Management of Real-Time Data for a Smart Flooding Alert System

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***Abstract*— Information and technology are key elements in converting cities to Smart Cities. The ability to provide real-time information to residents for supporting their decision making is a primary characteristic of Smart Cities. Some of the challenges of providing real-time data are the availability of such data and the platforms to share it with residents in a meaningful way. In this work, an interdisciplinary, international team of researchers and students from the University of Guadalajara and the University of Texas at El Paso share their progress towards managing (i.e., collecting, processing, and sharing) real-time data during flooding events through the Smart Flooding Alert System (Smart FAS). Flooding events impact the day-to-day activities of city residents such as their mobility and affect the city's infrastructure. The Smart FAS proposes the use of mobile devices and a wireless sensor network infrastructure for the collection of crowdsourced and sensor-generated data, respectively. The Smart FAS includes algorithms to calculate a metric that can be implemented for generating flood mobility routes that avoid flooded streets. Smart FAS uses metrics and mobile technologies for providing real-time information in a meaningful way to users. The proposed design and features of the Smart FAS proof-of-concept are evaluated using Smart Cities characteristics. The Smart FAS proof-of-concept can inform the development of further information and communication technologies (ICT) and Smart Cities platforms aiming to collect and share real-time data to city residents and stakeholders to support their decision-making process.**

Keywords — Smart City, Flooding, Mobility, Safety, Crowdsourcing, Flood Severity, Flood Route Index, ICT, Flood Index

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I. Introduction

Integrating information and technology to provide relevant and timely data to residents for decision making can drive the transformation of cities into Smart Cities. The integration of people, technology, and information can be used to create Smart City infrastructure [1]. Smart Cities solutions address a specific challenge/dimension such as infrastructure or mobility, but the data and platforms developed can be leveraged by other city dimensions or sectors given that a Smart City is an interconnected system of systems.

This paper describes the progress towards integrating sensor-generated and crowdsourced data into a *Flood Index (FI)*. The FI aims to support the decision-making of residents when choosing routes during flooding events. According to a report from the Center for Research on the Epidemiology of Disasters flooding accounted for 43% of all documented natural disasters from 1995 to 2013, affecting 2.5 billion people, and killing 244,000 people [2]. During critical flooding events, transportation infrastructure is impacted in several ways including structural damage, traffic delay, and users' safety. In urban areas, the mobility of residents can be negatively impacted during flooding events [3].

The cities of Guadalajara in the state of Jalisco, Mexico and El Paso in the state of Texas, U.S. have experience flooding events causing infrastructure, economic, and safety damages [4]–[6].

Previous work by the collaborative research team of faculty and students from the University of Guadalajara and University of Texas at El Paso defined the requirements and initial design of a *Flooding Alert System (FAS)* and created an initial proof-of-concept for the collection of crowdsourced and sensor-generated data during flooding events [7].

The main motivation for FAS is to address the need for collecting and managing real-time data to support decision making of residents when commuting in a flood susceptible city such as the city of Guadalajara. FAS integrates data from sensors composing a *Wireless Sensor Network (WSN)* with real-time crowdsourced data collected and shared through a mobile application. The proposed WSN consists of a network of sensor nodes where each sensor node has a microprocessor, a camera, and an image processing algorithm that sends flood-severity levels to the Smart FAS database. The description of the proposed WSN is out of the scope of this paper, please refer to [7] for more information. It is envisioned to deploy the proposed WSN in strategically selected points around the city. In addition, the required information could be captured by readily available existing cameras in the city. Furthermore, FAS incorporates the active participation of citizens through crowdsourcing to create a human-centered solution. The initial FAS design and its proof-of-concept was reported in [7], the later enabled the submission of flooding reports by users, showed reports in a map but it neither included the FI nor calculated a flood mobility route using the FI information.

This paper provides a detailed description of the new proposed features of the FAS (called *Smart FAS*). Smart FAS new features include:

- The FI assessing flood-severity levels of streets
- User guidelines to assess and assign flow severity level through crowdsourced data
- A framework to incorporate the FI into a routing algorithm to provide routes that avoid flooded streets.

The remaining of the paper is divided as follows: Section II presents a literature review on flooding information systems and Smart Cities concepts, Section III describes the Smart FAS design, Section IV includes the methodology and discussion of new features proposed in the Smart FAS, and Section V provides conclusions of the work. Future directions for this work are presented in Section VI.

