Internet of Things Using Smartphone Sensors to Track Dangerous Goods

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Abstract. Smartphones have had powerful edge computational capabilities at extremely feasible costs that encourage the development of many Internet of Things applications. Smartphone sensors associated with mobile applications support real-time tracking of vehicles and facilitate 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 enables interaction with drivers to determine transport schedules, restrictions, and possible route changes. Computational simulation prediction is an effective way of reducing risks and finding the optimal solution with few costs. Models were built by adding complexity and the simulated results are analyzed and compared for real-world traffic performance. The advanced simulation system makes a huge contribution to reducing traffic jams and their consequences. The results show the influence of improvements in traffic management reducing detection time and the effects caused by accidents involving the transport of hazardous materials, such as traffic jams, fuel consumption, and greenhouse gas emissions.

Keywords: Smartphones application · Tracking technologies · 5G · IoT · VANET · Hazardous materials

1 Introduction

Internet of Things (IoT) has been making devices smarter day after day [1] as well as creating new types of networks, entirely different pathways for data, information, and knowledge to travel [2]. One of its uses is in transportation such as Connected and Autonomous Vehicles (CAV). According to the Public Security Department of the Brazilian state of São Paulo, between 2001 and 2019, there was an annual average of 200 accidents involving dangerous cargo. About 10% of these accidents happened in the city of São Paulo, the biggest city in Brazil, which receives 45,000 annual applications for licenses to transport dangerous goods. In the factual workflow, transport companies need authorization from the government's Road Traffic Department, which attributes a time slot to execute the transport. There are constrained areas, but the municipality has insufficient staff to surveillance, and many times the drivers are disrespectful to the planned route, endangering many lives. IoT communication is a powerful solution to improve real-time control of dangerous goods transportation.

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This paper proposes using smartphone sensors for the management, monitoring, and control of hazardous materials road transportation as a non-intrusive and low-cost IoT solution. Section 2 introduces mobile networks, mobile applications, database hosting, and digital maps. Section 3 compares mobile technologies to track trucks: embedded modems × smartphones × vehicular networks. Section 4 proposes a workflow for hazardous cargo transportation. Section 5 simulates the benefits of better tracking control. Finally, Sect. 6 concludes the paper.

2 Related Works

There are currently over 9 billion mobile connections worldwide, which have an annual growth of 6.2% [3], and the IoT mobile is an important aspect of this growth. In cellular networks, mobile devices are classified as Mobile Stations (MS) [4]. Figure 1 illustrates the structure of a 3GPP (Third Generation Partnership Project) network where mobile devices are connected to the packet data network by Base Stations (BS). The GPRS System Support Server Node (SGSN) connects the base stations to the Home Location Register system (HLR), and to the Authentication Center (AUC) to get subscriber browsing authorization from the Internet Service Provider (ISP) using username and password. The connection between SGSN and ISP passes through the service access GateWay (GW) for browsing and using internet services [4]. With the evolution of GSM (2G) to WCDMA (3G) networks, the structure of the packet data network has been simplified; base stations no longer need external controllers; therefore, they have direct access to the SGSN. The LTE (4G) architecture is even simpler in terms of IP network elements, where packets transmitted by base stations are routed directly to the Mobility Management Entity/Gateway, giving the system greater autonomy.

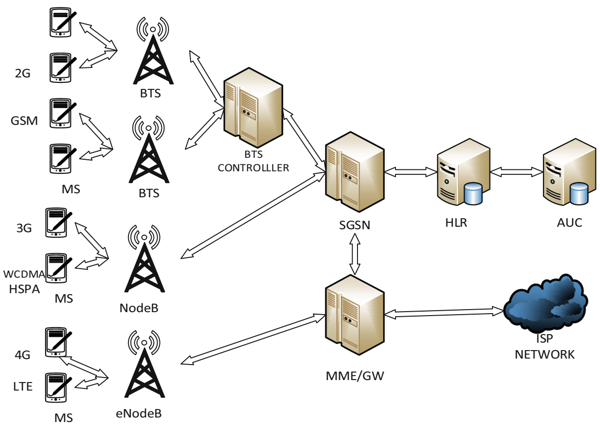


Fig. 1. The basic structure of the 3GPP network.

The fifth-generation, known as 5G technology, which is an evolution from the current LTE technology, will have more edge independence and greater spectral efficiency by working with nonorthogonal code, frequency, and time modulations. There will be more frequency bands available beyond the use of unlicensed frequencies, such as those used for Wi-Fi networks, as well as more efficient use of frequencies above 10 GHz to form high traffic cells and low coverage areas.

Figure 2 shows the signaling used in 5G networks, with the highest edge switching capability. The edge node B (eNB) implements great edge autonomy of device-to-device communication (D2D) [3].

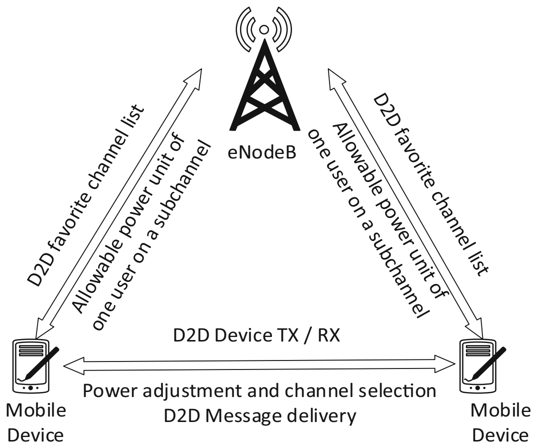


Fig. 2. D2D communication.

