Provisioning Road Weather Management using Edge Cloud and Connected and Autonomous Vehicles

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***Abstract*—The adverse weather conditions and unforeseen road surface may negatively affect driving safety. To provide better roadway safety and mobility, Road Weather Information System (RWIS) have been implemented. The performance of the existing RWIS can be improved using various emerging technologies such as connected vehicle technologies and edge cloud computing. This paper presents development of a cost-effective and resource-efficient road weather management system using edge cloud and connected vehicle technologies, as well as deployment of fuzzy inference system as road weather hazard assessment means.**

***Index Terms*—Edge computing, V2I communications, Connected and Autonomous vehicles, Road weather management**

I. Introduction

The adverse weather conditions and unforeseen road surface may negatively affect driving safety. For instance, snow or ice on roads reduces friction and foggy condition reduces visibility. These conditions affect not only surface friction, and road infrastructure, but also vehicle performance, and driver behavior, thereby increasing the risk of accidents.

In order to provide better roadway safety and mobility, Road Weather Information System (RWIS) [1] have been implemented. Mainly, RWIS provides information about snowy or icy road surface for both drivers and road maintenance units. Typically, in the RWIS, Environmental Sensor Stations (ESS) are deployed to collect road weather observations such as surface condition and surface temperature, in the vicinity. However, if adverse road weather conditions such as black ice or dense fog occur between ESSs, these conditions may still cause accidents and injuries, and decrease traffic speed and roadway capacity.

To address this issue, weather data collected by connected vehicles (CVs) on the roadways, especially between fixed ESSs, may be used to provide more robust road weather information and forecasting, which shall allow drivers for better decision making and enhanced safety. Such a vehicle infrastructure integration, which involves vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, has a potential not only to facilitate improvement in the accuracy and timeliness of road weather information but also to assist in the reduction of weather-related accidents on the roadways [2], [3].

One of the roadway hazard alert systems is Pikalert system [4] that utilizes mobile observations along with surface observations to provide near-term forecast indicating existing weather hazards along routes. For instance, Vehicle Data Translator (VDT) creates near real-time and forecasted weather and road conditions information for a specific segment.

However, there are limited works that characterize the performance of Connected and Autonmous Vehicles (CAVs) under adverse weather conditions [5]. As CAVs have abundant sensing capabilities, they can provide various road weather observations. Thus, CAV technology [3], [5] is pertinent to address numerous safety and mobility impacts of adverse weather conditions. And accurate real-time road weather data would enable safe decision control processes for CAVs.

Furthermore, most of the road weather systems are constructed taking into account the use of cloud computing platform. For instance, the paper presents a real-time road condition monitoring system using the cloud server [6]. Even though analyzing data at the cloud could be desired [7], due to the high bandwidth or low latency requirements, it may be cost-effective to process some data at the edge cloud [8] and to transmit only relevant results to the back-end cloud servers.

This paper presents development of a cost-effective and resource-efficient road weather management system using edge cloud and connected vehicle technologies not only to alert the CAVs about the road conditions in real time but also to provide them fast response if the road conditions change on their routes. It also highlights a cost-effective solution for road weather hazard assessment using a fuzzy inference system [1] that can provide yearned alert messages.

The rest of this paper is organized as follows. Section II highlights backgrounds. Section III presents the proposed System Architecture, while System Impementation is depicted in section IV. Section V concludes the paper.

II. BACKGROUNDS

A. Road weather management

An inclement weather may have a huge impact on road accidents and fatalities. For instance, road weather hazards such as snow, ice and heavy rain can make the road surface unsafe for drivers and can cause major traffic problems along a route. It can be observed that reduced skid resistance and low visibility may be major factors for such consequences in the adverse road weather conditions.

Recent days, intelligent transportation systems are widely used for transportation safety and drivers' comfort. In particular, Road weather management (RWM), which can collect, process, and broadcast road weather and condition information, is intended to improve traffic mobility and safety by alleviating the impacts of adverse weather on the surface transportation system.

Typically, road weather data collections can be achieved with various means including RWIS fixed ESS, and mobile ESSs.

Having a set of specialized sensors, the RWIS ESS can collect and transmit real-time localized road weather data. The RWIS ESS can monitor the road and collect observations such as surface temperature and surface condition in real time. Since these RWIS ESS are fixed, they can provide point data only.