II. LITERATURE REVIEW

A. Flooding in Urban Cities

In regions with a high propensity of precipitation, flooding events are inevitable. When such events occur, the day to day lives of residents can be negatively impacted in multiple ways including an inability to commute to their jobs, traffic delays, and traffic crashes, resulting in extensive economic impact [8]. Although improvements to the design of infrastructure can help to mitigate the impact of flooding, high-intensity rainfall can accumulate rainwater in a few minutes [8]. For instance, Guadalajara has recorded an average of 10 inches/month of rainfall per month during summer [9]. The limited capacity of the stormwater system, along with urbanization and solid waste in storm drains can increase cities' intensity and frequency of flooded streets [10]. Flooding events can change rapidly and unpredictably. Providing real-time flooding information can foster mobility and safety among residents during flooding events.

B. Overview of Related Work

Previous information systems have been developed to report flooding events to city residents (for example see [11]–[16]). Atlas de Riesgos, developed by the Urban and Territorial Development Program (PDDU) of Zapopan, a city that is part of the Guadalajara Metropolitan Area, consists of an active map that uses historical data to locate areas of flood risk [14]. This system does not currently provide real-time data.

Ciudapp is a website and mobile application that fosters communication between residents and Guadalajara officers 24 hours a day, 7 days a week [13]. With Ciudapp Guadalajara residents can send different reports on different categories, e.g., infrastructure, safety, and rain. Residents can consult the status of the resolution of their reports in real time, suggest new services for the city, receive alerts, and check news of interest. This application utilizes historical and crowdsourced data.

A mobile application named Floodwatch leverages real-time stream gauge data from the U.S. Geological Survey [15]. This application provides an alarm and online emergency guidelines for residents in affected areas in response to flooding. This application is only available in the U.S. for iOS devices. The proposed Smart FAS is intended to be implemented in cities outside de U.S. such as Guadalajara, Mexico especially those that can leverage sensor networks and benefit from crowdsourcing.

Historical data has been typically used to develop flooding emergency notification systems. For example, the work proposed in [16] uses meteorological, monitoring system, and weather forecasting data. Users of the Smart FAS can play the role of "human sensors" to significantly contribute to the accuracy of these weather-based systems.

AppLERT, a mobile application that uses data from a network of sensors was developed to monitor flooding levels in the metropolitan infrastructure at Manila, Philippines [11]. AppLERT provides incident and disaster notifications to users through mobile applications [11]. Currently, this application neither enables assessment of flood severity nor uses flood data to provide mobility routes during flooding events.

Creating emergency notification systems seems to be an adequate solution to share flooding information to residents. Available systems make use of historical databases and prediction models. A combination of both historical and real-time data is used in the Smart FAS to provide a resilient platform for users to continuously contribute and receive information about flooding events.

Some current approaches explore the generation of routes beyond the fastest or shortest path. For example, healthy routes that consider the least air pollution exposure are proposed in [17] and [18]. The current Smart FAS proposes the use of a *Flood Index (FI)* to assess the flood severity of streets and create routes that consider this flood severity to support Smart Mobility safety.

As shown in **Table 1,** the Smart FAS shares relevant features with current information systems and proposes additional ones to support residents' mobility during flooding events. Leveraging the integration of crowdsourcing coupled with a WSN, additional features can be incorporated to support data management for flooding events. The Smart FAS integrates mobile technologies, heterogeneous data (i.e., historical, real-time, WSN and crowdsourcing), image processing algorithms, flood-severity assessment, and safe route algorithms to generate and provide meaningful real-time information for residents living in flood susceptible cities.

TABLE 1. COMPARISON OF SERVICES FROM CURRENT FLOODING INFORMATION SYSTEMS

Services	Information Systems			
	Ciudapp	***Flood-watch***	***AppLERT***	***Smart FAS***
Crowdsourced Data	√		√	√
Wireless Sensor Network		√		√
Historical Data	√	√	√	√
Flood-Severity Level Assessment			√	√
Notifications	√	√	√	
Flood Mobility Route				√

III. THE SMART FAS DESIGN

This section describes the design of the main components and features of the Smart FAS.

A. Refined Architecture of Smart FAS

As shown in **Fig. 1**, two external entities interact with the Smart FAS: the residents (i.e., users) and the external weather forecast service that provides daily weather forecast reports. The residents can submit flooding reports, reports verifications, request for the weather forecast, and request for flood mobility routes that consider flood-severity levels. The Smart FAS has three internal components: the WSN, the mobile application (hereafter referred to as *FAS App*), and an internal database. Directional lines in **Fig. 1** represent the flow of information. Dashed lines indicate features under development. A brief description of each component follows.