2.1 Tracking Devices Embedded in Trucks

Tracking systems are often proprietary systems with high costs of acquisition and maintenance, due to being equipped with a dedicated in-vehicle device, so they are expensive to install, difficult to upgrade the software, or make new configurations. Therefore, many tracker systems use short text messages (SMS) and are subject to blockage by carriers. Additionally, embedded modems use AT commands, which come from the word "Attention", on the TCP/IP layer, thus struggling to establish dedicated connections.

Considering 3GPP network architecture to authenticate the user, which is known as Subscriber Identification Mobile (SIM), it is necessary to configure the Access Point Name (APN) between the Packet Data Protocol (PDP) parameters on the respective Subscriber Identification Mobile Card (SIM-CARD) [3].

The tracking modem must be set to the Access Point Name (APN) for addressing the mobile device to the Internet Service Provider (ISP); furthermore, it needs to maintain a permanent connection between the mobile device and the tracking server.

There are four technologies to establish dedicated connections on networks using the Internet Protocol (IP):

a) The use of public IPV6 addressing, which is not yet available for all modems.

b) The use of dynamic domain name server, Dynamic Domain Name server (DDNS), with IPV4 addressing and Simple Network Management Protocol (SNMP), or Hypertext Transfer Protocol (HTTP) communication, usually through TCP/IP port 80 and socket-type connection - a connection between transport and presentation layers-. Because of a failure in public IP addressing, the connection will always be established from the modem to the server.
c) The use of intermediate gateway servers, such as used in Voice-over IP (VoIP) services. On the whole, this solution is only interesting for large-scale devices and is difficult to standardize among all transport companies.
d) The use of devices with mobile operating systems is a solution that uses the Android operating system and can be configured on a dedicated device.

Regardless of the chosen technology, a vehicle-embedded modem is necessary. Figure 3 illustrates the typical connection of these modems, which receive geo-referenced satellite information and transmit them to the central system via the packet data network.

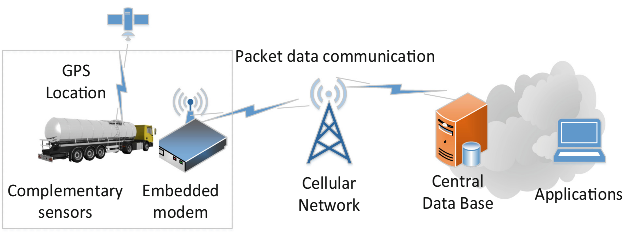


Fig. 3. Typical connection of a vehicle-embedded modem.

The 5G networks represent an evolution of 4G technology; however, other technologies of mobile devices, including 4G technologies embedded modems have become obsolete and need to be replaced, resulting in new costs of installation and configuration.

2.2 VANETs

Vehicular AdHoc Networks (VANETs) consider 5G the IoT generation, which can connect virtually any type of device, including vehicle-embedded modems. 5G promises to transfer core-to-edge functions, so it will significantly reduce latency in critical mission operations such as collision avoidance functionality in autonomous vehicles. Thus, this functionality is described as enhanced Vehicle to Everything (eV2X) within 3GPP LTE.

Figure 4 represents two IoT applications classifications [4–6]:

a) Massive applications: used in vehicle tracking. They have low cost, low power, small data, and many simultaneous devices.
b) Critical applications: used in vehicle crash control. They have high availability, very high reliability, and low latency.

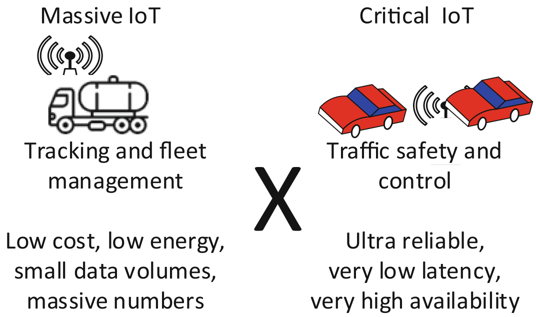


Fig. 4. Differing classification for massive and critical IoT applications.

Figure 5 shows the V2X connection (vehicles connected to everything) types: V2V vehicle to vehicle, V2I vehicle to Infrastructure, V2P vehicle to pedestrian, and V2N vehicle to network by RSU (Road-Side Unit) or carrier base station to access the internet and the application servers [7].

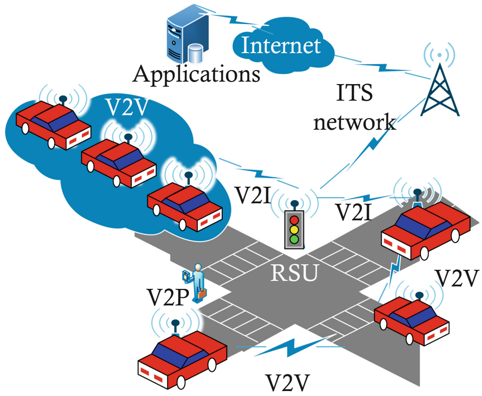


Fig. 5. V2X connection types

Embedded Systems Use Two Main concepts of intra-car networks:

- CAN: Controller Area Network. It connects various vehicle components through internal wiring, ideal for safety applications. The connection speed is 125 kbps and uses an OBU (OnBoard Unit) that connects to V2X for navigation applications and emergency detectors.
- MOST: Media Oriented System Transport, which is used for intra-car connections at 25 Mbps speed. It uses an MM (Master Most) to connect the vehicle directly to the V2N network; these connections support applications from audiovisual sources.