A critical component in the RWM would be incorporating probe vehicle data (PVD), which are factually sensor data from connected vehicles (CV). With the possibility of collecting road weather information from connected vehicles equipped probe vehicles, RWM could smartly include mobile weather sources that would not only immensely improve the ability to detect and forecast road weather and surface conditions, but also provide the capability to manage road weather response on specific roadway links. Hence, such CV technologies have the appealing potential to transform overall RWM. In recent days, data elements collected by vehicles can be classified as Mobile ESS.

Thus Mobile ESSs can be considered as advanced, vehicle-based technologies to collect, transmit, and use road weather condition, and other vehicle data for improved transportation system management. Some of the examples are Automatic vehicle location (AVL) equipped snow plows, maintenance fleet vehicles, agency fleet vehicles etc. Unlike fixed ESS, these real-time localized road weather observations can be obtained for any roadway segments.

The collection and and dissemination of spatial and temporal weather-related information are particularly essential to mitigate the impacts due to the adverse road weather conditions.

B. V2X Applications

Commonly, Vehicle-to-Everything (V2X) applications [4], [5] fall into the following three broad themes.

- Safety - includes V2I and V2V communications for safety.
- Mobility - includes real-time data capture and management (DCM) and dynamic mobility applications (DMA).
- Environment - includes applications for environment: real-time information synthesis system (AERIS) and road weather applications (RWA).

1) V2I Safety Applications: Some of the V2I Safety applications [5] related to road weather information are as follows.

- Curve Speed Warning: Roadside Equipment (RSE) broadcasts geometric and weather information under Traveler Information Message (TIM) for use by in-vehicle device.
- Spot Weather Information Warning: RSE connected with Traffic management contoller (TMC) and other weather information service can provide alerts and advisories in specific road segments during adverse weather conditions.

2) Mobility Applications: Some of the mobility applications [5] related to road weather information are as follows.

- Response, Emergency Staging and Communications, Uniform Management, and Evacuation. It can provide various road weather alerts and warnings to Emergency responders, including ambulance operators, paramedics, etc. such that they can have effective dispatching and routing decisions.
- Enable Advanced Traveler Information Systems. It can provide alerts and advisories to travelers during their trips. Combining these observations with forecasts from other sources, it can provide dissemination of medium-term and long-term advisories.
- Freight Advanced Traveler Information Systems. It provides weather and road condition information that can drastically improve the ability of freight operators to plan during adverse road weather conditions.

3) Environment Applications: RWA: Several road weather applications [4] have been identified, which are as follows.

- Motorist Advisories and Warnings (MAW). It includes road weather assessments and forecasts along specific road segments for the drivers to assist in decision-making processes
- Vehicle Data Translator (VDT). It incorporates connected vehicle data to create accurate weather and road condition outputs and combines it with ancillary weather data sources.
- Enhanced Maintenance Decision Support System (MDSS). It furnishes assessments and forecasts along road segments of road weather conditions as well as treatment recommendations for maintenance personnel.
- Weather-Responsive Traffic Information (WxTINFO). During inclement weather, it can furnish enhanced operation of variable speed limit systems to improve work zone safety, effective operation of signalized intersections, enhanced performance of lane restriction strategies, and improved ramp metering that can increase safety and mobility.

Certain V2X applications that aim at improving road safety require reliable and low latency message delivery.

III. System Architecture

A system architecture proposed in this paper mainly consists of the following components: V2I Hub, Roadside Unit (RSU) or Roadside Equipment (RSE), Environmental Sensor station (ESS), Mobile ESS, Connected Autonmous Vehicles (CAVs), and Backend cloud server.

Besides, the V2I hub may have connections with Traffic Management Controller (TMC) and Weather information services (WIS). System Architecture of Edge-cloud based Road weather Management is depicted in Fig. 1.

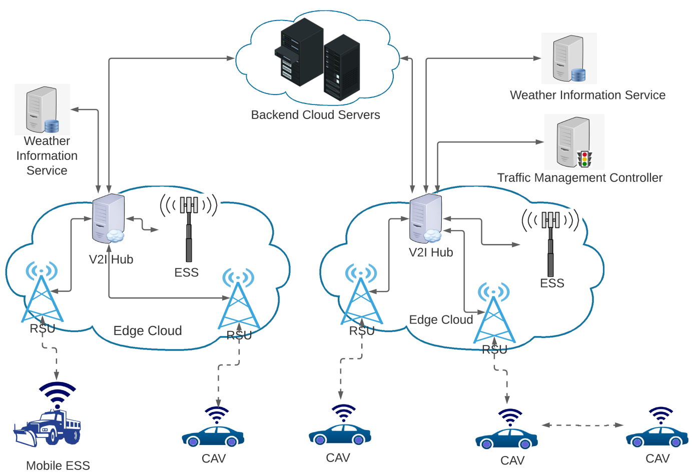


Fig. 1: System Architecture of Edge-cloud based Road weather Management.