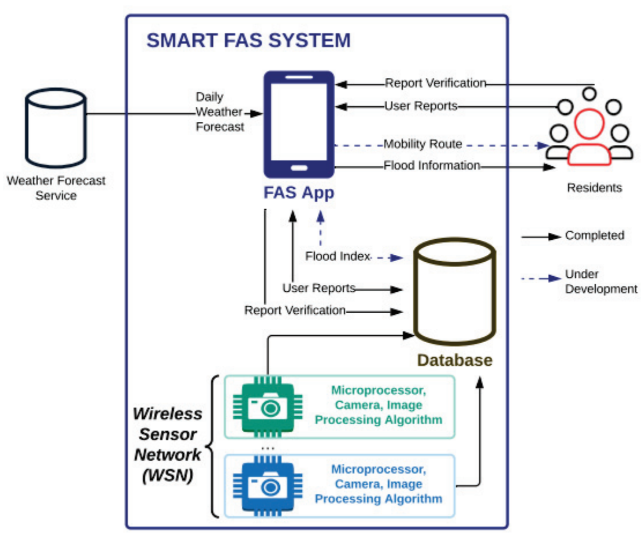

Fig. 1. Main components of the Smart FAS.

<u>Wireless Sensor Network (WSN):</u> The proposed WSN is composed of sensor nodes. Each sensor node contains a Raspberry microprocessor, a camera, and an image processing algorithm. The sensor node sends a flood-severity level identified with the sensor ID data to the Smart FAS database.

<u>FAS App:</u> The FAS App manages user's reports and their visualization in a map. Moreover, the design of the FAS App has been enhanced to: (1) provide guidelines to users for assessing the flood-severity level of streets using visual marks in the flood reports; (2) enable the verification of existing users' reports, calculate the FI; and (3) calculate a flood mobility route that avoids flooded areas. Services (2) and (3) are currently under development. The FAS App and WSN are the two main components processing flood-severity level data.

<u>Data Storage:</u> An internal database (i.e., an instance of a MongoDB, available at www.mongodb.com) stores and enables the management of flood report data (i.e., user's data and WSN data).

B. FAS App Services and Actors

The FAS App has two actors: residents and the weather forecast service. **Fig. 2** shows the use case diagram of the FAS App with its actors and services (use cases). Residents can request five services to the FAS App, three of which are implemented, and two are under development (highlighted in yellow).

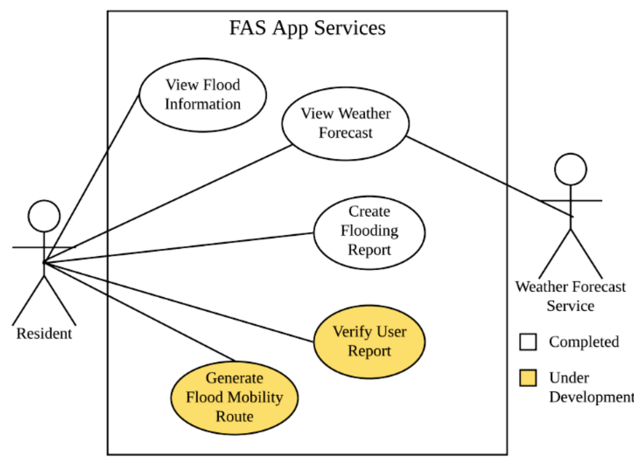

Fig. 2. FAS app use case diagram.

The FAS App enables the creation of flooding reports with the new features of providing visual guidelines and displays recorded flooding events and weather forecast reports. The Verify User Report module, currently under development, will enable users to verify previously uploaded flood reports by third parties (users). The use case to generate the flood mobility route, also under development, will make use of both the calculated FI and a mobility routing algorithm.

The Smart FAS includes the verification of the flooding records using crowdsourcing and the development of guidelines for users to consistently assess flood-severity levels. The values used in the guidelines are aligned with sensor-generated flooding data. Guidelines make use of visual references that specifies vehicle wheels to assess the flood-severity level. Section IV.C further describes these guidelines.

IV. Methodology and Discussion

A. Development of Flood Index

The FI is proposed as part of the Smart FAS to assess flood severity by integrating real-time data (i.e., flood-severity level) from two sources: WSN, and crowdsourcing through users' reports. Equation 1 represents the generic mathematical expression for the FI for the same flooding event.

$$FI = a_s * (x_s) + a_c * (x_c) \qquad (1)$$

where x_s represents the flooding severity level from sensor data, x_c represents the flooding severity level from crowdsourced data, and a_s and a_c are weights for sensor and crowdsourced data, respectively.