The vehicular networks are known as Dedicated Short Range Communication/Wireless Access in Vehicular Environments (DSRC/WAVE), they use the IEEE

802.11p protocol from the frequency band of 5855–5925 MHz. This band is adjacent to the free-use ISM band (Industrial, Scientific, and Medical) used for Wi-Fi and cordless phone, which employ the IEEE 802.11a/n/ac protocol from the band of 5470–5850 MHz; therefore they have a 5 MHz bandwidth.

There are studies for the usage of vehicular communications at frequencies above 30 GHz. However, the 5855 to 5925 MHz band allocated in Europe and the US (illustrated in Fig. 6) will be probably be used in Brazil. This bandwidth allows the deployment of 7 channels 10 MHz wide and provides data rates from 3 to 27 Mbps [4].

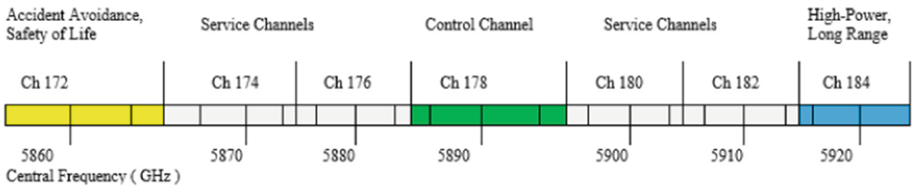


Fig. 6. VANET channels

2.3 Smartphones

The Smartphone is a consolidated technology; moreover, technological developments allow high processing capacity on mobile devices [8]. Despite the large scale of applications developed, smartphone applications are still on the rise.

The mobile carriers in Brazil have more than 779 MHz bandwidth, and, with 5G, the total bandwidth will far exceed the order of GHz. So, this will enable greater data transmission and even higher speeds than currently practiced.

2.4 Smartphones Sensors

Smartphone sensors are transducers that measure physical quantities and convert them into signals to be interpreted by operational system applications. Hence, these sensors can be used to measure, among other quantities, temperature, sound, proximity, pressure, acceleration, magnetic field, luminosity, and movement. Vehicle applications, then, are high-efficiency solutions for analyzing the growing complexity of urban vehicle traffic and enabling smarter drivability, such as vehicle location [9, 10], increased vehicle safety, driver behavior, and vehicle traffic behavior [11]. These are contributions to intelligent transport systems. For example, self-witness, [12] is a tracking system to restore ownership of the vehicle and can also be used to assist the driver in emergencies by pressing the panic button [13]. Consequently, using smartphones to collect data is a promising solution because mobile applications are easy to use, and they are in constant evolution.

For one thing, several algorithm studies enhance the use of acceleration, magnetism, and GNSS sensors to identify vehicle traffic conditions and driver behavior, specifically detecting abrupt accelerations or braking in order to indicate abnormal conditions such as rollover or collision. Then, sensor data can be analyzed to find driver behavioral patterns and vehicle traffic conditions; nonetheless, there is no perfect synchronization between the vehicle to be monitored and the source of information in a smartphone.

According to Moore's law [14], the computational efficiency doubles every 18 months; likewise, smartphones have always been updated with new functionalities and sensors improvements. So, with high popularity and scale gain, developers have had an interest in building smartphone applications using embedded sensors [15, 16] as follows:

(1) The accelerometer measures the acceleration in m/s^2 in three axes, x, y, and z [17]. It is useful to control the driver's behavior, such as strong acceleration, sudden line change, or abrupt breaks. Although car accidents usually cause an impact higher than six times the gravitational force, some smartphones are limited to three gravitational forces [18].
(2) The gyroscope detects the angular speed of the phone in rad/s and helps the accelerometer to identify the device orientation, increasing accuracy. According to Ballir et al. [19] the combined use of gyroscope, accelerometer, and GNSS sensors reaches a 99,6% accuracy rate of transportation diagnosis.
(3) The camera captures visual information, which is helpful for face recognition or environment surveillance.
(4) The Microphone captures audio information in dB, which, similar to the camera, is helpful for voice recognition and environment surveillance. So, the combined use with camera and speakers allows interactions between the driver in voice and video calls.
(5) The magnetometer detects magnetic fields in micro Tesla (uT). This can be used as a digital compass. Furthermore, combined use with other sensors improves the accuracy of location features.
(6) The GNSS (Global Navigation Satellite System) detects the latitude, the geo-referenced value concerning the equator line + North-South; longitude, the geo-referenced value relative to Greenwich + East-West; altitude or height in relation from sea level, and Speed.
(7) The Thermometer measures the device temperature in degrees Celsius and can be used to measure the ambient temperature.
(8) The Barometer measures the atmospheric pressure in hPa (1 Atmosphere represents 1013,25 hPa). According to Bhatti et al. [20], the pressure sensor has a combined use with other sensors to enhance the accuracy of the system and to reduce the chances of false accident identification; it is used to detect the pressure of a vehicle in a collision.
(9) The cellular signal sensor Network Provider is faster than the GNSS sensors, and the accuracy depends on the quantity of coverage cell overlap.

In cellular networks, the mobile station receives the signal from the best server base station. However, the mobility allows other six base stations to be candidates to the best server comparing themselves to the level of RSSI, (Received Signal Strength Indicator). Then, the mobility from cell to cell features the handover process. The signal unit is dBm. Figure 7 shows the process of trilateration, to determine the location, the intersection between three or more satellite coverage areas. The more satellites cover a given smartphone area, the greater the accuracy will be [9]. The unit is degrees.

