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TSM&O Solutions to Mitigate Wrong -Way Driving (WWD) Incidents on Arterials



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Abstract:	<p>This report presents a high-level concept-of-operations (ConOps) for mitigating Wrong Way Driving (WWD) crashes and incidents on arterials. The proposed Transportation Systems Management & Operations (TSM&O) strategies were developed to mitigate WWD incidents on North Tampa Street and North 21st & 22nd Streets in Tampa, FL. The ConOps identified the stakeholders involved and presented a systematic approach to the deployment of the proposed TSM&O strategies along the study corridors. The stakeholders include the road users, FDOT District Seven, the City of Tampa, District Seven TMC, law enforcement officials, and Road Side Equipment (RSE) vendors. The proposed solutions are categorized into <i>quick fixes</i>, enhancement of traditional solutions, and TSM&O strategies. Deployment of the proposed TSM&O strategies is approximated to cost \$60,000 per intersection, totaling to \$300,000 for five critical signalized intersections along the study corridors. The proposed solutions are expected to benefit all stakeholders by reducing WWD crashes and incident rates, reducing the severity of WWD crashes, and improving communication between agencies responsible for mitigating WWD incidents. The proposed solutions are easily implementable, and are transferable to similar facilities across the country, and can also be adapted to address other safety concerns such as aggressive driving, driving under the influence, etc.</p>	
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Acronyms and Abbreviations

ConOps	Concept of Operations
FDOT	Florida Department of Transportation
iiRPMs	internally illuminated Raised Pavement Marker
ITS	Intelligent Transportation Systems
LED	Light Emitting Diode
RSE	Road Side Equipment
RRFB	Rectangular Rapid Flashing Beacon
TMC	Transportation Management Center
TSM&O	Transportation Systems Management & Operations
WWD	Wrong Way Driving
TWSC	Two Way Stop Controlled

1. Overview

Wrong-Way Driving (WWD) is defined as the movement of a vehicle in a direction opposite to the one designated for travel¹. The predominant crash types resulting from WWD crashes are head-on or opposite-direction sideswipes as a result of two vehicles moving from opposite directions of the roadway. These crashes generally cause more incapacitating injuries and fatalities than non-WWD crashes. Annually, WWD crashes result in about 350 fatalities nationwide, and constitute 3% of all crashes that occur on high-speed divided highways². Several states including Florida, California, Texas, Illinois, and Arizona have become pioneers in mitigating WWD incidents.



The traditional WWD countermeasures that recommend changes to roadway signage and pavement marking improvements may not often work as efficiently. This calls for more active detection methods to ensure drivers are notified of WWD and that law enforcement officials, Transportation Management Centers (TMCs), as well as other road users, receive real-time warnings about WWD incidents. Some of the countermeasures that have been considered at the freeway off-ramp locations are Red-Rectangular Rapid Flashing Beacons (Red RRFBs), detection-triggered Light Emitting Diode (LED) lights surrounding the Wrong Way signs, and internally illuminated Raised Pavement Markers (iiRPMs).

Although WWD crashes on freeways usually draw more media attention, involve more vehicles, cause longer freeway closures, and result in more fatalities and serious injuries, WWD crashes on arterials are relatively more common. The likelihood of a WWD crash on arterials was found to be 2.3 times more than on freeways¹. Tackling the WWD issue on limited-access facilities (i.e., freeways) is relatively easy especially because there are only very few access points. On the other hand, mitigating WWD crashes on non-limited access facilities (i.e., arterials) is more complicated because there are multiple access points along the arterials. In other words, there are many possible locations where a driver may enter the facility the wrong way, and it is difficult (maybe even impossible) to have some type of WWD countermeasure(s) at each of these access points.



This report presents a high-level concept-of-operations for mitigating WWD on arterials. The objective of this project is to explore and propose Transportation Systems Management & Operations (TSM&O) solutions to achieve a significant reduction in the number of WWD incidents and crashes on arterials. As mentioned earlier, several states including Florida have deployed Intelligent Transportation System (ITS) technologies and TSM&O strategies at off-ramps and freeway mainlines to mitigate WWD incidents in real-time. However, only very few strategies, if any, have been deployed along arterials.