Based on the two data sources, three flooding scenarios are initially considered for this mathematical expression. The scenario I considers sensor node data directly to compute the FI. Scenario II uses only crowdsourced data for the FI. Scenario III integrates data from sensors and crowdsourcing for the FI computation.

The FI calculation makes use of two equations to consider data from sensors and crowdsourcing independently. By having separate, simple equations for sensor-generated and crowdsourced data, the weights may not be necessary. The addition of weighting factors to enhance the FI equation should be further investigated. The FI calculation must integrate the flood level measurements from sensors and crowdsourcing by using consistent values and units. Therefore, the crowdsourced data needs to be quantitative to be integrated with the sensor data. After the calculation of FI, the numerical value is converted to a more meaningful, user-friendly format to be shared with residents. Three flood-severity levels have been proposed:, low (FI≤6 in), medium (6 in<FI≤12 in), and high (FI>12 in) guided by the recommendations of the U.S. Federal Emergency Management Agency (FEMA) [19].

B. Flooding Level Detection with Sensor Nodes

The Smart FAS is designed to detect flood-severity levels using data from a WSN. Each sensor node has been designed to contain a *Raspberry Pi 4 Model B microprocessor,* a *Camera Module*, and an image processing algorithm previously described in [8]. Each node will detect the flood-severity level using visible marks from the image captured by the camera. The level of the marks is adjustable, and a proposed configuration of the marks as well as the complete configuration of the node is currently being adjusted to be aligned with the guidelines for users' reports (e.g., low, medium, and high flood-severity levels).

C. User's Guidelines for Collection of Crowdsourced Data

The Smart FAS integrates a human and technological infrastructure to provide real-time flooding data to foster Smart Mobility. The participation of residents as part of real-time crowdsourced data collection is paramount for a successful operation and sustainability of the Smart FAS. Residents are given the task to create reports related to flooding events. Users' reports consist of describing flood-severity levels, location, and time. The proposed crowdsourcing approach may introduce differences in how data is reported based on the users' perspective, experience, and willingness to cooperate and interact with the FAS App. The veracity of the crowdsourced data is an important feature to foster trust in the crowdsourced data collected. Therefore, Smart FAS promotes the standardization of the flooding reports using guidelines for users to consistently assess flood-severity levels. Guidelines make use of visual references relative to the height of a vehicle tire to assess the flood-severity level. These guidelines mitigate the risk of unreliable data. **Fig. 3** illustrates a generic example of user guidelines for perceived flood-severity levels using a physical reference. Since the interconnected WSN uses three quantitative flooding severity levels; similar flooding severity levels must be reported by the users' reports. Users are provided with three physical references that represent these three flooding severity levels including one-quarter of the tire height, half a tire height, and full tire height.

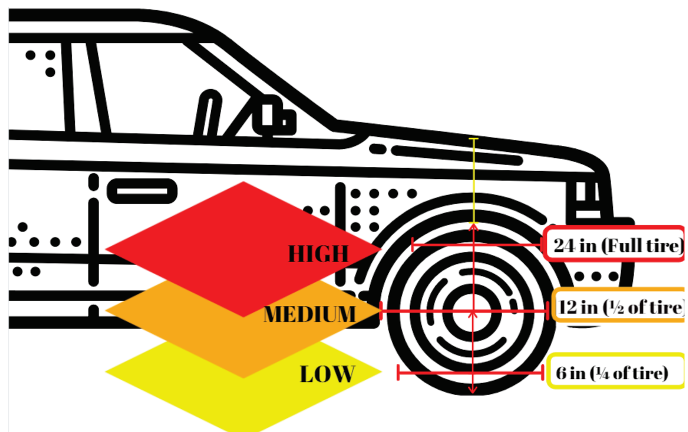

Fig. 3. User guidelines for assessing flood-severity levels.

D. Calculating the FI from Crowdsourced Data

As the data is collected by Smart FAS's WSN and crowdsourcing, the FI must be continuously calculated to keep residents informed, especially throughout flooding events. The FI is calculated for each *street segment* (i.e., the street section between two intersections) every time a new report is linked to that street segment or every five minutes if no new reports for that street segment are received regardless of the data source. The Smart FAS aims to keep users informed about the flood-severity level. The latest flood-severity level submitted by users' reports or WSN will be displayed. While the calculation of the FI using data from the WSN is straightforward, the computation of the FI using crowdsourced data presents a few challenges which are discussed next.

