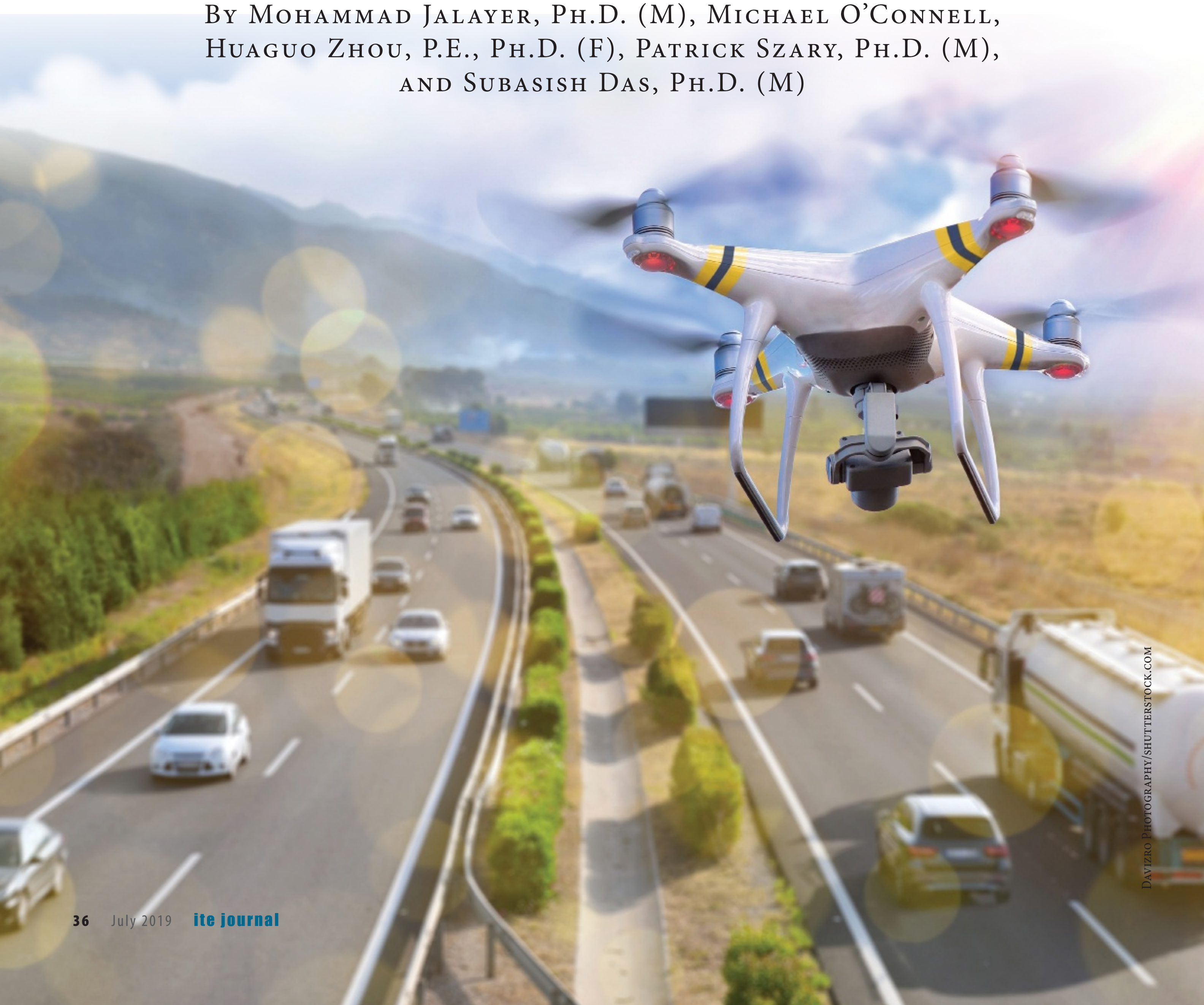
Application of Unmanned Aerial Vehicles

to Inspect and Inventory Interchange Assets to Mitigate Wrong-Way Entries

By Mohammad Jalayer, Ph.D. (M), Michael O'Connell, Huaguo Zhou, P.E., Ph.D. (F), Patrick Szary, Ph.D. (M), and Subasish Das, Ph.D. (M)