¹ Ponnaluri, R. V. (2018). Modeling wrong-way crashes and fatalities on arterials and freeways. *IATSS Research*, 42(1), 8-17.

² National Transportation Safety Board. (2012). *Wrong-way Driving - Highway Special Investigation Report*. NTSB/SIR-12/01. Washington, DC.

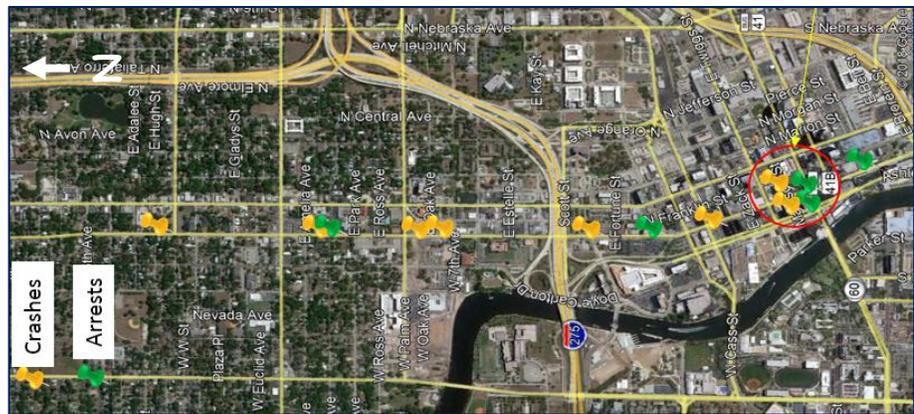
This project focused on mitigating WWD incidents on arterials by leveraging the existing ITS infrastructure and the communication equipment and protocols that are already in place. The proposed TSM&O strategies may be considered as a proof-of-concept for successful deployment in mitigating WWD incidents on non-limited access facilities. This project also seeks to generalize the solutions so that they can be applied to similar facilities in the U.S. and abroad.

2. Study Corridors

The research team worked with the FDOT Central Office, the FDOT District Seven, and the City of Tampa to identify critical arterials in Tampa which have experienced several WWD crashes and incidents. The critical corridors were identified to be North Tampa Street and North 21st & 22nd Streets in Tampa, Florida. These corridors are used as case studies in this project

N Tampa St

This 2.7-mile section is a one-way three-lane corridor with 23 Two Way Stop-Controlled (TWSC) intersections and 14 signalized intersections. The speed limit along the corridor is 40 mph on the northern section and it drops to 30 mph towards the southern section.



There were 8 WWD crashes along this corridor from 2012-2015. All crashes occurred at intersections and during the night. Five of these crashes occurred at signalized intersections and three occurred at TWSC intersections. Additionally, there were 6 WWD arrests along the corridor from 2015-2019.

N 22nd St & N 21st St

These are 1-mile, one-way pair of parallel segments with two lanes. There are seven TWSC intersections and seven signalized intersections along each corridor. The speed limit is 30 mph. The corridors experienced a total of five WWD crashes



from 2012-2015. All crashes occurred at intersections. There were 13 WWD arrests along these corridors from 2015-2019.

3. The Existing Scenario

The study corridors have traditional static WWD signs to direct drivers such as “DO NOT ENTER”, “NO TURN” and “ONE WAY” signs. However, the existing signs are only at intersections and most of them are not clearly visible, especially at night. These signs are inconspicuous and inconsistent from one intersection to another. There are no WRONG WAY signs along the segments to alert drivers who had missed the directional signs at intersections and turned the wrong way. Figures 1 and 2 illustrate this situation.