First, the crowdsourced data collection cannot be assumed to be continuous. Thus, submitted users' reports must be assigned a lifespan to ensure data is available for the calculation of FI. As a proposed specification, the Smart FAS assigns 5 minutes to submitted reports to be active in the system as well as for the calculation of FI. If an active report is verified by another user, 3 minutes are added to the lifespan of that report to utilize this report a little longer. Otherwise, unverified reports are only existing for 5 minutes and properly labeled to distinguish from verified reports. Reports identified as inaccurate are not considered for the FI computation. **Fig. 4** shows the proposed verification process and the lifespan of reports. As an example, the report submitted at 1:20 PM would be valid until 1:28 PM if verified. Otherwise, the report will be only available until 1:25 PM. The FI at 1:30 PM will be reported as a "low severity level" based on the last user's report available and lifespan.

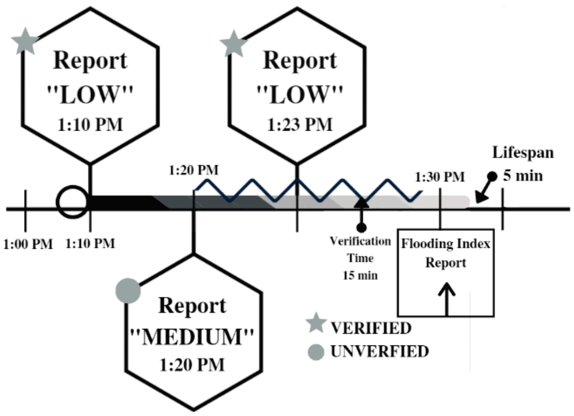

Fig. 4. The verification process for users' reports in Smart FAS.

A flooding event consists of three main phases such as: (a) accumulation; (b) stagnation; and (c) dissipation of water [20]. **Fig. 5** represents the three phases of flooding events and expected flooding levels. The Smart FAS design aligns to these phases and assumes the following expected behavior: (a) During the accumulation phase, the flood-severity level is expected to increase rapidly, (b) For stagnation, the flood-severity level remains in a steady-state condition, and (c) During the dissipation of water, the flood-severity level should be decreasing slowly.

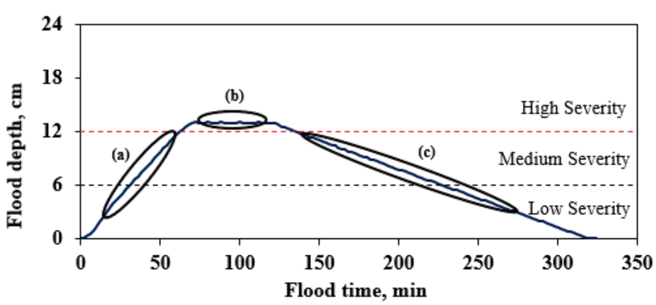

Fig. 5. Flooding event phases expected in Smart FAS.

The display of the FI will not only consist of the flood-severity level but also the flooding phase. For the FI calculated during the accumulation phase, an arrow pointing up should be added to the display of the FI. An arrow pointing down will reflect the dissipation phase. Lastly, a horizontal arrow will represent the stagnation phase of a flooding event. The display of the FI in the FAS App is currently under development.

E. Handling Missing Data for Flood Index

With the use of crowdsourced data, the most crucial scenario for computing the FI is when no recent reports are available (i.e., no reports in the last 5 minutes when a flooding event is expected to be occurring). Considering this extreme condition, the surrogate FI will be provided to users. The most immediate solution to compute the surrogate FI is to consider the latest FI computed by the Smart FAS and add the probability of precipitation (PoP) of the area of interest. The PoP will be retrieved from the weather forecast service and store it into the internal database as part of the Smart FAS implementation. Given that the PoP is a well-known metric for most residents, its inclusion in the surrogate FI is feasible. It is important to note that, the assumption is that the PoP lower than 60% represents a low probability and higher than 60% represents a high probability of precipitation. The surrogate FI consists of the following:

a. Flood-severity level in the past 5 minutes;
b. The PoP value for the corresponding specific 50 minutes interval; and
c. Surrogate alert indicating expectations of flood-severity level.