Davizro Photography/shutterstock.com

Interchanges are critical elements of freeway and highway systems that provide access to nearby urban, suburban, and rural areas. Since the development of the interstate highway system in the 1950s, crashes associated with driving in the wrong direction on freeways have created a critical issue for transportation agencies. Wrong-way driving (WWD) occurs when a driver, either inadvertently or deliberately, drives in the opposing direction of traffic along a high-speed, physically divided highway or its access ramp.[1] Reasons a driver may go in the wrong direction include but are not limited to, driving under the influence of substances such as alcohol or drugs, fatigue, and a confusing geometric roadway design. WWD crashes are known for their tendency of being more severe than other types of freeway crashes, which result in more fatalities due to them being mostly head-on or opposite-direction sideswipe collisions. According to the National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS) database, during 2004 to 2011, an average annual total of 359 people perished in 269 fatal WWD crashes.[2] This means that the average number of fatalities per WWD fatal crash was 1.33, as compared to the 1.09 death rate for all other fatal motor vehicle crashes, thus necessitating further evaluation and action.

Several previous studies have demonstrated that exit-ramp terminals are common locations for drivers to enter a physically separated highway in the wrong direction.[3] Furthermore, past studies identified several common issues associated with the WWD crash-prone intersections. Issues with signing and pavement markings, including defective or missing devices, poor location or placement, and insufficient conspicuity, were commonly cited. Some geometric features also correlated to WWD crashes, such as interchange or intersection layout, the presence of raised median or channelizing islands, turning radii, and large median openings.[4,5] To achieve the *Toward Zero Deaths* vision initiative administered by NHTSA, many different countermeasures have been implemented by state departments of transportation (DOTs) and local agencies. Note that to propose appropriate safety recommendations, an extensive field review and analysis of safety data must first be accomplished. However, an on-the-ground field study is not only time-consuming and labor-intensive but also exposes the field data collection crews to traffic hazards.

Unmanned aerial vehicles (UAVs)—or drones—have seen a rising number of applications in a variety of domains such as policing and firefighting, nonmilitary security work, surveillance of pipelines, land management, earth observations, and infrastructure inspection.[6,7,8] UAVs, equipped with high-quality cameras, can be employed to collect high-quality data faster, safer, smarter, and more precisely. The UAVs can be operated by a pilot on the ground, programmed to follow a path and collect the required information automatically.

The purpose of this study, which is the first of its kind, is to evaluate the feasibility of utilizing UAVs in collecting high-quality data on exit-ramp terminals pertaining to WWD. It also discusses challenges and shortcomings, and develops solutions to address those challenges. Field data were collected at two typical freeway interchanges (i.e., partial cloverleaf interchange and modified diamond interchange) in the state of New Jersey, USA. The findings of this study could carry significant implications for state and local agencies across the nation to collect the necessary highway inventory data that can assist field inspection of WWD crash sites, with the aim of reducing the frequency and severity of WWD crashes.

Method and Data

To conduct a traffic-related UAV study, a proper step-by-step framework must first be established. This framework breaks down the whole process into several steps, each with its associated details. According to Khan et al. (2017), the framework includes scope definition, flight planning, flight implementation, data acquisition, data processing and analysis, and data interpretation/traffic application (see Figure 1), as described in the following sections.[9] For these operations, the pilot should have passed the Federal Aviation Administration (FAA) Airman Knowledge Exam and received a valid FAA Remote Pilot license, or have a 14 CFR part 61 license with a remote pilot endorsement.

Scope of Work

Regarding the scope of work, which is the critical step in the framework, this paper evaluates the application of UAVs to inspect, inventory, and monitor exit-ramp terminals pertaining to WWD crashes. It is worth mentioning that exit-ramp terminals are the most common locations for drivers to enter a physically divided highway in the wrong direction. Based on our extensive experiences on WWD crashes, we identified a list of critical parameters for collecting and monitoring, using the developed wrong-way entry checklist (see Figure 2). Notably, the study features are associated with the signs (e.g., DO NOT ENTER sign), pavement markings (e.g., wrong-way arrow), and geometric design features (e.g., raised curb median). Based on these characteristics, the type of UAV flight is determined.

