A Smartphone-Based Solution to Manage Hazardous Materials Transportation: A Review

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Abstract. Management solutions of hazardous materials transportation use in-vehicle embedded devices. Smartphones have had powerful edge computational capabilities at extremely feasible costs which encourage the development of many mobile applications, including vehicles accidents detection applications. Smartphone sensors associated with those applications support real-time tracking of vehicles and enable the detection of abnormal conditions. The integration of smartphone information with databases of vehicle traffic monitoring departments increases the speed of detecting potential accidents and allows interaction with drivers to determine transport schedules, restrictions, and possible route changes. So, the objective of this paper is to compare mobile applications using smartphone telemetry information. Results show these applications may reduce the effects caused by accidents involving the transport of hazardous materials, such as traffic jams, human health, and environmental damages.

Keywords: Smartphone application · Accident detection · Tracking technologies · Embedded devices

1 Introduction

The effects of hazardous materials leaking endanger the human population and the environment [1]. Dangerous goods are necessary for citizens' lives and must be transported carefully to avoid accidents and mitigate risks [2]. Traditionally, traffic surveillance is conducted with two distinct approaches: a) Road-based technologies: In-road detectors like inductive loop detectors [3], magnetometers [4], piezoelectric detectors, pneumatic tubes, and roadside detectors like video image detectors [5], active or passive infrared detectors, microwave sensors, radar sensors, ultrasonic sensors, and passive acoustic sensors [6]; and b) Vehicle-based technologies: probe vehicles, automatic vehicle location systems, automatic vehicle identification systems, and smartphones.

Among those approaches, smartphones deserve more attention, due to their powerful edge computational capabilities at extremely feasible costs that encourage the development of several mobile applications. Smartphone sensors associated with mobile applications support real-time tracking of vehicles and allow the detection of abnormal conditions. The integration of smartphone information with databases of vehicle traffic

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monitoring departments increases the speed of detecting potential accidents and enables interaction with drivers to determine transport schedules, restrictions, and possible route changes. The reduced detection time and more telemetry information reduce the effects caused by accidents involving the transport of hazardous cargo, such as traffic jams, and human health and environmental damages.

A standard procedure to track hazardous cargo is a fleet location tracking solution with in-vehicle sensors, also known as Onboard Terminals (OBT), which communicate by telecommunication networks to send the truck tracking data. Specific systems have been designed, such as Project SCUTUM (SeCUring the EU GNSS adopTion in the dangeroUs Material transport), developed by The European Global Navigation Satellite Systems Agency – GSA [7], to track dangerous materials using Global Navigation Satellite System – GNSS, as the most promising application for European Geostationary Navigation Overlay Service – EGNOS, the precursor of the Galileo European constellation.

Another example is the Mitra system, which tracks trucks for the transportation of dangerous goods through an onboard terminal and GNSS receiver [8], which relays information of location, speed, direction, and contents of the vehicle to a central information exchange server by telecommunication operator systems. The server routes the information to a variety of databases, namely those holding road, event, and risk assessment information. The road databases contain detailed information about the road system, such as the time and place where road works are underway or the proximity of schools and hospitals. These databases also provide details about critical infrastructure and the presence of other vehicles transporting dangerous goods. The alerts are provided by OBT sensors, including a panic button that can be triggered by the driver. However, due to the variety of OBT standards, it is not clear whether the use of the Mitra system can be applied worldwide.

Despite the importance of surveillance of dangerous goods, between 2001 and 2019, there was an annual average of 200 accidents involving dangerous cargo (according to the Public Security Department São Paulo State of Brazil). About 10% of these accidents happened in the city of São Paulo. This city receives 45,000 annual applications for licenses to transport dangerous goods. In the current workflow, the transport companies need to ask for authorization from the government's road traffic department, which attributes a date to execute the transport. There are constrained areas, but the municipality has insufficient staff for monitoring traffic, so only 5% of the streets in the city of São Paulo have surveillance; thus, keeping all dangerous goods vehicles under surveillance is impossible, and many times the drivers are disrespectful to the planned route, endangering many citizens lives. The purpose of this paper is to compare tracking technologies through a literature review and propose a smartphone-based app to request, schedule, route, track, and notify the transport of dangerous goods into the city of São Paulo. It offers a solution with easy implementation and a low cost of maintenance. Section 2 presents the review design, Sect. 3 presents results and discussion, and Sect. 4 concludes the research.

2 Review of Relevant Literature

This section is structured in four topics showing the main characteristics of applications that support the use of smartphones as measurement probes as well as dedicated hardware to collect vehicles data: (1) mobile location-based solutions related to the traffic of vehicles; (2) solutions for identifying and notifying vehicle accidents; (3) dangerous goods tracking solutions, all of them using dedicated in-vehicle devices; and (4) general tracking solutions, all of them using dedicated in-vehicle devices.