An example of reporting the surrogate FI when missing users' reports data is illustrated in **Fig. 6** and described as follows:

1. Several users' reports were collected at a given time (the example shows several reports were collected at 5:00 p.m.)
2. At 5:00 p.m., the FI is reported by using the latest user's report collected plus the flooding trending arrow.
3. The next FI report must be computed at 5:05 p.m. although no users' reports have been collected or are available for the FI computation.
4. The Smart FAS reads the FI reported during the previous cycle to develop the surrogate FI report. The time for this FI is also collected by the Smart FAS.
5. The Smart FAS also utilizes the weather forecast to gather the PoP information and assess whether the flooding event may remain the same or increased in terms of severity.
6. Based on the PoP information and previously mentioned thresholds to predict flooding conditions, a message is generated to provide a reference to users. If the PoP probability is greater than the threshold (e.g., 60%), the message will state that the flood-severity level may have increased. On the contrary, the message will state that the flood-severity level will remain constant.

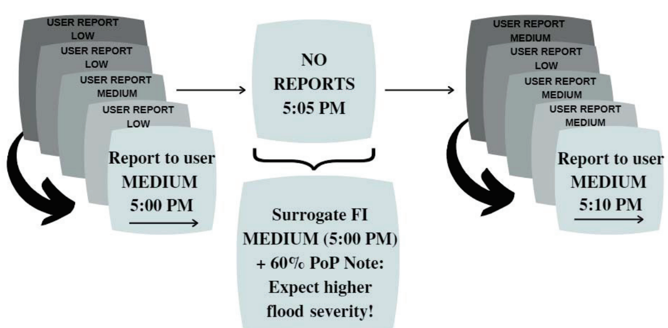

Fig. 6. Smart FAS handles missing crowdsourced data with a surrogate value.

The process for the surrogate FI provides the most current FI with associated validation time information to users when crowdsourced data is missing. The supplementary information aims to guide residents' decision-making process. The lifespan of the surrogate FI is proposed to terminate when either the PoP is less than 60% (low precipitation probability) or a new user report is submitted. The calculation of surrogate values is under development in the Smart FAS.

F. A Framework to Incorporate Routing Algorithm

Current traffic navigation applications calculate the shortest or fastest routes utilizing techniques that consider distance and travel time such as [21]. In addition, traffic incidents such as accidents, disabled vehicles, slowdowns, and even speed traps are added to provide explanations of the choice of route and predicted travel time [22]. To incorporate the FI as a factor in the computation of a flood mobility route, several challenges must be overcome. The FI must be used as a factor that affects vehicle speed. For instance, the FI representing low flood-severity level could be translated into 50% vehicle speed reduction, while the FI representing medium flood-severity level can be translated into an 80% vehicle speed reduction. A street segment with the FI that represents high severity level must not be considered in route calculation for mobility safety concerns. A mathematical expression is formulated to compute the *Flood Route Index (FRI)*, i.e., flooding index at the route:

$$FRI = \sum_{l=1}^{n_l}\left[(w_{fc}\mathrm{FI}_{lc} + w_{fs}\mathrm{FI}_{ls}) * dl\right] \qquad (2)$$

where l defines the link that represents a street segment, n_l is the number of links along the routes, w_{fc} is the weight for crowdsourced data, w_{fs} is the weight for sensor data, FI_{lc} represents adjusted speed based on the FI calculated from crowdsourced data, FI_{ls} represents adjusted speed based on the FI calculated from for sensor data, and dl represents the length of the link (i.e., the length of the street segment).

The algorithm to calculate the flood mobility route between two places in the City of Guadalajara is illustrated in **Fig. 7**. This mockup for the proposed interface implementation was manually generated using map images from OpenStreetMaps (available at: www.openstreetmap.org) which is also used in the FAS App. This algorithm is composed of the following steps:

1. Users must first select two points, that is, the origin and destination as shown in **Fig. 7a**.
2. The best initial route (see **Fig. 7a**) is determined based on the sum of the individual links' travel times.
3. The Smart FAS detects flood-severity levels at or near the initial route as illustrated in **Fig. 7b**.
4. As seen in **Fig. 7b**, links affected by flooding reports are assigned a speed reduction factor based on the flood-severity level (e.g., low = 50% speed reduction, medium = 80% speed reduction, and high = 100% speed reduction).
5. The mobility route algorithm reads speed reduction factors for each link along the initial route, updates the link travel times, and computes FRI to select a new flood mobility route. Equation (2) is applied to calculate the FRI.
6. The Smart FAS checks for alternative routes by following the same exercise and considering FIs as well as calculating the FRI for each route (see **Fig. 7c**).
7. The route with the lowest FRI is suggested as the alternate route.