Flight Planning

The flight planning stage involves several preflight procedures to facilitate a safe flight operation and environment.[9] It is during this phase that potential flight risks and hazards are assessed, along with mitigation procedures to address such risks. The planning phase also defines the equipment to be used in the operation, flight route, approximate altitude of flight operation, launch and landing locations, and operator location. It is important for the operators to ensure they are clear to fly in the proposed airspace and that there are no temporary flight restrictions or other potential airspace

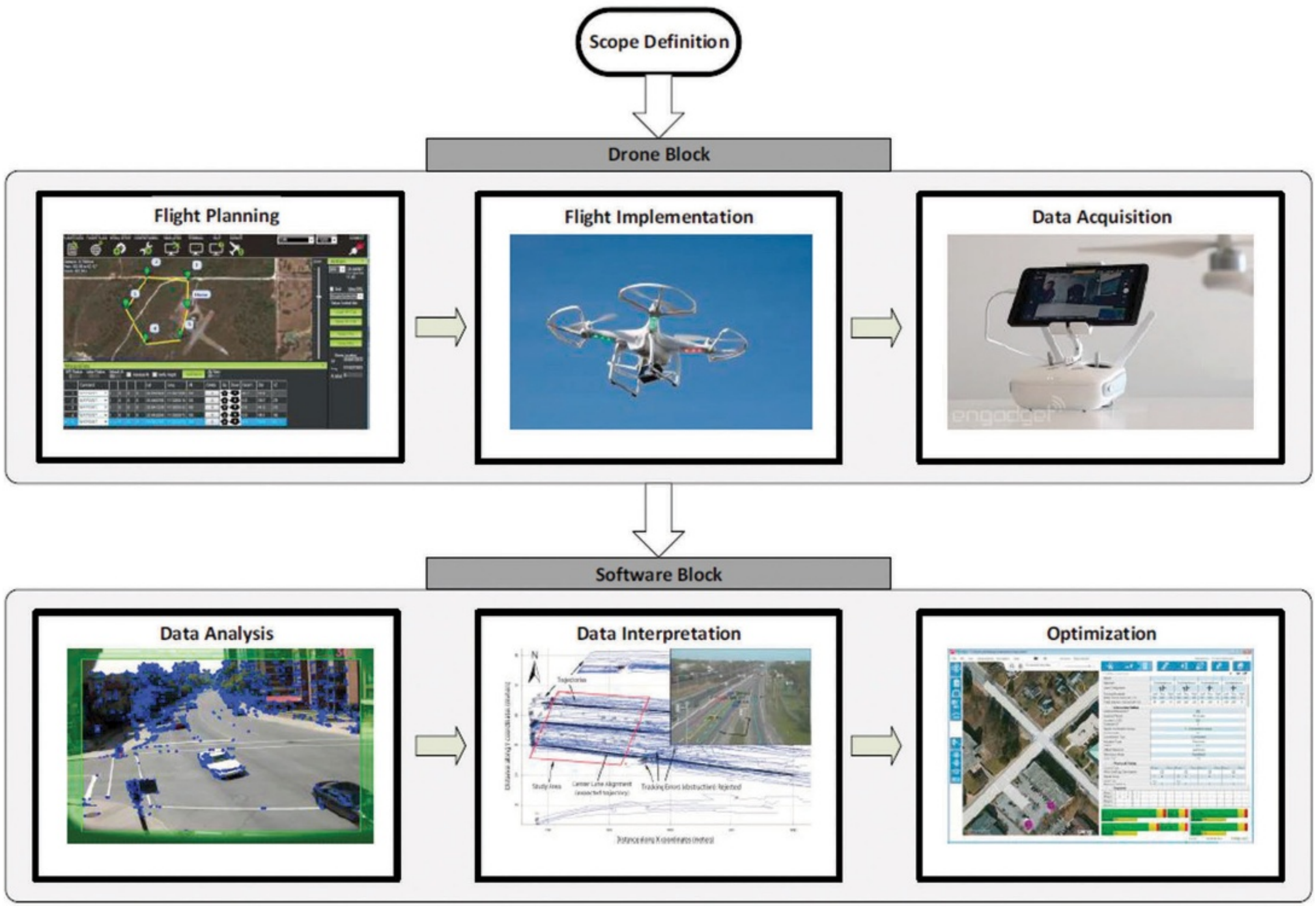


Figure 1. The proposed framework[9]

SIGN	CHECK IF	YES	NO	COMMENTS
DO NOT ENTER	At least one present			
	In good condition			
WRONG WAY	At least one present			
	In good condition			
ONE WAY	Present at location for cross under/over traffic			
	NO RIGHT TURN			
	NO LEFT TURN			
	NO U-TURN			

PAVEMENT MARKNG	CHECK IF	YES	NO	COMMENTS
WRONG-WAY ARROWS	Present			
	Pieces in good condition			
Other Markings	Elephant tracks (turning guide line			
	Stopping lines at end of exit ramp			

GEOMETRC DESIGN FEATURES	CHECK IF	YES	NO	COMMENTS
Raised Curb Median on the crossroad	Present			
	Present			
	Present			
Design to Discourage Wrong-Way Entry	Present			

Figure 2. A sample of wrong-way entry checklist.

limitations. During this time, the pilot must also ensure that weather conditions are suitable for flying and that all visual and time of day regulations are met. Considering all of these factors, we selected two interchanges in the state of New Jersey for further evaluation as shown in Table 1.

Regarding the safety aspect, we assessed these two locations to assure there were no additional airspace limitations specified by the FAA. The airspace above the area of operation for both sites was class G, with no current temporary flight restrictions (TFRs) or other limitation. Moreover, we obtained the necessary permit and documentation from the concerned departments (e.g., Rutgers University) to operate the UAV from their property. As for the environmental aspect, we considered the