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Validation of Visibility Data from Road Weather Information Systems by Comparing Three Data Resources: Case Study in Ohio

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Abstract**—**Adverse weather conditions, particularly those with low visibility, are critical to the driving tasks. However, the direct relationship between visibility distances and traffic flow/roadway safety is uncertain due to the limitation of visibility data availability. The recent growth of deployment of Road Weather Information Systems (RWIS) makes segment-specific visibility information available which can be integrated with other Intelligent Transportation System, such as automated warning system and variable speed limit, to improve mobility and safety. Before applying the RWIS visibility measurements in traffic study and operations, it is critical to validate the data. Therefore, an attempt was made in the paper to examine the validity and viability of RWIS visibility data by comparing visibility measurements among RWIS, airport weather stations, and weather information recorded by police in crash reports, based on Ohio data. The results indicated that RWIS visibility measurements were significantly different from airport visibility data in Ohio, but no conclusion regarding the reliability of RWIS visibility could be drawn in the consideration of no verified ground truth in the comparisons. It was suggested that more objective methods are needed to validate the RWIS visibility measurements, such as continuous in-field measurements associated with various weather events using calibrated visibility sensors.

Keywords**—**Low visibility, RWIS, traffic safety, visibility.

I. Introduction

ADVERSE weather including rain, snow, fog, etc. has big impacts on driver capabilities, traffic flow, crash risk, and fuel consumption. In inclement weather, roadway mobility will be reduced with decreased roadway capacity, lower vehicle speed, and increased traffic delay. It was found by a previous study that adverse weather reduced arterial traffic volume and speed by up to 30% and 40% respectively, and increased travel time delay up to 50% depending on road weather conditions and time of day [1]. As one of the main contributing factors to traffic crashes, adverse weather leads to millions of injuries and fatalities on roads worldwide. In U.S., the national statistics show that 24% of the total roadway crashes occurring from 1995 to 2008 are related to weather [2].

Particularly, the inclement weather types affecting visibility such as fog/smoke, heavy rain/snow, and blowing sand/soil/dirt are challenging to drivers whose vision can be impaired, and decision-making can be compromised. Though a large amount of studies has been dedicated to investigating the effects of weather characteristics on traffic flow and road safety [3], [4], few studies have explored the direct relationship between visibility and traffic flow/roadway safety due to the limited visibility data.

In a study exploring the weather impacts on traffic flow in three cities in U.S., rain and snow were found to reduce traffic free-flow speed and speed-at-capacity up to 10% when visibility dropped from 4.8 to 0 km (3.0 to 0 mi) [4]. By studying the relationship between weather and roadway capacity on a rural interstate highway in Idaho, it was found that 1 km (0.625 mi) was the critical visibility on traffic speed: when visibility distance was greater than that, speeds kept constant; speed started to decrease with visibility when visibility distance was below that [5].

In terms of the safety impact of visibility, due to the limited visibility measurements, most existing research has focused on studying crashes occurring under a specific low visibility weather circumstance, mainly fog and rain [6]-[9]. According to a review conducted by Theofilatos and Yannis [3], low visibility had generally indicated a consistently positive relationship with road crash frequency, but the impact of visibility on crash severity was not straightforward. A Netherlands's safety fact sheet contended that low visibility resulted in lower speeds but shorter car following distances which could overpower the reduced speed and increase crash risk accordingly [10]. Meanwhile, it was concluded by two studies that low visibility increased crash severity [6], [11]. Another study however pointed out that drivers intended to be slower and more cautious in low visibility conditions, resulting in reduced crash severity when a crash occurred [12]. Apparently, additional research is needed regarding the effects of low visibility on crashes, especially the direct relationship between visibility distance and crash regardless the weather type.