Figure 1: The Wrong Way Driver's View Along the Corridor

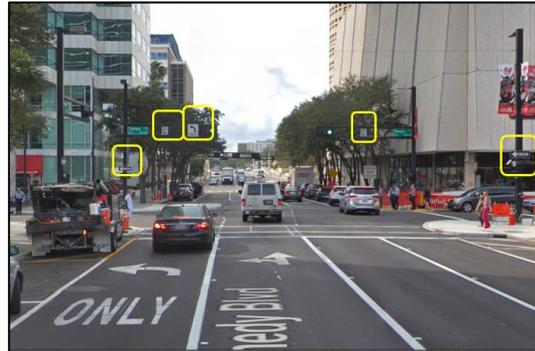


Figure 2: The Existing Directional Signs at an Intersection

An in-depth analysis of the intersections that WWD crashes occurred along the study corridors revealed a few critical issues. One of the most critical scenarios was when a one-way street intersected another one-way street. A good example from the study corridors was the N Tampa St. and E Kennedy Blvd intersection (see Figure 3) where two WWD crashes occurred and two WWD citations were reported. Another common scenario was at the stop-controlled intersections where drivers were making a right turn to the wrong way of a one-way street, as seen in Figure 4.

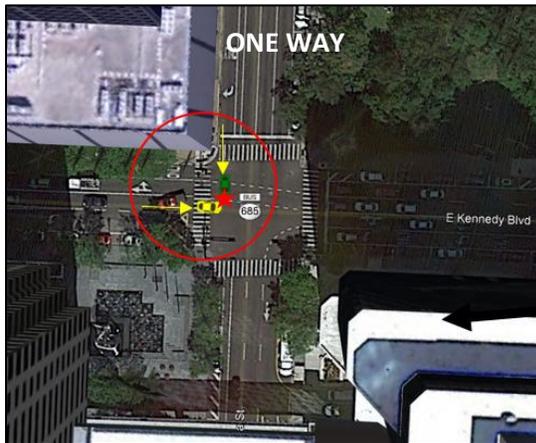


Figure 3: WWD Crash at Two One-Way Intersecting Road

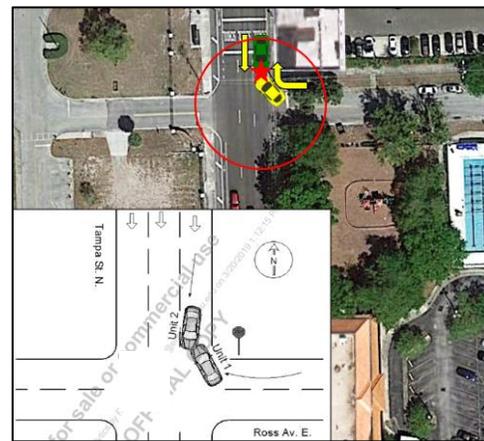


Figure 4: WWD Crash at a Stop-Controlled Intersection

4. Concepts for the Proposed System

4.1 Overview

The City of Tampa has witnessed a number of WWD crashes on arterials. Understanding the seriousness of this issue, FDOT Central Office, FDOT District Seven and the City of Tampa are undertaking multiple efforts to mitigate WWD incidents. The use of traditional signage and pavement markings have proven to be relatively less effective as evidenced by the number of WWD crashes and citations reported. Therefore, innovative strategies (e.g., flashing red-RRFBs), and design alternatives are necessary. These strategies may include Wrong Way warning signs, Wrong Way detection technologies, and technologies to alert WW drivers and other road users in real-time.

4.2 Stakeholders Involved

In developing the user needs, the following stakeholders involved with the proposed strategies were identified:

- FDOT District Seven
- The City of Tampa
- District Seven TMC
- Law Enforcement Officials
- Road Side Equipment (RSE) Vendors
- Road Users

4.3 Description of the Proposed Traditional Solutions

The solutions to mitigate WWD incidents along the study corridors and other corridors with similar problems are identified. The proposed solutions are divided into three categories: *quick fixes*, enhancement of existing signs, and TSM&O strategies.

4.3.1 Quick Fix

The *quick fix* includes proper lane markings to direct traffic to go through instead of turning left to the wrong way. This fix is to the problem spotted at one of the corridors where there are two consecutive intersections, one with the one-way road and the next with a two-way road where drivers could make a left turn, as shown in Figure 5. Enhanced pavement markings directing the drivers to continue straight can be a quick and economical fix to deter drivers from turning the wrong way.