conditions of weather and the wind in the study locations and gathered the detailed information about the site characteristics such as trees, traffic flow, etc. We note that we conducted the flight at noon to minimize the effects of shadows which resulted in a higher quality of data. Concerning the route planning, we used a tool to mark the waypoints on the map that can then be uploaded into the UAV for an automatic operation.

Flight Implementation

The flight implementation stage is where we conduct the UAV flight over the study area. Depending on the characteristics of the operation, flights can be conducted manually or autonomously (so long as the pilot in command has the ability to regain manual control).[9] In this study, we concluded that due to the risk of overhead wires, utility poles, roadside foliage, and vehicular traffic that this flight should be conducted with manual controls. Altitude, distance from the operator, UAV stability, and ground vehicle traffic was monitored by both the pilot and visual observer during the operation to minimize risk to the operators and non-participants.

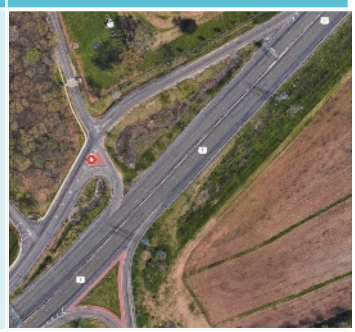
Data Acquisition

Data acquisition is another critical stage in the identified framework and is heavily dependent on the scope of work specified in the first step.[9] Standard acquired data from UAVs can consist of photogrammetry, video, and other data types from various sensors including infrared and thermal. Based on the scope of work and requirements, data acquisition can be performed online, in real-time, or offline, at the office. As in many other studies, this study has also completed the flight operations and then proceeded with collected data including photos and video captured by the UAV.

Data Processing and Analysis

Based on the previous studies, the processing and analysis of data captured by the UAVs can be carried out, implementing semi-automated video analysis and fully automated video analysis.[9] The former is a straightforward approach with a high level of accuracy without any sophisticated image processing algorithm, whereas

Table 1. Study Interchange Types and Locations.