Accordingly, in order to improve traffic performance and roadway safety, access control and speed limit control are the most common treatments for low visibility roadway conditions. Low visibility warning system (LVWS) and variable speed limit (VSL) systems have been implemented on some roadway segments and found a reduction in the traffic speed and speed variance which resulted in the reduction of crash risk [8]. However, the systems have not been systematically or widely implemented due to the limited visibility data resources. Meanwhile, no research has been found on the guidance of traffic management in reduced visibility condition. In some states of U.S., such as California,

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Florida, Utah, South Carolina, Alabama and Tennessee, operators at traffic management centers may control traffic by displaying warning messages on dynamic message signs, or altering speed limit with VSL signs or highway advisory radio when visibility goes low. Yet, there is no consistent threshold of low visibility used in those LVWSs. According to the two syntheses of current LVWSs, the thresholds of low visibility vary between 500 and 1,320 ft. (152 and 402 m) [13], [14]. Therefore, a guidance about how to choose the low visibility threshold is needed, which has to be supported by reliable real-time visibility measurements.

The recent growth of deployment of real-time monitoring technology for traffic and weather provides a new possibility of assessing and managing traffic performance and crash risk in real-time on roadways. U.S. Department of Transportation identified six high-priority connected vehicle road weather applications which will fundamentally change how the traffic management and operations conduct in adverse weather including reduced visibility condition [15]. Apparently, the reliability of the data resources will play a significant role in such applications. This paper attempts to validate visibility measurements from a growing real-time weather monitoring system: RWIS, by comparing the visibility measurements from all potential data sources in Ohio where more RWIS stations have been installed along roadway than other states in U.S.

II. Description of Visibility Data Resources

Currently, there are two main resources of real-time visibility measurements: weather stations at airports, and RWIS near highways. Meanwhile, weather categories including those low visibility types are recorded by police in crash reports. See more details in Fig. 1.

A. Source 1: Airport Weather Station

Weather data including visibility are generated by Automated Weather/Surface Observing System (AWOS/ ASOS) sensors at regional airports. AWOS/ASOS is a multi-sensor system installed at more than 900 airports across the states to measure wind speed and direction, temperature, dew point, cloud coverage, visibility, precipitation, and even barometric pressure [16]. The weather information collected from AWOS/ASOS is used by pilots and airport-based weather personnel. There are 33 airport weather stations in Ohio, as shown in Fig. 2. The current reportable visibility distances from airport weather stations in statute miles are: <0.25, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.5, 3, 4, 5, 6, 7, 8, 9, 10+ [16].