From the case scenario shown in **Fig. 7a**, the initial mobility route will provide an FRI consisting of travel time and distance as in any other traffic navigation system. Given the presence of different flood-severity levels along the initial route, the Smart FAS will calculate the new route by applying speed reduction factors depending on the flood-severity levels. Considering the speed reduction and distance of street sections, a new mobility route was selected with a revised FRI (**Fig. 7c**). In this case, the initial mobility route was not suggested to users due to the street section with a high flood-severity level. The implementation of the proposed FRI in Smart FAS is currently under development.

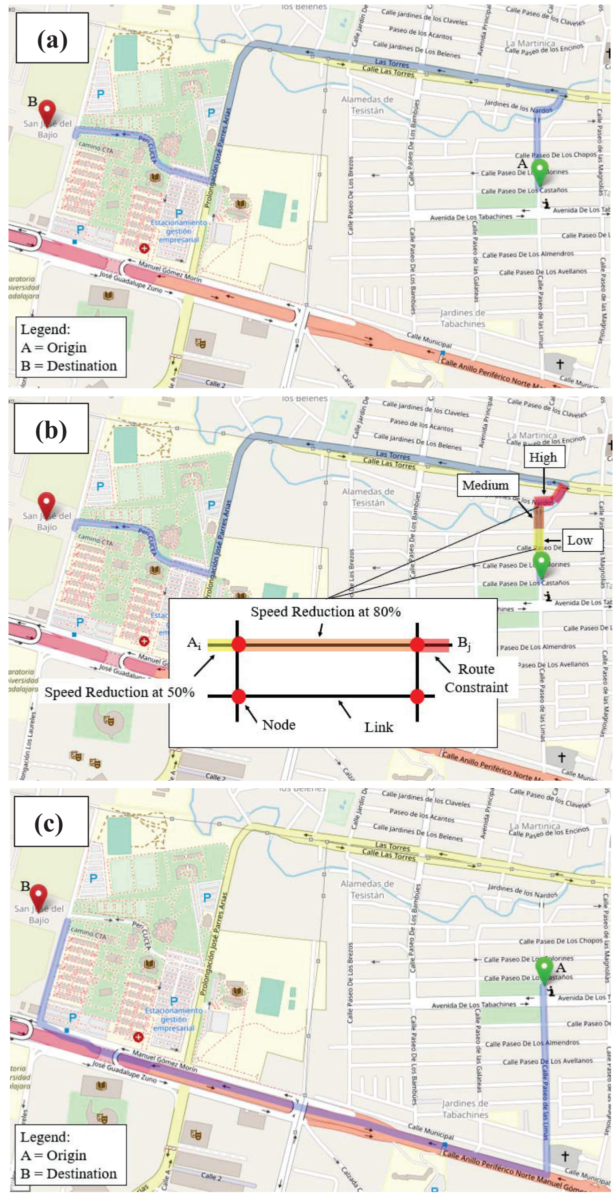

Fig. 7. Mockup of the proposed use of FI and FRI in the mobility routing algorithm of the Smart FAS.

G. Alignment of Smart FAS to Characteristics of Smart Cities Solutions

The Smart FAS is a human-centered solution that can be implemented to support the mobility of residents by providing real-time information useful for their decision-making process during flooding events. **Fig. 8** depicts the relationship between the proposed Smart FAS design and Smart Cities concepts and principles. The Smart FAS is designed to comply with at least the following four important Smart Cities characteristics [23]:

- *Resiliency* of the Smart FAS is achieved by the incorporation of more than one source of data: real-time sensors and crowdsourced from the WSN and mobile applications, respectively. Additional means when users have low band connectivity for the WSN shall be considered when an internet connection becomes unavailable during storms.
- *Scalability* of the Smart FAS is envisioned by promoting the participation of residents through crowdsourcing and a WSN. Implementing the Smart FAS leveraging third-party tools contributes to this characteristic.
- *Modularity* is covered by breaking down Smart FAS into independent components: database, a WSN, and the FAS App that are interconnected to effectively provide the system's functionality. The mobile application is used for crowdsourcing, display flood reports, and forecast information. The Raspberry microprocessor process data from the camera, which acts as a sensor, throughout an image processing algorithm that determines the flood-severity level. A database is used to manage data from both the FAS App and WSN.
- *Interoperability* has been considered in the design of the Smart FAS through the interaction of standard data formats and third-party tools used in both the WSN and the Smart FAS. For example, the FAS App can make use of additional third-party tools for the display and management of reports.