Interchange			Aerial Photography
Number	Type	Location	
1	Modified Diamond	U.S. 1/ College Farm Rd.	
2	Partial Cloverleaf	U.S. 18/ Davidson Rd.	

the latter uses the advanced image processing algorithms, which require high computational power and video coding experts and is more suitable for real-time traffic monitoring.[9] For the purpose of this study, we employed the first approach to obtain the desired results with the highest accuracy and reliability.

Data Interpretation/Traffic Applications

Following data processing and analysis, we need to interpret the processed picture and video data by creating tables, charts, and graphs. This step is much related to the scope of work.[9] Based on the results obtained from the previous step, we produced a table that included the list of features associated with an exit-ramp terminal concerning signs, pavement markings, and geometric design features. This included the useful information for state and local agencies to monitor the interchanges and collects required data to reduce the frequency and severity of WWD crashes.

Results and Discussions

As discussed earlier, we surveyed two interchanges in the state of New Jersey using a DJI Phantom 4. Figure 3 shows samples of pictures captured by the UAV. The research team recorded the time spent in each step described in the previous section. Defining the scope of work and flight planning, and conducting flight operations took one hour per location for a team of two researchers, one as a pilot. The Phantom 4 has a built in 12.4-megapixel camera, capable of collecting high-quality photo and video data. The image files contained both digital photos and global positioning system (GPS) locations for the interchanges. The images could be easily imported into other tools such as ArcGIS or AutoCAD for further data reduction process.

For this study, we first identified a list of common features associated with exit-ramp terminals concerning WWD crashes as listed in Figure 2. As for the signing, we specifically evaluated the presence and condition of signs including DO NOT ENTER, WRONG WAY, ONE WAY, NO RIGHT TURN, NO LEFT TURN, NO U-TURN, KEEP RIGHT, and MEDIAN AHEAD road signs. Regarding the pavement markings, we assessed the presence and condition of Wrong-Way Arrow signs, and other markings such as elephant track and the stopping line at the end of the exit ramp. For the geometric design features, we explored the presence of raised curb median or channelizing islands, and any other design features to discourage wrong-way entry. Figures 4 and 5 illustrate the completed wrong-way entry checklists for two study interchanges. At interchange #1, there are no wrong-way arrows, other markings (e.g., elephant tracks and stopping lines at the end of exit ramp), and design features (e.g., raised curb median) to prevent vehicles from entering to the exit ramps. Similarly, at interchange #2, there is no DO NOT ENTER sign and other markings (e.g., elephant tracks), and design features (e.g., raised curb median) to stop vehicles from entering into the exit ramps.

Figure 3. A sample of pictures captured by the UAV.

SIGN	CHECK IF	YES	NO	COMMENTS
DO NOT ENTER	At least one present	√		Without a strip of retroreflective material Angel of visibility is poor
	In good condition	√		
WRONG WAY	At least one present	√		Without a strip of retroreflective material
	In good condition	√		
ONE WAY	Present at location for cross under/over traffic	√		Without a strip of retroreflective material Angel of visibility is poor
	NO RIGHT TURN		x	
	NO LEFT TURN	√		Without a strip of retroreflective material
	NO U-TURN		x	

PAVEMENT MARKNG	CHECK IF	YES	NO	COMMENTS
WRONG-WAY ARROWS	Present		x	No pavement marking
	Pieces in good condition		x	
Other Markings	Elephant tracks (turning guide line		x	
	Stopping lines at end of exit ramp		x	

GEOMETRC DESIGN FEATURES	CHECK IF	YES	NO	COMMENTS
Raised Curb Median on the crossroad	Present		x	left trun is easy to do
	Present		x	
	Present		x	
Design to Discourage Wrong-Way Entry	Present		x	

Figure 4. Wrong-way entry checklist for interchange #1 (US 1/College Farm Rd.).