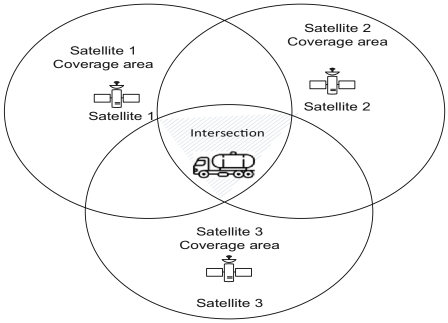


Fig. 7. Trilateration process of the satellite coverage area.

Figure 8 illustrates the location process as a function of the overlapping coverage signal levels of the cellular mobile carrier's base stations.

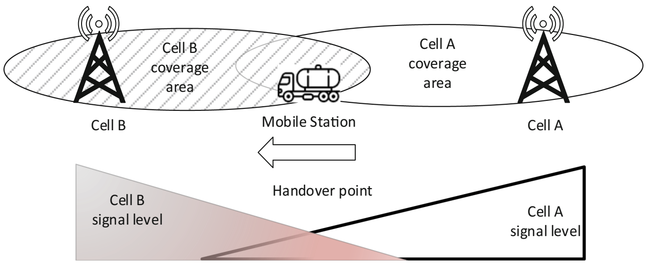


Fig. 8. The location process is presented as a function of the signal levels of the cellular mobile operator's base stations.

Figure 9 illustrates a real coverage area of fourth-generation base stations, which the mobile station is over point x, the cell site 1 is the best server and the other six base stations are candidates. The map considers the Mobile Country Code of Brazil (MCC = 724), Mobile Network Code carrier Claro (MNC = 5), type = LTE, location (an avenue near USP) latitude = −23.55003881438536, longitude = −46.72997760884627.

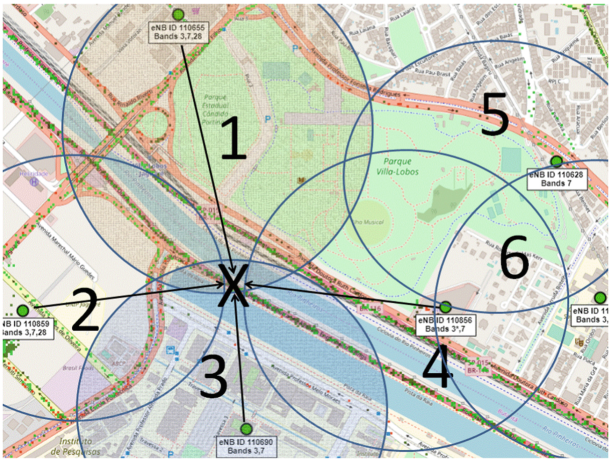


Fig. 9. Real coverage areas of 4G base stations, Source: https://www.cellmapper.net/map

Figure 10 presents the three families of smartphone sensors, GNSS, Radio Frequency, and embedded hardware [21].

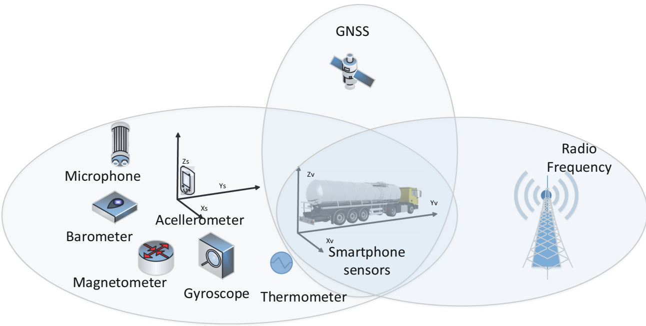


Fig. 10. The three families of smartphone sensors, GNSS, Radio Frequency, and embedded hardware [22].

The intelligent transport systems' goal is to minimize traffic congestion, so maximize the traffic flow capacity. One way to get it is the avoidance of accidents, planning, routing, and monitoring traffic.

In São Paulo city the main traffic surveillance tool is license plate readers and inductive sensors, but only 5% of the streets have surveillance, and the average time to detect an accident is 15 min.

The telemetry has the potential to be included in surveillance activity, and there are many types of applications in this area, (1) users in vehicles are connected by crowdsourcing applications [23], which can estimate traffic conditions in different parts of the city. (2) Custom applications can analyze road traffic patterns, and future traffic conditions can be estimated with dangerous situations avoidance [24]. (3) Insurance companies install IoT applications developed to track stolen vehicles, as well as monitor driving behavior, encouraging them to drive safely [25]. Various methods to detect drowsy or tired, and help drivers to cope with it, or suggest rest is presented by Clement et al. [22]. (4) A smartphone application, which estimates the driver's driving behavior using combined smartphone sensors such as the accelerometer, gyroscope, magnetometer, GNSS, and camera, has been proposed by Johnson et al. [18, 26]. It can classify non-aggressive or aggressive driver behavior and detect an accident. (5) The ADRS Accident Detection and Reporting System: a smartphone application designed by Bhatti et al. [20] detects the occurrence of an accident with the help of acceleration, speed, pressure, GNSS, and sound data. It immediately sends this information along with the location to the nearest hospital, which dispatches an ambulance.

2.5 Smartphone Orientation

When the vehicle and the Smartphone are in the same orientation, it is easy to correlate them, but there is no specific place to accommodate the device inside the vehicle, i.e. the vehicle's x-axis will not always be represented by the Smartphone's x-axis. Figure 11 shows the three orienting axes of vehicles (V) and smartphones (S) [11].