Existing Lane Marking



Proposed Lane Marking



Figure 5: Adding Directional Pavement Markings to Avoid Wrong Way Left Turns

4.3.2 Enhancement of Existing Signs

Because most WWD crashes at the study corridors occurred at night, there is a need to enhance the existing signs to make them more conspicuous. The proposed solution is to supplement the NO LEFT/RIGHT TURN and ONE WAY signs with a red LED sign to command the attention of motorists, as shown in Figure 6. The signs will be programmed to illuminate at night or during low light and blank out during the daytime. Installation of enhanced WRONG WAY signs (i.e., LED lights surrounding the WRONG WAY signs) at midblock locations will help drivers know that they are going the wrong way, and help them reroute to the right direction. Since arterials and other non-limited access facilities have multiple access points, wrong way drivers have several opportunities to get off the road or make U-turns or any required corrective maneuver once they realize that they are moving in the wrong direction.



Figure 6: Enhanced Signs

4.4 Description of the Proposed TSM&O Strategy

The proposed TSM&O solution provides a warning to all drivers to avoid the chances of drivers going in the wrong way, supports the detection of wrong way drivers, and alerts or notifies other drivers, pedestrians, bicyclist, law enforcement officials, and the TMC about the presence of a wrong way driver. The proposed system ensures active protection of all road users from the dangers posed by the wrong way drivers. It integrates information from the road side equipment (RSE) to alert and in some cases stop road users from entering the corridor where a wrong way driver may have been present. These include the use of sensorial Wrong Way detection technologies (e.g., thermal imaging cameras), communication to the traffic signals, and/or TMC & law enforcement officials, incorporating the use of existing traffic signals, etc. The system will have three components: warning, detection, and notification.

4.4.1 System Operation

The first operation will involve having the Wrong Way driving event detected by the system and activation of the upstream signals, the TMC and law enforcement being notified of the Wrong Way event. A critical situation for the system deployment was where a one-way street intersects another one-way street. The system will operate in the following sequence, as explained in Table 1 and illustrated in Figure 7:

Table 1: System Operation

<p><i>Field Detection of Wrong Way Driver & Activation of Flashing Red Signals</i></p>	<p>Step 1: The drivers approaching an intersection will be provided with directional and warning signs enhanced with LED at night and clearly visible during the day. The signs to be installed will include the enhanced “NO LEFT/RIGHT TURN” alongside the traffic signal heads and “ONE WAY” on a pole/mast arm in the drivers’ direct line of sight.</p> <p>Step 2: The roadways will have red internally illuminated Raised Pavement Markers (iiRPMs) at the stop lines to warn drivers that they are about to go the wrong way.</p> <p>Step 3: The “WRONG WAY” signs will be installed along the corridor between intersections to notify the drivers who miss the enhanced Wrong Way signs and proceed the wrong way along the corridor.</p> <p>Step 4: The wrong way drivers will be detected by the thermal imaging cameras installed at the signalized intersections. Once detected, the upstream traffic signals will be activated to flashing all-red warning all drivers along the corridor to stop and proceed with caution.</p>
<p><i>Verification of WWD Event by TMC and Agency Response</i></p>	<p>Step 5: Once the wrong way driver is detected, pertinent information will be sent to the TMC and the law enforcement officials. The TMC personnel will verify the information and communicate with the law enforcement officials for more reactive responses. The TMC personnel will continue to track the wrong way driver until the situation is resolved.</p>