SIGN	CHECK IF	YES	NO	COMMENTS
DO NOT ENTER	At least one present		x	
	In good condition		x	
WRONG WAY	At least one present	√		Without a strip of retroreflective material
	In good condition	√		
ONE WAY	Present at location for cross under/over traffic		x	
	NO RIGHT TURN		x	
	NO LEFT TURN		x	
	NO U-TURN	√		Without a strip of retroreflective material

PAVEMENT MARKNG	CHECK IF	YES	NO	COMMENTS
WRONG-WAY ARROWS	Present		x	
	Pieces in good condition		x	
Other Markings	Elephant tracks (turning guide line		x	
	Stopping lines at end of exit ramp	√		

GEOMETRC DESIGN FEATURES	CHECK IF	YES	NO	COMMENTS
Raised Curb Median on the crossroad	Present		x	
	Present		x	
	Present	√		
Design to Discourage Wrong-Way Entry	Present		x	

Figure 5. Wrong-way entry checklist for interchange #2 (US 18/Davidson Rd.).

We note that this process takes 30 minutes for each interchange. Depending on the intersection geometry and number of assets, the UAS was air-born for a total of 5–10 minutes per flight. Based on our results, the UAV has the capability to collect high-quality data faster and smarter to inspect, inventory, and monitor interchange assets concerning the WWD crashes. Moreover, UAV can fly toward the opposite direction of the exit ramp to collect required data. Implementing UAV also can mitigate the risks of an on-the-ground field study by reducing the exposure of data collection crews to traffic hazards.

Conclusions and Recommendations

This study utilizes the rapidly emerging UAV technology to tackle some of the national challenges associated with wrong way events. To be specific, this study is the first to explore the application of UAVs to inspect, inventory, and monitor interchange assets about WWD crashes, with the aim of reducing this type of crash. Several past studies have found that exit-ramp terminals are the most common WWD entry points. Moreover, past studies reported a number of typical issues related to the high WWD crash-prone locations. These issues include inadequate or missing traffic control devices, poor location or placement of these devices, insufficient conspicuity of signs and pavement markings, and layout of interchange or intersection.

To mitigate the severity and frequency of WWD crashes, state DOTs and local agencies have been implementing many various safety countermeasures. We note that to develop effective safety recommendations, there is a need to conduct an extensive field review and investigation of multiple years of crash data. However, a field survey is not only time-consuming and labor-intensive, but also exposes work crews to traffic hazards. Drones equipped with high-quality cameras, on the other hand, can collect high-quality data faster, safer, smarter, and more precisely. Our research results proved that UAV could inspect, inventory, and monitor interchange assets to gather information on features associated with WWD crashes. This technology can also complement and improve the traditional on-the-ground surveys.

The findings of this study will have significant implications for state DOTs and local agencies to achieve the *Toward Zero Deaths* vision through reducing WWD crashes, in particular for those in which WWD has been found to be a major concern. It should be noted that although this study represents one of the early attempts to evaluate the application of UAVs for interchanges assets, concerning WWD crashes, conducting more research on the technological advances of UAVs would be desirable. Future inclusion of a larger number of test locations will also help increase the sample size and facilitate the development of recommendations. Given the rapid pace of deploying UAVs in transportation applications and ongoing policies, rules, and developments related to UAVs, it can be expected that the UAVs technology could help alleviate the WWD issues in the future. **itej**