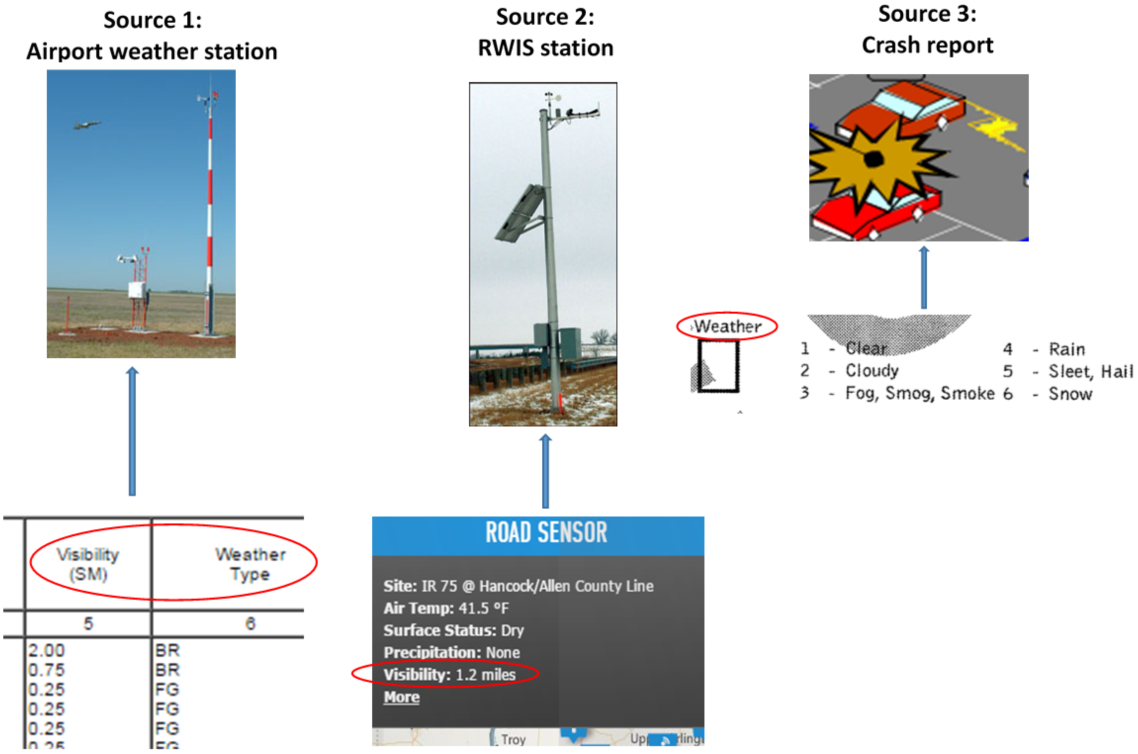

Fig. 1 Three potential resources of visibility data

B. Source 2: RWIS Station

RWIS is a combination of technologies to collect, transmit, process, and disseminate information about weather conditions on or near roadway. An environmental sensor station (ESS) is the field component of RWIS measuring pavement and meteorological conditions, with sensors either embedded in the road or on nearby towers placed at the roadside [17]. Those sensors can usually measure atmospheric data including air temperature, pavement temperature and condition, wind speed and direction, precipitation rate and type, humidity, and visibility distance.

Ohio Department of Transportation (ODOT) currently operates about 180 ESSs across all major highway corridors throughout the state. Comparing to 33 airport weather stations in Ohio, RWIS can definitely cover more roadway areas in Ohio, shown in Fig. 2. Ohio's RWIS is currently not configured to alert low visibility situations and guide a VSL strategy, but it is capable of detecting present weather conditions including visibility distances. Each RWIS site can report visibility distance up to 1770 or 2000 m (1.1 or 1.2 mi).

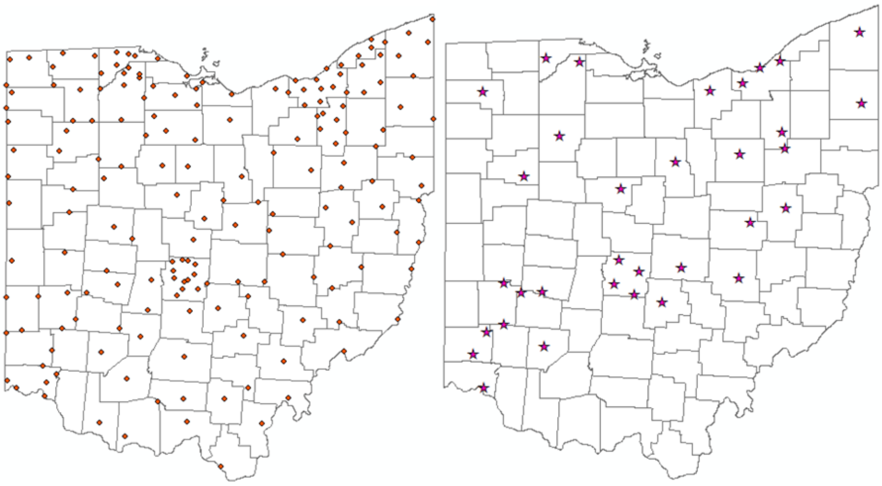

Fig. 2 Location of 179 RWIS stations (left) and 33 airport weather stations (right) in Ohio

C. Source 3: Crash Report

In the police-recorded crash reports, weather information at the time of a crash was coded into one of some categories such as clear, cloudy, fog/smog/smoke, rain, snow, and etc. shown in Fig. 1. Though there is no direct visibility information in crash reports, it is reasonable to assume that fog-related crashes occurred in low visibility conditions, which might not be able to extend to other adverse weather conditions such as snow or rain. Therefore, fog-related crashes can be extracted to compare with the visibility measurements from the nearby weather stations at the crash occurring time.

III. Data Description and Preparation

In this study, with the extensive use of spatial techniques, three visibility datasets were integrated. As there is no confirmed ground truth of the three visibility data resources, a paired comparison was conducted to check how the visibility data among the three resources match to each other. The result might be able to shed some light on the feasibility and reliability of the three data resources in traffic study and operations.