2.1 Mobile Location-Based Solutions Related to the Traffic of Vehicles

There are four technologies that best represent mobile location-based solutions [9]:

- Navigation: Crowdsourced data to find the best route and improve transparency in urban transportation.
- Bus tracker: Provide travelers with estimated arrival times of buses at a given stop.
- Real-time ride-hailing: Provide a complete platform for ordering, procuring, and purchasing rides. The ability to track the location of one's driver is often claimed as a key benefit of the system since it is an efficient manner of transacting payments. The ability to match demand with supply in real-time, while providing a convenient mechanism for completing the transaction, as well as a platform for tracking and rating one's experience, is disrupting conventional services such as the taxicab industry.
- Parking spot for location and reservation: They are emerging in several urban markets around the world, for both public on-street parking as well as privately operated garages. It is possible to search reserve and route to a parking lot. They save time and fuel searching parking lot, as well as reducing traffic jams.

2.2 Smartphone-Based Solution for Vehicle Accidents

Among the significant research in this topic, there are twelve technologies that best represent smartphone-based notifying solutions for vehicle accidents:

- Accident detection and disaster response framework utilizing IoT: The system detects accidents using the accelerometer; the threshold value of forces is greater than 10,000 N. After accident detection, it sends the location from the GPS receiver to the nearest emergency service. The user can cancel the false-positive accident occurrence via a smartphone app that was developed using Android Studio and Firebase's real-time database [10].
- Accident detection system using a combination of multiple smartphone sensors to reduce the false positive - GPS (speed and location), accelerometer, gravitational force, pressure, and sound: The app was developed in Android Studio and reports the incident to the nearest hospital. The user can press the cancel button within 10 s in the case of a false alarm [11].
- Accident detection system using ACN: A proposal for a smartphone-based ACN (Automatic Crash Notification) system to substitute a built-in system, an android app that detects accidents using a combination of smartphone sensors, GPS, and

accelerometer. The user has 20 s to cancel false-positive alarms. The notifications are sent to an assigned provider [12].

- Android application for accident detection and notification: The solution implemented by the accident reporting and guidance system considers detecting the accident through the signal received from the accelerometer and the speed given by GPS. It can use two phones to reduce the false-positive. The algorithm finds the nearest emergency service and sends a notification [13].
- Trauma accident detecting and reporting system: The project uses an accelerometer & gyroscope to detect a fall. Its use is broader, but it could be used for the traffic of vehicles. The false positives are avoided by neural network algorithms or using a Support Vector Machine (SVM) algorithm [14].
- Car Accident Detection and Notification System Using Smartphone: The solution proposes a Car Accident Detection and Notification System (CADANS). It uses smartphone sensors to detect accidents, mainly the accelerometer, but to differentiate a car accident from a smartphone drop, the GPS receiver contributes with the speed deviation measure, and the microphone contributes to eliminating false positives with high dB measurements. The camera is used to notify an accident using the carrier operator and informs the location based on the GPS position of the vehicle. The user can confirm the accident occurrence via a mobile app that was developed using Eclipse IDE [15].
- Utilizing the emergence of Android smartphones for public welfare by providing advanced accident detection and remedy by ambulances: The system detects accidents using the accelerometer. After detection, it sends the location from a GPS receiver and a pre-recorded voice message to the emergency service. The user has 15 s to cancel the false-positive accident occurrence through a smartphone app that was developed using Eclipse IDE [16].
- Smartphone application to detect car accidents: The system uses an accelerometer for detection and uses Dynamic Time Warping (DTW) and Hidden Markov Models (HMMs) to reduce false positives. The car accident is reported by existing telecommunication networks and informs the location based on the GPS position of the vehicle [17].
- Providing accident detection in vehicular networks through OBD-II devices and Android-based smartphones: The solution of accident detection considers GPS deceleration information provided by an OBD-II interface, such as airbag triggering detection. The communication between the OBD-II and the smartphone is provided by Bluetooth. The smartphone accelerometer sensors were disregarded to avoid false positives in case of a fall. A rescue system sends data with GPS location to an emergency system database. The user has 1 min to cancel a false-positive alarm. The app was developed for the Android platform [18].
- Smart vehicle accident detection and alarming system using a smartphone: This accident detection solution uses smartphone sensors that measure accelerometers, pressure sensors, and GPS data to compare the current and the previous speed. The user can cancel a false-positive alarm. An emergency message is sent to the user's emergency contact number. The app was developed for the Android platform [19].
- Mobile phone location determination and its impact on intelligent transportation systems: Location-based services utilize mobile devices to collect GPS and carrier base

stations trilateration data, including Automatic Vehicle Location (AVL) in case of an accident, crash, or other emergencies. There is no user interaction [20].