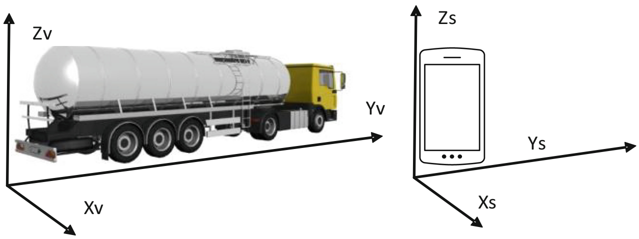


Fig. 11. The three orientation axes of vehicles (V) and smartphones (S)

The Smartphone can be placed in multiple locations and with different orientations inside the vehicle at the time of driving such as the driver's pocket, dashboard, seat, etc. Data collection can be performed with different orientation possibilities; there are relatively simple algorithms to make the treatment and in-depth analysis of the data [10]. One way to solve the orientation problem is to use an algorithm to compare the accelerometer values of the 3 axes from the value of the modules and identify the dominant axis as a speed indicator, and to avoid false alarms the best way to collect acceleration is through Eq. 1 which gives the acceleration module with the square root of the sum of squares of the acceleration values of the three axes [21].

$$|a| = \sqrt{a_x^2 + a_y^2 + a_z^2} \tag{1}$$

Equation 1 gives the value of the acceleration module, but it is not possible to know the direction of the vehicle. The combined use of the acceleration sensors with gyroscope, network provider, and GNSS sensors increases the accuracy and allows detecting position and travel speed. Based on digital maps, route analysis compares the tracked route with the planned route, in which traffic problems can be identified.

2.6 Mobile Applications

There are development platforms used to support applications to collect data from many smartphone sensors, and there are several applications to handle statistical data, capable to collect from smartphones and update data in central servers [27]. Figure 12 represents the data flow between sensors and applications of the Android operating system.

The four main data acquisition APIs are described below:

a) SensorApi - Read sensor data
b) RecordingApi - Provides data collection and storage on servers.
c) SessionsApi - Provides the application to manage user activity sessions.
d) HistoryApi - Provides access to the database with data insertion, deletion, and reading capabilities.

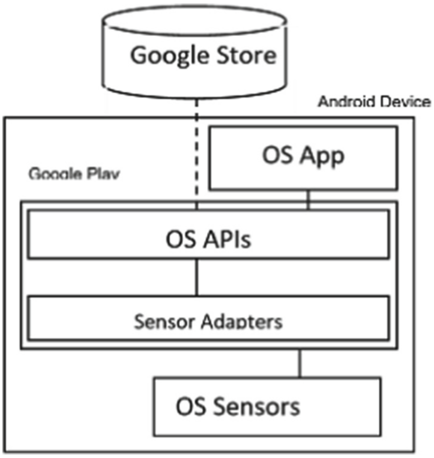


Fig. 12. Data flow between sensors and application [28]

The main location application is a digital map, where routes are defined according to restriction areas and can vary depending on the day of the week, the weather, or vehicle flow. Developed cities have georeferenced databases with various layers of interest, streets, avenues, bus corridors, schools, hospitals, restriction zones, etc. Digital maps are cartographic data digitized and stored as images and vectors; they are easily integrated with other applications to estimate routes. The use of geo-referenced maps allows route planning considering the road situation update due to congestion, falling trees, floods, marches, and other physical obstacles that may influence the traffic flow.

The first step before using digital map interfaces is to create an authentication key to provide secure access to the service. Once authenticated in web servers, users can use the map app to export in real-time the location of a smartphone. Another function is to calculate the distance and duration of a defined route date from a start address to an end address [29]. The combined use of a planned route and its real-time visualization is a very efficient way to track vehicles.

3 Comparative Analysis: Embedded Modem × Smartphone × VANETs

This section compares the technologies for hazardous cargo tracking considering multiple transport companies, legacy government management systems, and budgetary difficulty to invest in a standardized system.

3.1 Comparative Analysis: Embedded Modem × Smartphone

Embedded modems are installed in a fixed position, so the sensors' orientations will be always in the same directions as the vehicle, but smartphones' solution represents a non-intrusive solution, easier configuration, and best update.

3.2 Comparative Analysis: Cellular Networks × VANETs

On the one hand, the great advantage of VANETs networks is that the frequency band is used for a relatively small number of vehicles compared to mobile networks, on the other hand, smartphones operate over a big range of licensed frequency with higher data transmission rate and larger coverage area [30]. Table 1 presents a comparison between mobile operators' networks in 5G technology with VANETs.

Table 1. Cellular × VANET features.

Feature name	Cellular	VANET
Standardization	3GPP LTE-A	IEEE 802.11p/WAVE
Frequency band	Licensed band	5855–5925 MHz
Mobility support	$\leq$350 km/h	$\leq$140 km/h
Data rate	$\leq$300 Mbps	3–27 Mbps
Coverage range	$>$5 km	300–1000 m
Access method	D2D	Ad hoc
Latency	$<$1 ms	0,2 ms
Security	SIM card K Authentication	PKI Authentication

The IEEE 802.11 OCB (Outside the Context of a BSS) concept defines the onboard device that will equip vehicles and allow V2X networks, but it will take at least a decade to equip all vehicles and allow full interaction between them [30]. Despite smartphones do not have all the information that intra-car networks have, they are available now to all drivers, i.e., have immediate applicability.

4 The Proposed Solution for Hazardous Cargo Transportation Management

An Integrated Operations Center is a common room occupied by several areas of expertise such as police department, civil defense, firefighters, road traffic company, and medical emergency. The departments have legacy systems that focus on their areas but the systems are not integrated, neither using the same database. Moreover, only 5% of streets have surveillance in the city of São Paulo, so the lack of integration raises the delay to the time of response in abnormal conditions.