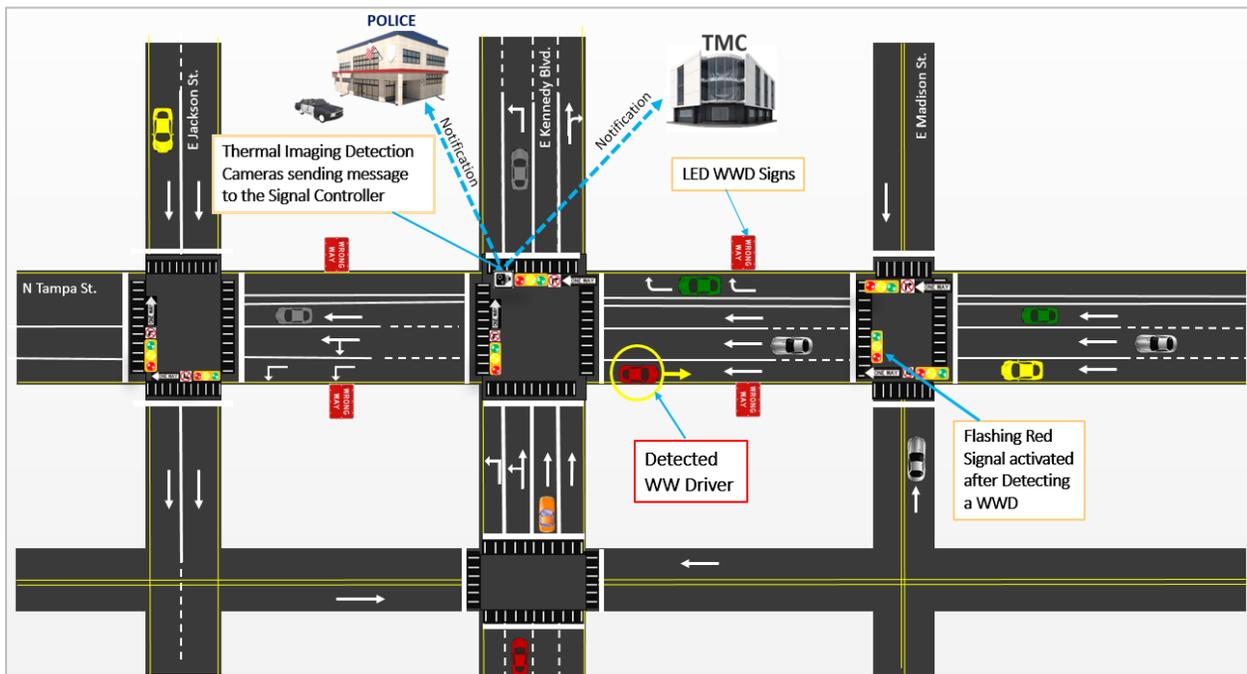


Figure 7: The Proposed TSM&O Solution

4.4.2 System Architecture

a) High-level Physical Architecture

The physical architecture of the proposed system includes; technologies that will be installed at intersections and along the corridor including flashing LED lights on Wrong Way signs, thermal imaging cameras, and the interface between ITS equipment and the TMC. These technologies will enable the system to detect, warn, and notify all road users and the responsible agencies on the presence of a wrong way driver along the corridor. Figure 8 shows the proposed system's high-level physical architecture.