A. Edge Cloud

Edge cloud computing is a distributed architecture functionality such as processing and storage, that is located closer to the data source (i.e. CAVs) [9].

In the proposed system, the edge cloud incorporates a V2I hub, which is an edge cloud server, as well as stationary roadside units (RSUs) and Environmental Sensor station (ESS). The edge cloud also ensures the connection between the CAVs and the backend cloud servers.

Mainly, the edge cloud in the proposed architecture is characterized by following key characteristics:

- Segmented network. A network covers a specific segment that can serve a certain number of CAVs. This divides the large amount of data traffic into rational portions per segment.
- Distributed Computing. Comupting resources are geographically distributed such that it can not only minimize the concentration of computation but also reduce the processing time, in turn, latency needed for communication with CAVs.
- Data localization. Local data can be collected, processed, and/or stored by utilizing the segmented network along with distributed computation. Obtaining relevant information to a specific segment, data can be expeditiously processed and analyzed such that the system can notify CAVs in the real time. Ultimately, this shortened response time to hazardous situations, will help reduce accidents and road fatalities.
- Reduced backhaul. Due to data localization including distributed computation, CAVs may not need to frequently contact the backend cloud servers.

The vehicle infrastructure integration can enable V2V and V2I communications through various wireless communication protocols, for instance, conventional Dedicated Short Range Communications (DSRC) standard, which is based on IEEE 802.11p, and the emerging 3GPP-defined Cellular V2X (C-V2X) technology [10]. As C-V2X technology is promising, it has the potential to become the preferred solution for CAV applications.

The system not only deploys distributed stationary RSUs but also includes the RWIS ESS. RSUs are responsible for assisting CAVs, that means, forwarding and exchanging various message to and from the latter. While the RWIS ESS is mainly responsible for collecting and transmitting various environmental related data. And both RSU and RWIS ESS are connected to the V2I hub.

When a CAV comes within range of the RSU, particular data elements can be wirelessly transmitted to the RSU, then routed to the V2I hub. After processing, the given outputs are made available to data subscribers.

The edge computing solution is intended to assure low latency on data transfer between vehicles and the edge cloud server via RSUs, especially delivering critical hazard warnings.

B. Proposed Road weather management

Road weather data collections can be achieved not only with various conventional means including RWIS fixed ESS, mobile ESS, but also with emerging technologies such as CAVs.

CAVs having various sensors, can provide information on general weather and surface condition. Particularly, CAVs can detect weather conditions with Lidar/Radar and camera, eg Lidar can detect precipitation type, light intensity, while cameras can detect fog intensity. Similarly, CAVs can classify pavement condition, eg camera can detect wet, dry, surface conditions, and Radar can detect icy conditions. Futhermore, CAVs can also provide real time updates to High Definition (HD) maps with hazards caused by adverse weather such as flooding, blizzard across specific segments of the roadway.

Fig. 2 shows the flow diagram of proposed road weather management.

The road weather data collected at either fixed RWIS ESSs or connected vehicles equipped probe vehicles are transmitted to the V2I Hub. Deploying reliable and effective road weather hazard assessment, accurate road weather hazard information can be obtained, which could be relayed to drivers to prevent weather related accidents and traffic congestion.