The usage of mobile apps to track trucks represents a non-intrusive solution because it dispenses embedded hardware installation. In the specific case, in which dangerous cargo transportation must be previously authorized by government authorities and, during the transport, can receive new directions, it is feasible having a bidirectional application in which the driver can send and receive information in real-time. The location process requires prior analysis of the coverage area. Smartphones are equipped with sensors that allow them to be located through calculations and trilateration of signals from satellites and radiofrequency base stations.

A relational database is proposed to host the information. (1) Id is the primary key for identifying and distinguishing a smartphone. (2) VehicleID 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 (7) altitude, (8) acceleration, (9) gyroscope, (10) compass, (11) pressure, (12) temperature, and (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 driver.

Figure 13 illustrates a functional diagram for authorization and tracking hazmat cargo.

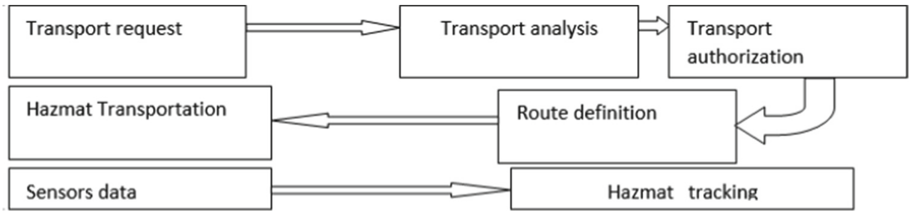


Fig. 13. A functional diagram for authorization and tracking hazmat cargo.

Figure 14 shows the interface of the smartphone application, which consists of the following activities:

Application for license requests to transport hazardous materials. The substances are classified into 13 classes according to the UN [28].

a) The responsible to transport must choose a date available for the municipality
b) The company must insert the origin address of the transportation.
c) The company must insert the destination address of the transportation.
d) The company must upload an emergency plan to restore normal situations in case of an accident
e) The municipality authorizes the transport on a given date and time slot.
f) The driver starts the transport
g) The smartphone and the hazardous material are tracked by the Integrated Operations Center

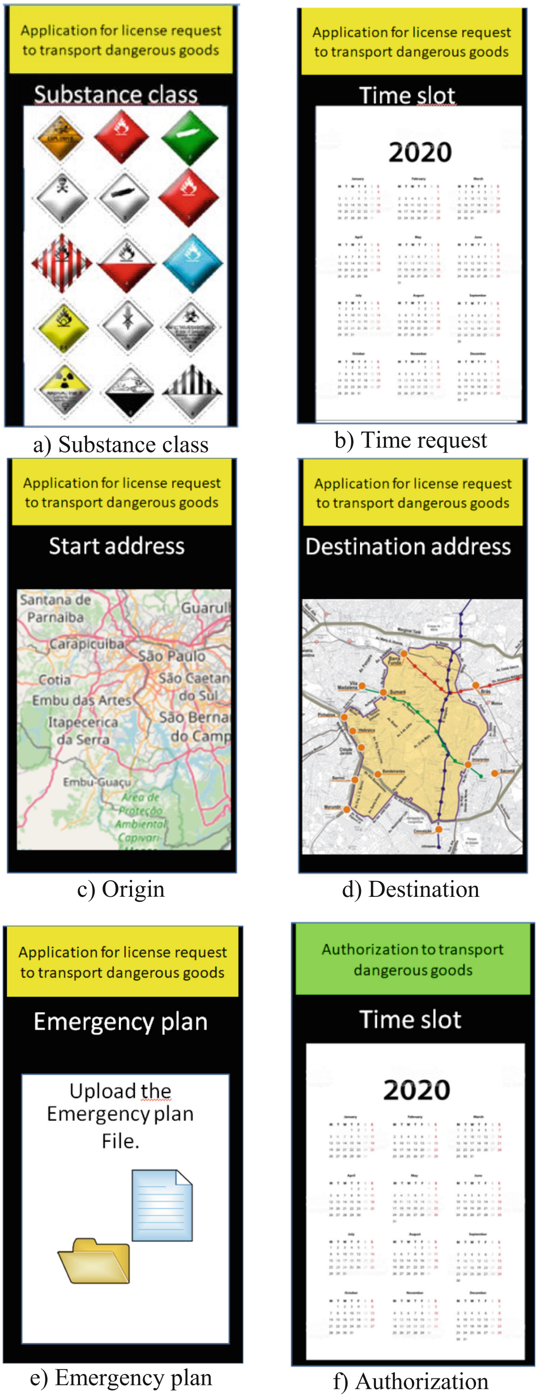
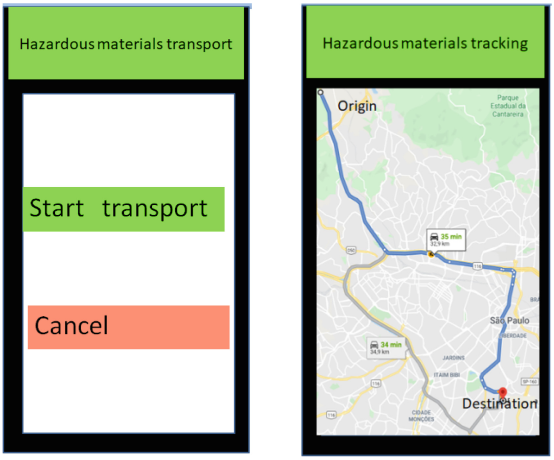


Fig. 14. The interface of the smartphone application.



g) Start transport h) Tracking

Fig. 14. continued

The accident injury scale is an acceleration function, but the lack of surveillance allows bad drivers to exceed the speed limit, which is the biggest cause of a truck accident. However, once the drivers know they are monitored by the Integrated Operations Center, they know it can punish them.