- An IoT approach to vehicle accident detection, reporting, and navigation: The solution considers an embedded device with a shock sensor, GPS receiver, and cellular IoT. The in-vehicle device communicates with a smartphone by Near Field Communication (NFC) that sends the passengers identification and vehicle data through the telecommunication networks. The solution detects the accident and determines the shortest path to rescue teams. There is no user interaction [21].

2.3 Dangerous Goods Solutions with Dedicated In-Vehicle Devices

In the literature, a small amount of research addresses the problem of dangerous goods tracking solutions; all of the following three technologies use dedicated in-vehicle devices, pre-installed OBT.

- Development and application of real-time monitoring system for dangerous chemicals transport vehicles based on the Internet: The system uses dedicated hardware as a concentrator to collect the real-time vehicle, driver, and dangerous goods data, and transmit it through the mobile network [22];
- Dangerous goods dynamic monitoring and control systems based on IoT and RFID for regulating the road transport of dangerous goods, a framework for a dynamic monitoring system: The systems use an OBT to collect dynamic information from the vehicle (1): speed, engine speed, engine oil pressure/temperature, fuel amount, static electricity, tires pressure/temperature, battery voltage, brakes pressure/temperature; dangerous goods (2): pressure, temperature, humidity, concentration, acceleration, inclination, liquid level; and driver (3): driving time, blood pressure, pulse, breathing, mental state, and fatigue. The data are transmitted via carrier network to a monitoring system, which has more information from the road, weather, the region, and events such as holidays. The systems have an information process layer and an application layer responsible for accident analysis, prediction, and emergency treatment [23, 24].
- Real-time microservices-based environmental sensor system for hazardous materials transportation networks monitoring: a system is proposed to monitor and control the transportation of hazardous materials. This system is based on microservices architecture over a cloud environment that provides eight services: 1) Pre-transportation, 2) Routing, 3) Monitoring and tracking, 4) Data collection, 5) Substance and risk knowledge, 6) Transport documentation, 7) Historical information, and 8) Alert and query information. The solution considers a wireless sensor network – WSN through which in-vehicle sensors (OBT) communicate with telecommunication networks [25].

2.4 Dedicated In-Vehicle Devices to Providing Tracking Solutions

In the literature, a small number of research addresses tracking solutions, all six of them using dedicated in-vehicle devices, pre-installed OBT.

- Post-disaster emergency vehicle routing [26]: A constraint-based model for fast post-disaster emergency vehicle routing that uses mixed-integer programming and constraint programming techniques to find the best routing of rescue vehicles.

- V2V accident avoidance [27]: A proposal to use vehicular ad-hoc networks (VANETs) based on the speed and coordinates of the vehicles and then, sends traffic alerts to drivers. It seems to be an excellent solution when all vehicles are equipped with V2V transponders. It is still a system that needs massive implementation.
- Onboard terminal to detect an accident and send notification [28, 29]: Proposals to use a button sensor situated on the vehicle will detect an accident immediately and send a message to a microcontroller. The microcontroller sends an alert message with the help of a GSM modem to a police control room or a rescue team, which will include the location with the help of the GPS. Also, the alert message containing the location of the accident will be sent to the relatives of the victim. In case there is no casualty the driver can terminate the alert message by a switch provided in the vehicle. There is another system for detecting accidents, but this one also considers the speed of a GPS receiver [3]. Moreover, there is a third system, called OnStar, that uses an embedded cell phone that notifies an accident triggered by the air-bag sensors [30].
- IoT-VANET-based systems for quick medical assistance [31]: It is proposed a low-cost hardware prototype application to detect accidents and a testbed to report them providing quick medical assistance at their location [32]. The solution considers a system that collects data from the OBU using data mining techniques to define the severity of the accident. There are projects considering in-vehicle dedicated hardware to detect accidents and send notifications through GSM networks [33, 34]. There are techniques of clustering and prediction to increase the performance of tracking over IoT-VANET systems [35].
- Dynamic route prediction [36]: Using an artificial intelligence algorithm, this system compares the data received from the GPS receiver, such as speed and location, to the traffic data from other systems to predict the traffic flow.
- Crowdsourcing for data mining [37]: Using platforms such as *Twitter*, this solution proposes mining tweet texts to extract incident information on roads as an efficient and cost-effective accident detection solution.