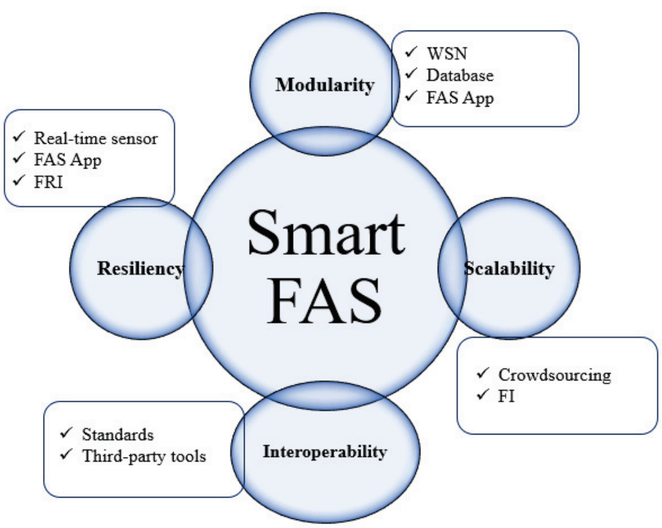

Fig. 8. Alignment of Smart FAS design to characteristics of Smart Cities solutions.

V. CONCLUSIONS

The proposed Smart FAS combines crowdsourcing and sensor data to collect and provide real-time information during flooding events through a human-centered approach that has initially been implemented as a proof-of-concept to support Smart Mobility but can also benefit other Smart Cities dimensions. The Smart FAS is designed to display the FI values to assess the flood-severity level of streets and an FRI to compare the relative risk levels of flood mobility routes, a feature that to the best of our knowledge has not been included on current related systems.

The following conclusions can be drawn from this study:

1. The proposed FI can be calculated from either sensor, crowdsourced data, or both, considering the associated challenges. The levels of flood-severity levels are taken from the recommendations from the FEMA agency and require further investigation. The integration of sensors and crowdsourced data is being revisited to develop a consistent process.
2. The transformation of crowdsourced data into quantitative values is crucial for the computation of a consistent FI. Crowdsourced data can be transformed into quantitative values by using a physical reference. The user's guidelines developed to assess flood-severity levels using a physical reference, such as a typical vehicle's tire, should improve the accuracy and consistency of user reports' data.
3. A user credibility score system can be explored in the Smart FAS for enhancing the accuracy of data collected from crowdsourcing. The credibility system should also assist in mitigating the inclusion of inaccurate data into the FI calculation.
4. A verification process is currently under development to improve the accuracy of reports and therefore, the accuracy of the FI calculation. Verified reports will be given a longer lifespan to be included in the calculation of FI, while unverified reports are still used as a reference with lower importance.
5. The Smart FAS is designed to report the FI every 5 minutes. The FI consists of the flood-severity level (i.e., low, medium, and high) and will be displayed using an arrow depicting the trend of the flooding event (e.g., increasing, constant, or decreasing). If flooding data is not available, the surrogate FI will be shown to users during flooding events. The surrogate FI consists of the most recent FI reported by the smart FAS plus the PoP and a surrogate alert note. This functionality is currently under development.
6. A framework to implement the use of a routing algorithm to avoid flooding areas is proposed with the inclusion of the FI as the main factor for mobility speed. The FRI calculated with the proposed routing algorithm can be used to compare mobility routes during flooding events.
7. The outcomes of this work can inform development teams of Smart Cities solutions that integrate data from different sources to support the decision making of a wide range of stakeholders, including city residents

VI. FUTURE WORK

At the time of submitting this paper, the new features shown in **Fig. 2** of the Smart FAS have been designed conceptually and partially implemented. Further work must be carried out to fully deploy the Smart FAS for public release including: (1) the deployment of the WSN at strategic locations to collect sensor data about flooding levels than can be used to validate crowdsourced data, (2) evaluation of the current functional proof-of-concept in a representative area of interest, including a usability study (with IRB approval), and performance evaluation to validate the effectiveness of the

Smart FAS with an increasing number of user participants, and (3) include a credibility user score system to enhance the accuracy of the crowdsourced data.

In addition, the Smart FAS can be enhanced by: 1) adding the use of SMS messaging services to support users that may not have continuous access to a mobile data plan increasing system reliability, (2) developing a predictive model using historical data from the Smart FAS and weather forecasts to inform users of potential flooding events in areas of interest, (3) implementing the Spanish version of the FAS app, and (4) extending the use of Smart FAS to other transportation modes such as bicycles, bus, and mass transit systems.

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