The flow chart in Fig. 3 illustrates the process of data preparation and assembly. As the first step of the processing procedure, ESSs were matched with a nearby regional airport in the geographic information system (GIS) so that the data generated by the airport visibility sensors can be compared to the visibility measurements from RWIS stations. The distances between airport weather stations and their closest ESS are from 1 to 13.8 mi (1.6 to 22.2 km) in Ohio, with the average distance of 5.3 mi (8.5 km). A specific buffer size was used to compare the visibility measurements from RWIS and airport stations, which will be further discussed later.

Five years (from 2009 to 2013) of visibility measurements from RWIS and airport weather stations were used for analysis, excluding those invalid or suspicious measurements. Between 2009 and 2013, at least 36 ESSs in Ohio were not taking visibility measurements, and some measurements were questionable with readings out of the detection range, such as those negative visibility readings and visibility values larger than 2,000 m (1.2 mi). Meanwhile, by checking the 5-year airport visibility measurements, no disabled visibility sensors have been found at airport sites, but there were some unreasonable measurements such as those values larger than 32,767 m (20 mi) which is the detection limits for the visibility sensors at airport weather stations. The unreasonable measurements were deleted from the dataset for analysis. Unfortunately, the false visibility readings within the normal detection range, if any, are unable to be captured without conducting the visibility sensor calibration. Those false or inaccurate measurements might be caused by the influence of dirt or salt, lack of maintenance or some other technical malfunctions. Furthermore, police reported crashes during the same 5-year period were used as the third visibility data resource. The statewide fog-related crashes in the state highway system (i.e., Interstate, US Route and State Route highways) were collected from Ohio Department of Public Safety. Crash data within state highway boundary (no more than 32 m or 105 ft. away from the centerline of roadways, according to the method that ODOT uses to clean the crash data) were first extracted in GIS by locating crashes with their longitudinal and latitudinal coordinates in the shapefile of Ohio state highways. In order to verify the consistency of airport/RWIS visibility data with the weather information recorded in crash reports, fog-related crashes within the vicinity (no farther than 3 mi or 4.8 km) of airport or RWIS weather stations were extracted and matched with visibility measurements of closest time right before the occurring of crash (no longer than 30 minutes). Matching rates of fog-related crashes were compared between airport and RWIS datasets. Furthermore, common crashes within the vicinity of both airport weather station and ESS were extracted, and the consistency of all the three visibility resources was investigated.