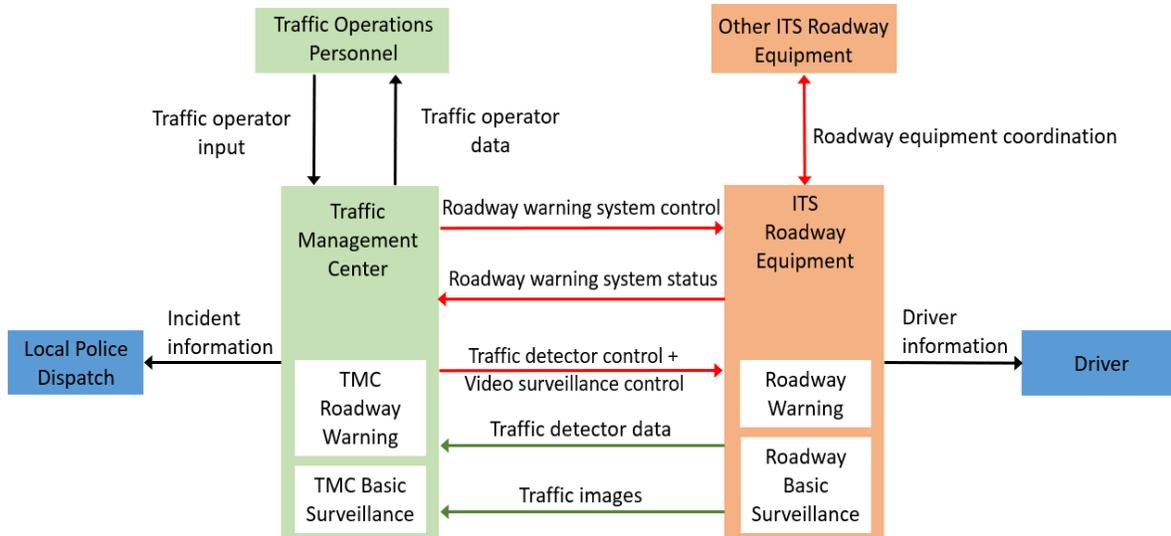


Figure 8: High-Level Physical Architecture (Adopted from USDOT, 2019)³

b) High-level Functional Architecture

The functional architecture of the proposed system comprises several functions including detecting wrong way drivers, sending warnings to other road users, sending incident information to the law enforcement agencies and the TMC. Table 2 describes the high-level functional architecture of the proposed system.

Table 2: High-Level Functional Architecture

Functional Object	Functional Description	Physical Object
Roadway Basic Surveillance	<ul style="list-style-type: none"> Monitors the wrong way movement of vehicles through intersections 	ITS Roadway Equipment
Roadway Warning	<ul style="list-style-type: none"> Alerts wrong way drivers about the wrong way maneuver, warn other road users approaching hazards on the roadway. Activates flashing all-red signals to alert the wrong way drivers and other road users 	ITS Roadway Equipment
TMC Basic Surveillance	<ul style="list-style-type: none"> Remotely monitors and controls surveillance equipment and collects, processes and stores the collected data. Sends the information to traffic operations personnel 	TMC
TMC Roadway Warning	<ul style="list-style-type: none"> Remotely monitors and controls the systems used to warn drivers and other road users along the corridor about a potential wrong way driver. 	TMC

³ USDOT, 2019. ARC-IT Version 8.2: The National ITS Reference Architecture

<https://local.iteris.com/arcit/html/servicepackages/sp140.html#tab-3>

4.5 Deployment Constraints

The primary constraint of this system is the budget limitation. The active management of traffic is expensive due to the different devices and technologies involved (for e.g., some devices may need to be redesigned to cater to the specific needs of this project), the constant vigilance of TMC operators, and the initial investment to place all devices in the field. Therefore, efforts must be done during the pre-deployment phase of the project to identify critical intersections (intersections with high WWD crashes) that can potentially benefit from deploying the system.

4.6 Technology Constraints

Thermal imaging detection accuracy may be compromised by error messages especially due to the presence of nonmotorized users (i.e., pedestrians and bicyclists) on arterials. This may falsely trigger the activation of the upstream signals to flashing red and result in delay, particularly during peak hours.

4.7 Change Priorities

Of immediate attention along the study corridors are the enhancement of traditional signing and pavement markings. These can be installed at all intersections to ensure drivers have a clear indication of the wrong way. Order of deployment must prioritize intersections with a high number of wrong way crashes and incidents, and intersections with uncommon geometry and/or traffic patterns (e.g. one-way street intersecting another one-way street)

4.8 Changes Considered But Not Included

Along with the proposed system, several other options were considered for mitigating wrong way driving incidents on arterials. One significant and more technologically advanced option was integrating the Connected and Automated Vehicles (CAV) technology within the wrong way detection and warning system. The vehicles equipped with On-Board Units could display messages warning the wrong way driver that they are going in the wrong direction and advice them to reroute. The On-Board Units could also display traveler advisory messages to motorists within the defined range, warning them of the wrong way driver.

5. Cost Breakdown

The system benefits from the use of the existing traffic signals. The cost, therefore, will be from the enhancement of traditional signs, placement of new WRONG WAY signs along the corridor, and installing the thermal camera detection and notification system.

The total estimated cost for deploying the proposed system at system-level in the City of Tampa is \$302,400. Table 3 provides intersection-level and system-level deployment costs. It is worth noting that 12% of contingency cost is also included in the budget. In addition, about 10% of the total budget is allocated for operating and maintaining the system, this is considered to make the project stable in the long run. The proposed system will be deployed at the following five critical intersections along the study corridors:

- E Kennedy Blvd. & N Tampa St.
- E Cass St. & N Tampa St.
- Scott St. & N Tampa St.
- Adamo Dr. & N 21st St.
- E 7th Ave & N 22nd St.