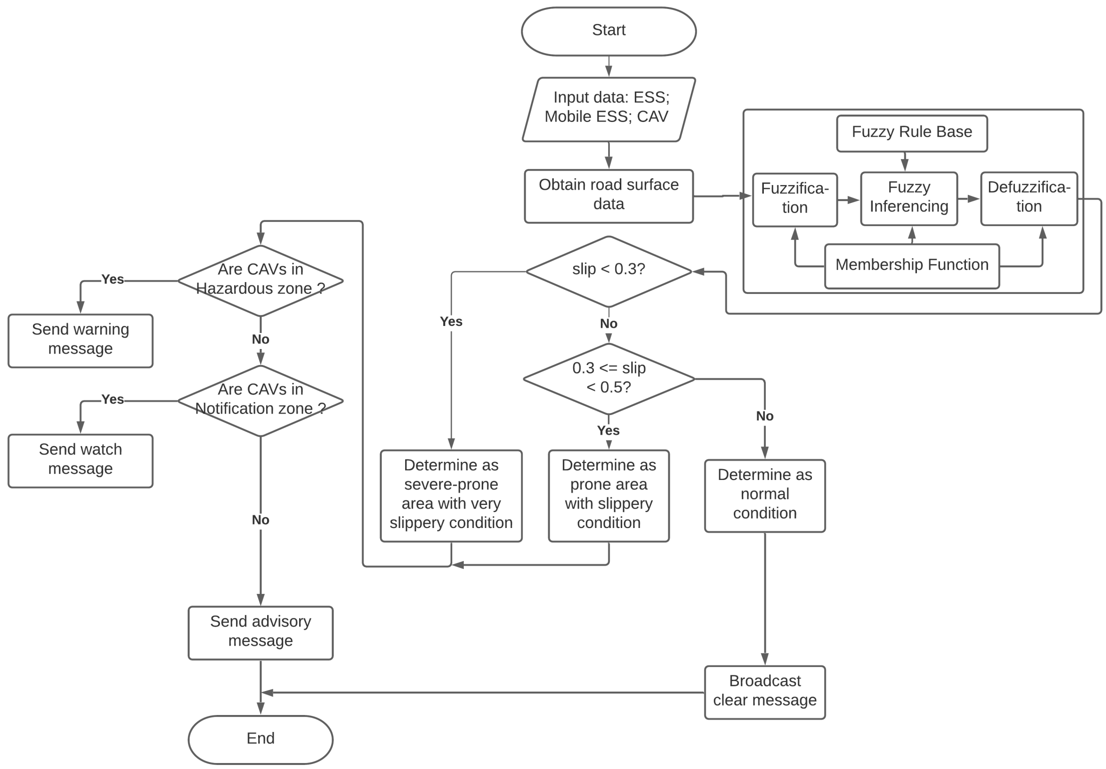


Fig. 2: Flow diagram of proposed road weather management.

The edge cloud server (V2I Hub) can also receive large quantities of Cooperative Awareness and Decentralized Environmental Notification Messages (DENM), such that it can analyze and filter these events based on vehicles in the vicinity. The RSU can send warnings to vehicles as DENM messages through specified communication means (DSRC or C-V2X).

Besides, V2I hub can obtain forecast models from the backend cloud server, weather information from WIS, traffic related information from TMS.

C. Fuzzy Inference System

Fuzzy logic is a subset of Artificial Intelligence (AI). And Fuzzy Inference System (FIS) is a popular computing framework based on the concept of fuzzy set theory. Its success is primarily due to its closeness to human perception and reasoning, as well as its intuitive handling and simplicity, which would be important factors for acceptance and usability of the systems.

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping provides a basis from which decisions can be made. The process of fuzzy inference involves formulating membership functions, logical operations, and IF–THEN rules.

The main advantage of applying fuzzy logic methods is that most of the data can be interpreted by means of linguistic variables. Furthermore, not only complex nonlinear functions can be modeled but also experience of experts can be considered easily.

IV. System Implementation

We have created a testbed to implement the proposed system mainly using Python.

A. Edge computing platform

Development of edge computing platform for distributed V2I environment involve numerous technologies. The edge computing platform basically consists of the EC server known as V2I hub, which incorporates the application server, database server, and Message Queuing Telemetry Transport (MQTT) broker.

a) PostgreSQL: It is a powerful, robust, open-source relational database system.

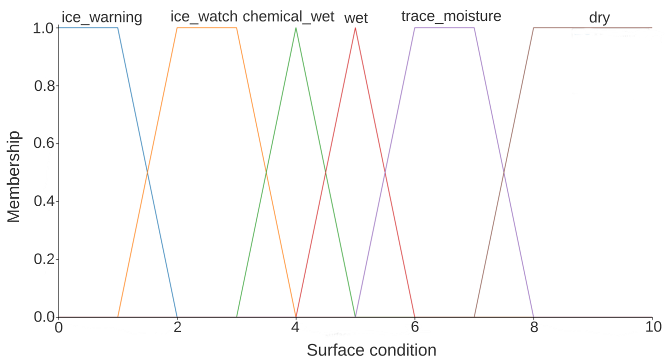
b) MQTT: It is a lightweight, publish/subscribe and, efficient message queueing protocol which is becoming the de-facto standard message protocol for Internet of things. CAVs or Mobile ESS are MQTT clients which publish messages to the MQTT broker such that other MQTT clients subscribe messages they want to receive. The MQTT broker receives the published messages and sends them to the clients subscribing it. In this system, the Mosquitto broker is used.

