication system and can take required actions to avoid potential head-on collisions.

To test the above hypotheses, each scenario is simulated using the driving simulator. First, drivers will be asked to drive through the segment with existing and improved communication systems. Lane utilization, as well as the number of drivers traveling on the wrong direction of the reversible lane, is recorded for each scenario. Next, the efficiency of the proposed warning system is investigated by informing the driver of the existence of wrong-way driving using navigation apps, and then monitoring his/her behavior and recording the number drivers with crashes in the associated scenario. We expect to get the approval forms for testing human subjects in a few weeks and then we will be able to release the results of the simulation of different scenarios.

4. Acknowledgement

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