Table 2. The main alerts from smartphone sensors to the Integrated Operations Center

Sensor	Function	Reference
GNSS/Network_provider	Speed > 90 km/h	Highway limit
GNSS/Network_provider	Urban area Speed > 60 km/h	Urban area limit
GNSS/Network_provider	Difference between planned route and tracked route > 200 m	Considering a planned route and real-time tracking, the route analysis compares the location considering the traffic behavior
Accelerometer	$\|a\| = \sqrt{a_x^2 + a_j^2 + a_z^2} > 3 * 9{,}8\,\mathrm{m/s^2}$	A smartphone drop in free fall means 9,8 m/s^2 acceleration
Gyroscope	$\|\omega\| = \sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2} > \pi/6\,\mathrm{rad/s^2}$	The truck's stability considers 280 as the maximum side slope
Ambient temperature	Ambient Temperature > 80 °C	A closed vehicle under the Sun reaches 70 °C
Microphone	Noise > 140 dB	An explosion produces high noise, bigger than traffic or engines noises

According to Reis et al. [31, 32], an alert is triggered as a possible accident. In order to avoid false-positive alarms, it is necessary a well-done calibration considering artificial intelligence techniques [33], as well as bidirectional interaction between drivers and Integrated Operational Center. Table 2 presents the main alerts and their reference calibrations.

5 Simulation Results

Considering the more relevant times of obstruction, it is possible to analyze three blocks:

- Detection time: Currently, 15 min is the average time for a patrol to detect an accident. It can be reduced to 3 min, considering the online surveillance, tracking vehicles, filtering, and classifying the alerts
- Field teams' displacement time: Currently, 45 min is the average time for field teams to move from headquarter to an affected location. This reduction will be studied in future works.
- Removal and release of pathways time: Currently, 90 min is an average time to remove vehicles without complex leaks of hazardous substances. It can be reduced to 45 min, considering the knowledge of substance characteristics, the field team can control the situation with a better approach.

The simulation considered the attendance rhythm as 2,000 vehicles/hours/lane, an HCM2000 limitation [34]. Reports from São Paulo Traffic Engineering Company – CETSP [35] present measures of the arrival rate of 1,930 vehicles/hour/lane. IoT technologies can improve traffic management control, so they can promote a reduction from 150 min to 93 min of obstruction time per accident.

Figure 15 illustrates a 150-min obstruction time after an accident, in the current situation; and a 93-min obstruction time after an accident, with improvements, in the proposed situation.

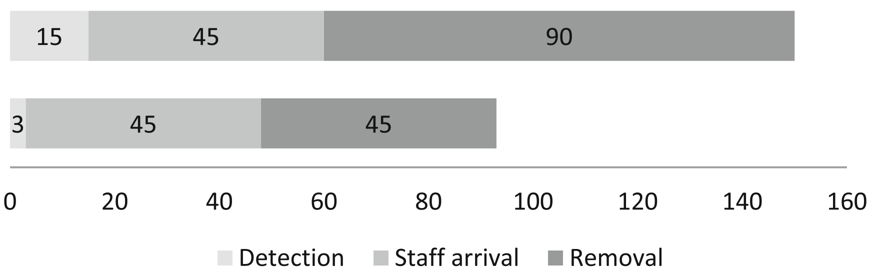


Fig. 15. The events of an accident are composed of detection, staff travel, and removal time.

Blocking one of the six lanes of an express urban way the total attendance rate will be lower than the arrival rate, so it will form a queue during the obstruction time, and the queue will be released after the situation is regularized.

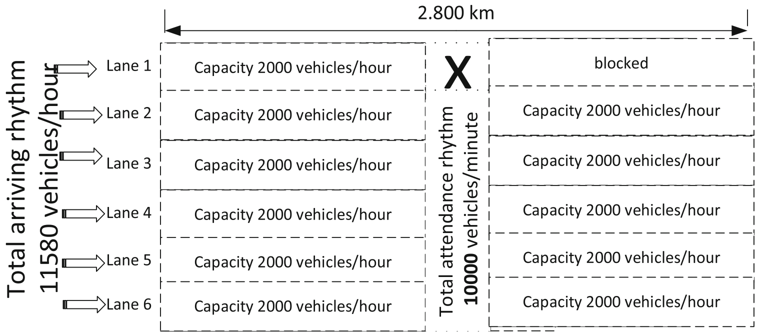


Fig. 16. The scenario that was simulated in Rockwell Arena.

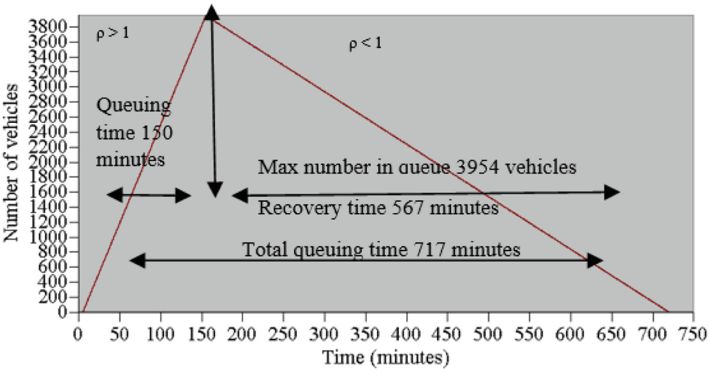
Figure 16 Illustrates the scenario simulated in Rockwell Arena [36].

Figure 17 presents the results of the simulation. Initially a reduction from 12,000 to 10,000 vehicles/hour and the release to the full capacity after the system regularization. The area of the triangle formed by the total queuing time and the maximum number of vehicles in the queue is called total delay, whose unit is veh-min [36, 37].