B. Fuzzy Inference System (FIS) Module

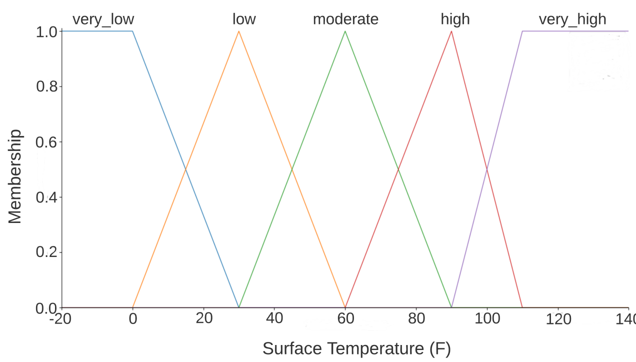
Typically, FIS module includes fuzzification, defining fuzzy rule base, and defuzzification. This module uses the surface condition and the surface temperature as input linguistic variables and the slipperiness as the output. The linguistic variables and the linguistic terms are presented in Table I.

TABLE I: FIS Variables

	Variables		
	Antecedent		***Consequent***
	Surface condition	***Surface temperature***	***Slipperiness***
Terms	ice warning	very low	very slippery
	ice watch	low	slippery
	chemically wet	moderate	normal
	wet	high	
	trace moisture	very high	
	dry		



(a) Surface conditions



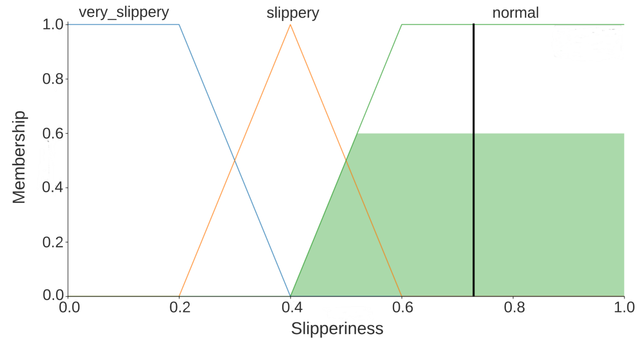
(b) Surface temperature

Fig. 3: Membership functions of Input parameters

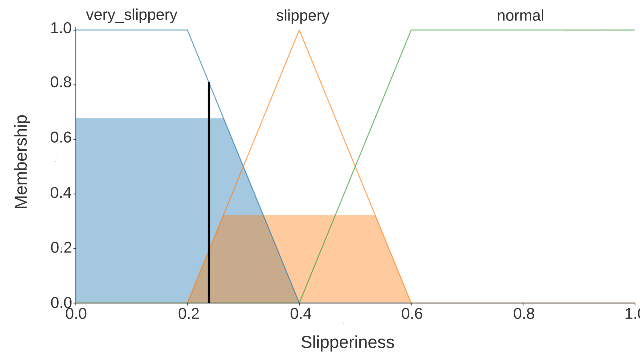
Membership functions of both antecedents, namely, surface conditions and surface temperature, are shown in Fig. 3.

Mamdani fuzzy inference systems (FIS) are based on highly formalized insights about the structure of categories and articulated fuzzy IF-THEN rules that can be based on expert knowledge. In this paper, most rules generated have combination of AND-type and OR-type, while some are of the AND-type only. For instance, in case of latter rule, it considers the effects of one variable antecedent combined to other variable antecedents to yield the particular consequent. In this FIS module, 10 fuzzy rules have been constructed. In Table II, a snippet of the fuzzy rules is presented.

The FIS module uses large datasets for rule generation in order to represent all possible combinations between variables.



(a) Obtained slipperiness is 0.73



(b) Obtained slipperiness is 0.24

Fig. 4: Membership functions of Output parameter

In this regard, we have used road weather data collected at the RWIS ESS Station RTOI4, Altoona (I-80/US 65), Iowa, USA [11]. Dataset consists of about 8000 samples from 1 January to 31 December 2019, which yields sufficient rules to cover the situations that actually occur throughout a year.