Table 3: Cost Breakdown

Device	Quantity	Cost Per Unit	Total Cost Estimate	Quantity	Cost Per Unit	Total Cost Estimate
	Intersection-level deployment Costs			System-level Deployment Costs		
No Turn LED Signs	4	\$4,150	\$16,600	20	\$4,150	\$83,000
Red iiRPMs	24	\$250	\$6,000	120	\$250	\$30,000
Thermal Imaging Wrong Way Vehicle Detection System	1	\$25,000	\$25,000	5	\$25,000	\$125,000
Traffic Surveillance Camera	2	\$3,000	\$6,000	10	\$3,000	\$30,000
Wrong Way Signs	2	\$200	\$400	10	\$200	\$2,000
Other Associated Costs						
Contingency @12%	--	--	\$6,480	--	--	\$32,400
Intersection-level Cost			\$60,480	System-level Cost		\$302,400

6. Timeline

The timeline for system deployment is anticipated to be 12 months. After assembling the project team, the specific tasks will include reviewing the ConOps document, preparing the system-level requirements, and procuring the project. After procurement, the next tasks will include system deployment, verification, and testing. Table 4 provides the specific tasks and their deployment timeline for the year 2020.

Table 4: Timeline

Task	Year 2020											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Stakeholder Consultation & Needs Assessment												
Review of the ConOps												
Procurement												
System Deployment												
System Testing & Validation												

Note: ConOps includes system requirements and preliminary engineering

7. Anticipated Benefits

The application of the proposed solutions will mainly lead to several safety benefits. The system will primarily reduce the frequency of WWD incidents. The WWD detection, warning, and alert system will ensure that the wrong way driver and other roadway users are alerted immediately. The early WWD warning system has two main advantages. First, the wrong way driver becomes aware of the wrong maneuver and finds a way to reroute. Second, other road users already along the corridor proceed with caution. Apart from reducing the WWD crash frequency, the system will also reduce the severity of the WWD crashes. This might be an outcome of road users driving with relatively lower speeds after being notified about the potential wrong way driver. Moreover, the notification system to the TMC and law enforcement will improve the incident response time and reduce the number of violations. The notification to law enforcement will invoke a reaction from them regardless of the occurrence of a crash. Drivers knowing that the system has cameras that can detect wrong way maneuvers will be careful not to perform such maneuvers. The proposed system can be modified to suit other applications such as warning road users about an on-going police chase or emergency response vehicle that requires a right-of-way.

8. Summary

This document presents a high-level concept-of-operations for mitigating WWD incidents on arterials. It gives an overview of the WWD crashes and citations recorded along the North Tampa Street and the North 21st & 22nd Streets, and the existing mitigation strategies. The proposed solutions are categorized into the *quick fixes*, enhancement of traditional solutions, and TSM&O-related strategies. The proposed mitigation strategies leverage the warning signs, detection technologies, and traffic signals to detect, warn, and notify wrong way drivers and other road users.

The application of the proposed strategies is anticipated to bring several safety benefits including the reduction in the frequency of WWD incidents by ensuring that the wrong way drivers and other road users are notified in real-time. The proposed strategies will help the wrong way driver realize that they are going the wrong way and provide an opportunity to make corrective maneuvers. Also, other road users will proceed with caution along the corridor. These solutions can be transferred to other arterial corridors that experience high WWD crash rates and have room for future modifications (e.g. incorporating CAVs).

9. Acknowledgments

We are grateful to the National Operations Center of Excellence (NOCOe) for giving us the opportunity to participate in this tournament. We would like to thank Adam Hopps, and the NOCOe team for all their support, suggestions, and recommendations throughout the project. We would also like to express our most sincere appreciation to Raj Ponnaluri, Ph.D., P.E., PTOE, PMP, the Connected Vehicles and Arterial Management Engineer at FDOT Central Office, and Peter Hsu, P.E., the FDOT District Seven Traffic Safety Engineer, for their kind support, guidance, and mentorship.