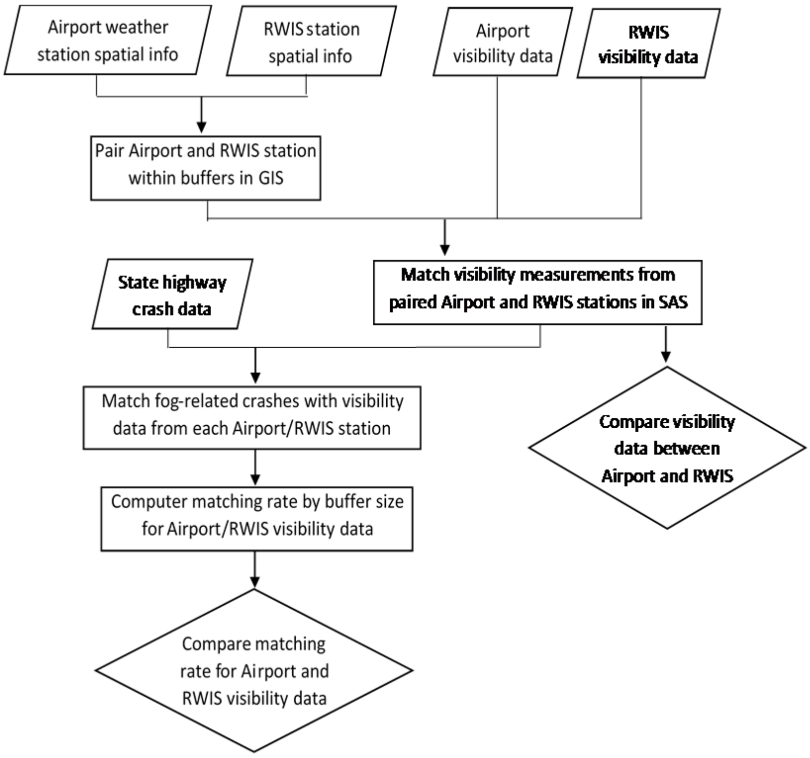

Fig. 3 Flow chart of data processing

IV. Comparison of Three Visibility Resources

As addressed in Fig. 3, after integrating and assembling the large datasets in GIS and SAS, two sets of comparison were conducted in the study, which include the direct comparison between visibility measurements from RWIS and airport weather stations, and matching rate comparison of fog-related crashes for RWIS and airport visibility data.

A. Comparison between RWIS and Airport Visibility Measurements

Visibility distances measured from an ESS and nearby airport weather station at the same time were paired and compared using the cleaned-up five-year visibility measurements. Due to the different detection range of RWIS visibility sensors (up to 2,000 m or1.2 mi) and those at airport weather stations (up to 32,767 m or 20 mi), it was not surprising that the visibility distances from two resources were significantly different from each other at the significance level of 5% according to a t-test. However, we are more interested in reduced visibility conditions for roadways instead of those clear weather conditions with sufficient visibility distances. Therefore, visibility measurements lower than 2,000 meters (1.2 miles) were extracted for comparison to avoid the different detection range issue.

By running a t-test for reduced data, it was found the visibility measurements were still significantly different from paired RWIS and airport weather stations at the 5% significance level. The result is not surprising as visibility measurements from RWIS and airport visibility sensors are reported in different format with various ranges. For RWIS, visibility sensors report visibility as integers in meter, but visibility distances are reported as a number representing a range. For instance, any visibility between 0 and 0.25 mi (0 and 402 m) is reported as 0. In addition, visibility measurements from airport weather stations could not be treated as ground truth without validation. Therefore, this result basically cannot prove anything regarding the reliability of the RWIS visibility measurements.

B. Comparison of Visibility Measurements for Fog-Related Crashes

As no solid conclusion can be drawn by the direct comparison of visibility measurement from RWIS and airport weather stations with the concern of different detection range and reporting format of both stations, another visibility data resource (i.e., weather information recorded in crash reports) was introduced for analysis. RWIS and airport visibility measurements were further compared to weather records in crash reports.

The analysis started with the verification of how well the police coded fog information matched RWIS and airport visibility measurements. Matching rates by various buffer sizes (shown in Fig. 4) were calculated for the fog-related crashes which occurred on the adjacent highways.

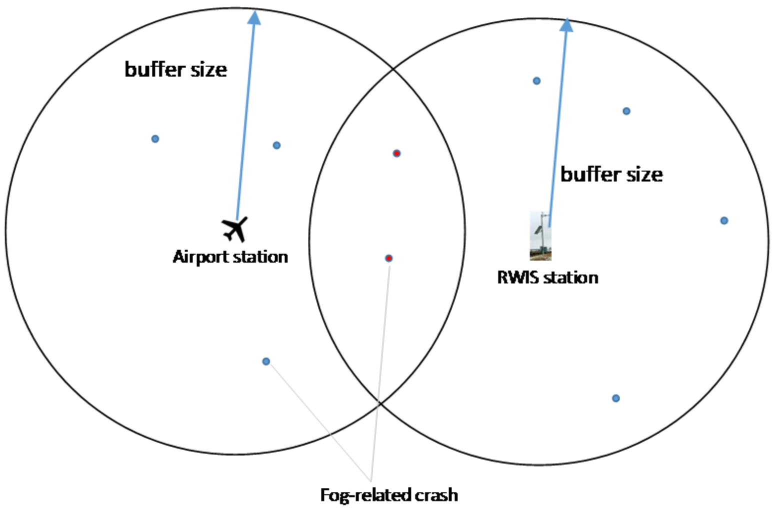

Fig. 4 Link fog-related crashes to weather stations by buffer sizes

TABLE I
MATCHING RATES OF FOG-RELATED CRASHES BY BUFFER SIZES FOR RWIS AND AIRPORT VISIBILITY DATA IN OHIO

buffer size (mile)	fog crashes within buffer	matched	not matched [a]	Matching rate
Airport				
0.5	1	0	1	0%
1	3	1	2	33%
1.5	16	6	10	38%
2	32	8	24	25%
2.5	46	12	34	26%
3	62	17	45	27%
RWIS				
0.5	30	10	20	33%
1	65	18	47	28%
1.5	94	24	70	26%
2	145	40	105	28%
2.5	187	54	133	29%
3	242	71	171	29%

[a] "not matched" means visibility measurements from weather stations were not lower than the assumed threshold of fog (i.e., 1 km or 0.62 mi).