During defuzzification process, the degree of memberships from all the rules are aggregated on the output membership functions and are defuzzified to obtain crisp outputs in terms of the slipperiness. Some of the outputs from FIS module are depicted in Fig. 4.

From Fig. 5, it can be observed that the majority of outputs of FIS module lie above the slipperiness of 0.5, thus these road weather observations can be considered as normal conditions.

C. Road weather risk assessment and alert module

This module not only uses some methods to determine the risk of each road segment on the basis of outputs obtained from the FIS module. but also transforms the outputs generated from the road weather risk assessment to actual alerts or advisories messages.

Obtaining such outputs on road weather observations, the system uses location information from ESS, or vehicles (ie. CAV, Mobile ESS) to identify locations with severe road conditions. For instance, if the slipperiness is less than 0.3, which is considered as very slippery then the road segment is determined as a severe-prone area. If it is between 0.3

TABLE II: Fuzzy Rules

	Rules	
Rule 1	IF surface condition is ‘dry’ AND surface temperature is ‘very high’ OR	
	surface condition is ‘dry’ AND surface temperature is ‘high’ OR	
	surface condition is ‘dry’ AND surface temperature is ‘moderate’ OR	
	surface condition is ‘dry’ AND surface temperature is ‘low’ OR	
	surface condition is ‘dry’ AND surface temperature is ‘very low’	THEN slipperiness is ‘normal’
	....	
Rule 9	IF surface condition is ‘ice warning’ AND surface temperature is ‘moderate’	THEN slipperiness is ‘slippery’
Rule 10	IF surface condition is ‘ice warning’ AND surface temperature is ‘low’ OR	
	surface condition is ‘ice warning’ AND surface temperature is ‘very low’	THEN slipperiness is ‘very slippery’

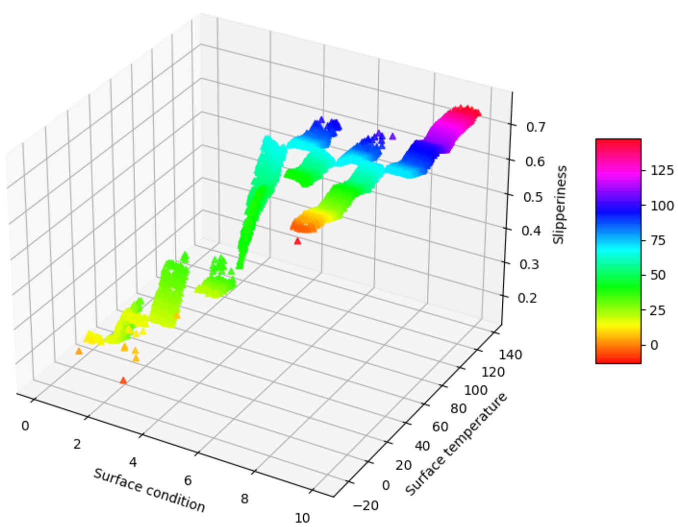


Fig. 5: 3D Scatter plot for input and output parameters.

and 0.5, which is considered as slippery, the road segment is determined as a prone area [1].

Upon detecting sever-prone or prone area, the system shall construct zones, namely, Hazardous zone and Notification zone. Hazardous zone is considered as a core area of the identified location, whose range is predetermined, and Notification zone would be beyond Hazardous zone upto the certain range.

Relevant messages are broadcasted to the CAVs in the particular zone. Depending upon the zone, the message could be warning, watch or advisory, as depicted in Fig. 2.

V. Conclusions and Future works

This paper presents development of a cost-effective and resource-efficient road weather system using edge cloud and connected vehicle technologies, as well as deployment of Fuzzy inference system as a road weather hazard assessment means. In the proposed system, the zone based alerting is depicted. In this preliminary work, we have considered only road surface conditions such that relevant road weather messages are produced.

One of the future works includes a scalable and efficient solution for the workload orchestration problem in the edge computing platform using the fuzzy logic. And to obtain robust road weather management system, we shall not only account various atomspheric parameters such as visibility issue due to fog, rainfall but also incorporate machine learning algorithms to the fuzzy logic system. Futhermore, we shall conduct simulation for traffic mobility and compare with the existing solutions.

Acknowledgment

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