3 Application and Discussion

3.1 Smartphone Application to Manage the Hazmat Transportation

High maturity cities such as São Paulo/Brazil have an integrated operations center, a commonplace to host several departments of different areas of expertise: police, civil defense, firefighters, road traffic companies, and medical emergency. The authorities from those areas stay in the same room, but each one has its legacy system without sharing the same data source. Considering that the major problem in hazardous cargo transportation is the lack of surveillance [38, 39] and the difficulty to synchronize the authorization process with the transport tracking. So, the use of mobile apps to track trucks represents a flexible non-intrusive solution, without embedded hardware installation. In this specific case, dangerous cargo transportation must be previously authorized by government authorities, and during the transport can receive new directions, thus, it is feasible when having a bidirectional application in which the driver can send and receive information in real-time. Using smartphones to collect data, the driver behavior and traffic conditions can be analyzed for decision-making if abnormal conditions are detected.

In case of loss of communication, the smartphone can collect data from its sensors, even being offline, and send it as soon as the communication is reestablished. The location process is supported by the fact that smartphones are equipped with sensors that allow them to be located through calculations and trilateration of signals from the coverage area of satellites or radiofrequency base stations.

A relational database is necessary to host the information. (1) Personal Id is the primary key for identifying and distinguishing a smartphone. (2) Vehicle is the number used to identify the vehicle and correlate it to the smartphone. (3) Time records the current date and time. (4) Latitude, (5) longitude, (6) speed, and (7) altitude. (8) Acceleration. (9) Gyroscope. (10) Compass. (11) Pressure. (12) Temperature. (13) Noise. From a web map app, it is possible to track vehicles in real-time and view them graphically. Any route change can be sent from the operations center control room to the truck driver.

Figure 1 illustrates a functional diagram for authorization and tracking hazmat cargo.

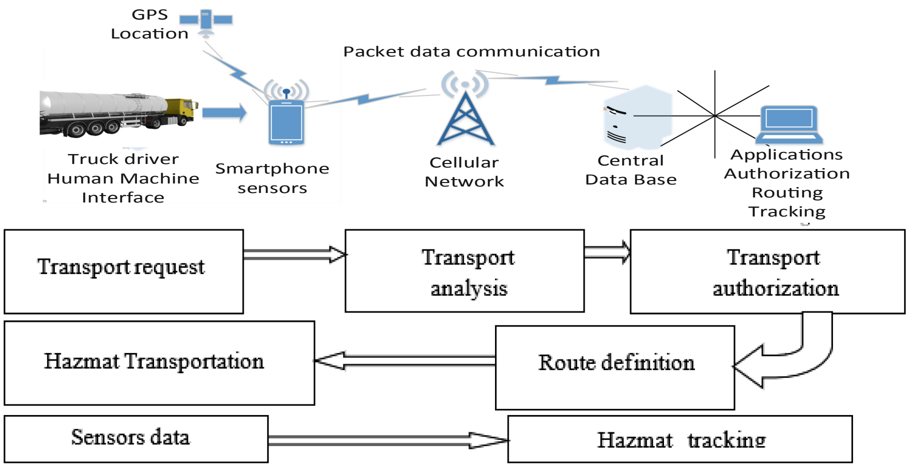

Fig. 1. A functional diagram for authorization and tracking hazmat cargo.

3.2 False-Positive Avoidance

To avoid false alarms, and unnecessary field teams' displacement [40, 41], the proposal considers artificial intelligence techniques, as well as, synchronized actions between pre-planned routes and sensors tracking with bidirectional interaction between driver and Center of Integrated Operations.

Reis et al. [2, 42], proposed smartphone sensor alarms configuration, considering carrier sensor, satellite sensor, accelerometer, gyroscope, barometer, thermometer, camera, and microphone; and according to simulations the improvements in information technology, telecommunication, and tracking management reduces the time spent in a traffic jam up to 61% [43].

4 Conclusions

Looking for the best solution to hazardous material transportation tracking with multiple mobile carriers, legacy government management systems, and budgetary difficulty to invest in a standardized system, in the biggest city of Brazil, the use of smartphones has five advantages:

- A smartphone does not require vehicle embedded systems installation.
- Smartphone uses recent data transmission technology and has a more economical natural evolution to future technologies, with the consolidation of fifth-generation networks; smartphones can have new mission-critical functions that require low latency.
- A smartphone is an available technology; it dispenses fleet adaptation or replacement in contrast to VANETs.
- Smartphones have powerful hardware, and several possibilities of sensors application, which brings flexibility and feasibility to adapt to legacy government systems.
- There are many application development platforms that custom solutions can be built through low-cost hackathons (hacker marathons) [44].

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