Matching rate refers to the percentage of recorded fog-related crashes within a specific buffer size of weather stations (i.e., airport or RWIS weather stations), matching with the visibility data from visibility sensors at the crash time. More details of matching rates can be found in [8]. In order to link the fog information to visibility measurements, the meteorological definition of fog was used: fog was defined based on visibility distance less than 1 km (0.62 mi) [18]. Therefore, weather records with visibility distance less than 1 km (0.62 mile) were categorized as foggy condition for RWIS and airport visibility data in the study.

Based on a previous study using airport visibility data, the matching rate decreased with the increased buffer size as weather information is more reliable for locations closer to a weather station [8]. Therefore, small buffer size between 0.5 and 3 mi (805 and 4,828 m) radius was studied for fog-related crash matching rate and the results are shown in Table I. It indicates that matching rates are around 30% for all buffer sizes no larger than 3 mi, except for the buffer size of 0.5 mi for airport visibility data due to the limited sample size (only one fog-related crash within the buffer). The low matching rates of both RWIS and airport visibility data in Ohio lead to the concern of weather coding in crash database. It was pointed out before that recorded weather conditions may not be accurate [19], [20]. As shown in Table I, the matching rates for fog-related crashes in Ohio are low even for small buffer sizes, and surprisingly there is no obvious change of matching rates with buffer size. Therefore, it is likely that a large portion of weather information was recorded inaccurately in crash database which overrode the effects of buffer size on matching rates. However, even there exist some doubts regarding the accuracy of police-recorded weather information in crash reports, we cannot exclude concerns of the accuracy and reliability of visibility measurements from RWIS and airport weather stations. The comparison of visibility measurements among three data resources cannot prove the reliability of RWIS visibility measurements. More objective methods are needed to valid the RWIS visibility measurements, such as continuous in-field measurements associated with various weather events. Without validating the reliability of RWIS visibility measurements, no further study or application involving visibility data should be conducted.

V. CONCLUSION

Having more stations than most of the states in U.S., Ohio's

RWIS is currently not configured to alert low visibility situations and guide a VSL strategy though it is capable of detecting real-time visibility distances along state highways. Therefore, in recognition of the need for better use of weather data from widely deployed RWIS in Ohio to mitigate the hazards of low visibility related crashes and improve the traffic operation performance, the paper attempted to validate the RWIS visibility data by comparing them to the airport weather measurements, as well as the weather information recorded in police-recorded crash reports.

By comparing visibility distances measured from paired RWIS and airport weather stations, as well as visibility measurements from RWIS and airport weather stations for police-recorded fog-related crashes, it was unable to reach any solid conclusion regarding the reliability of RWIS visibility data. The RWIS visibility measurements were found to be significantly different from airport station measurements, but it does not necessarily mean that RWIS visibility data are not reliable due to two reasons: (1) RWIS and airport weather stations report visibility differently and they are hard to be compared directly; (2) airport visibility data cannot be treated as the ground truth without validation. Meanwhile, the introduction of weather information from crash reports did not seem to help draw a conclusion of the RWIS data reliability in the study. Instead, it brought some doubts regarding the accuracy of police-recorded weather information in crash reports. Therefore, comparing various visibility data resources to check RWIS data reliability might not be a good way to go if no data resource can be confirmed as the ground truth. It is suggested to use more objective methods to valid the RWIS visibility measurements, such as continuous in-field measurements associated with various weather events using calibrated visibility sensors. Overall, no matter which method is to be used for visibility data validation, no further study or application involving RWIS visibility data should be conducted unless the reliability of RWIS visibility measurements is verified.

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