References

1. Zhou, H., M. Pour-Rouholamin, and M. Jalayer. Emerging Safety Countermeasures for Wrong-way Driving. *Final Report Submitted to the American Traffic Safety Services Association (ATSSA)*, 2014.
2. National Highway Traffic Safety Administration (NHTSA). *Fatality Analysis Reporting System (FARS)*. Washington, DC, www-fars.nhtsa.dot.gov/main/index.aspx. Accessed Feb. 15, 2017.
3. Jalayer, M., H. Zhou, and B. Zhang. Evaluation of Navigation Performances of GPS Devices near Interchange Area Pertaining to Wrong-Way Driving. *Journal of Traffic and Transportation Engineering (English Edition)*, doi: 10.1016/j.jtte.2016.07.003.
4. Morena D. A. and T. J. Leix. Where These Drivers Went Wrong. *Public Roads*, Vol. 75, No. 6, 2012, pp. 33–41.
5. Zhou, H. and M. Pour-Rouholamin. *Guidelines for Reducing Wrong-Way Driving Crashes on Freeways.* Publication FHWA-ICT-14-010. FHWA, U.S. Department of Transportation, 2014.
6. American Association of State Highway and Transportation Officials (AASHTO). *State DOTs Using Drones to Improve Safety, Collect Data, and Cut Costs*. Washington, DC www.aashtojournal.org/Pages/NewsReleaseDetail.aspx?NewsReleaseID=1466. Accessed Feb. 15, 2017.
7. Barmpounakis, E. N., E. I. Vlahogianni, J. C. Golias. Extracting kinematic characteristics from unmanned aerial vehicles. In *Transportation Research Board 95th Annual Meeting,* No. 16-3429, Washington, DC, 2016.
8. Kanistras, K., G. Martins, M. J. Rutherford, and K. P. Valavanis. Survey of unmanned aerial vehicles (UAVs) for traffic monitoring. *Handbook of Unmanned Aerial Vehicles,* 2015, pp. 2643–2666.
9. Khan, M. A., W. Ectors, T. Bellemans, D. Janssens, and G. Wets. UAV-Based Traffic Analysis: A Universal Guiding Framework Based on Literature Survey. *Transportation Research Procedia*, Vol. 22, 2017, pp. 541–550.

Mohammad Jalayer, Ph.D. (M) *is an assistant professor in the department of Civil and Environmental Engineering at Rowan University, NJ, USA. He received a doctorate in civil engineering from Auburn University in 2016. Over the past couple of years, Dr. Jalayer has led various research projects related to traffic safety and operations. His main research interests include highway safety and crash modeling, traffic operations and evaluation, and intelligent transportation systems.*

Michael O'Connell *is a research associate with the Center for Advanced Infrastructure & Transportation (CAIT) at Rutgers, The State University of New Jersey. He has been a part of both the Transportation Safety and UAS programs for more than five years. Michael performs high-level safety data analysis and assessments for a wide variety of projects. He is a licensed UAS pilot and has acted as pilot-in-command for a multitude of flight operations on behalf of the Center. He provides technical guidance to the University regarding UAS activities, and is well versed in federal regulations and guidelines.*

Huaguo Zhou, P.E., Ph.D. (F) *is a professor in the Department of Civil Engineering of Auburn University, Auburn, AL, USA. Dr. Zhou has more than 20 years of transportation research experience, with a specialty in highway geometric design, access management, and traffic safety. Over the last 10 years, he has led 10 different research projects on development of low-cost and advanced countermeasures to reduce wrong-way driving crashes. Currently, he is a member of the Transportation Research Board access management and traffic control devices committees.*

Patrick Szary, Ph.D. (M) *is the associate director for the Center for Advanced Infrastructure & Transportation (CAIT) at Rutgers, The State University of New Jersey. As PI/Co-PI he has generated more than $30M in funding for CAIT which was established in 1998 and is a part of the U.S. Department of Transportation (USDOT) University Transportation Centers (UTC) program. He has been an integral part of CAIT since its inception as a USDOT Tier I UTC in 1998 and through his leadership CAIT recently won the prestigious 2018 Region 2 UTC. He has been instrumental in making the Center a stable resource in the dynamic and ever-changing NY/NJ metropolitan area. He has oriented the Center to align the research topics and themes to ensure that they are in tune with stakeholders' needs and objectives. Safety, intelligent transportation systems, and UAS for infrastructure inspection are some topics of immediate interest.*

Subasish Das, Ph.D. (M) *is an associate transportation researcher with Texas A&M Transportation Institute in College Station, TX, USA. His major areas of expertise include statistical analysis and machine learning with an emphasis in transportation safety and operations, spatial analysis with web GIS tools, interactive data visualization, and deep learning for CV/AV technologies. Subasish completed his M.S. and Ph.D. in Civil Engineering from the University of Louisiana at Lafayette, and he is an Eno Fellow.*