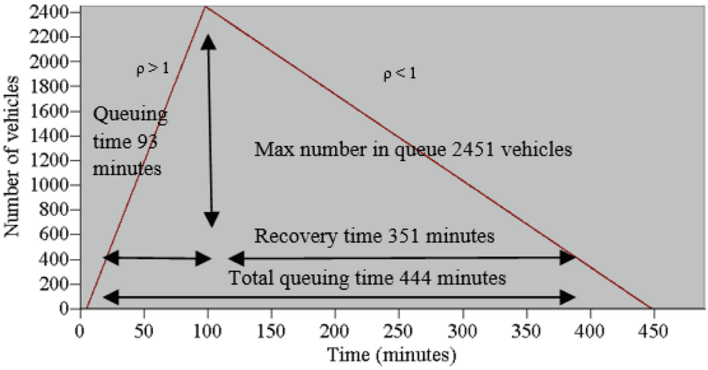
a) Graphic of the number of vehicles queued in 150-min obstruction.
b) Graphic of the number of vehicles queued in 93-min obstruction.
c) Graphic of arrival and departure functions in 150-min obstruction.
d) Graphic of arrival and departure functions in 93-min obstruction.

Table 3 presents the results of the simulation considering one of the six lanes obstruction.

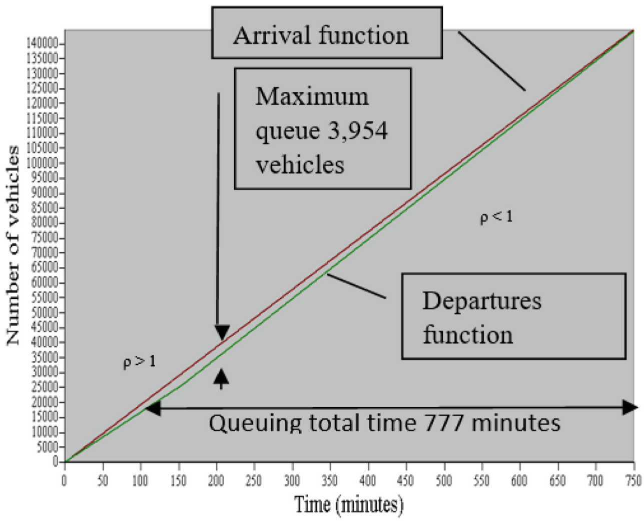
As a result of simulations is possible to conclude that the total delay reduced from 1,418,269 veh-min to 545,182 veh-min, which is 61% of the reduction in total delay, presented in Fig. 18. It represents savings on fuel consumption, CO_2 emission, less time in traffic jams, a better quality of life, and more productivity of urban citizens [33, 38, 39].



a) 717 minutes of total queuing time.

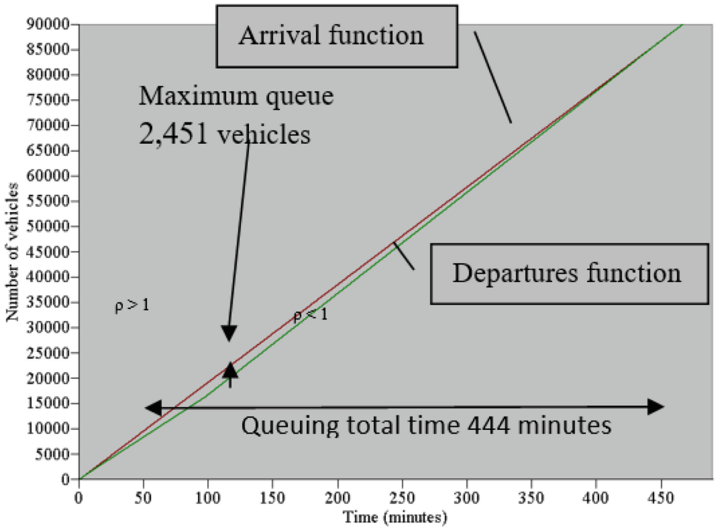


b) 444 minutes total queuing time



c) maximum queue of 3,954 vehicles

Fig. 17. Graphs with simulation results.



d) maximum queue of 2,451 vehicles

Fig. 17. continued

Table 3. Results comparison 150-min × 93-min obstruction.

Features\Simulation	150-min obstruction	93-min obstruction
Total waiting time	717 min	444 min
The maximum quantity of the vehicles in a queue	3,954 vehicles	2,451 vehicles
Congestion impact or total delay	1,418,269 veh-min	545,182 veh-min

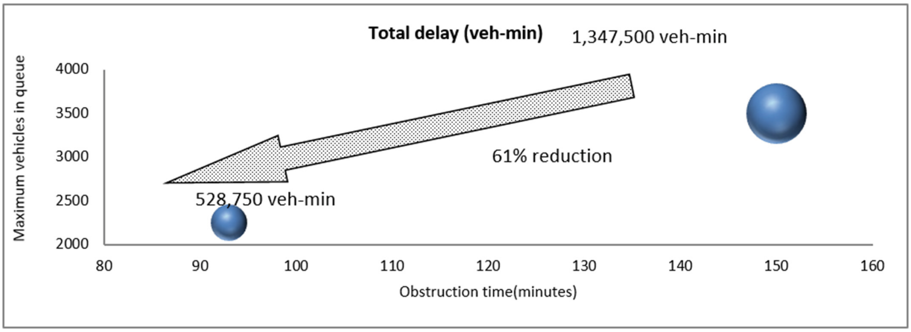


Fig. 18. Graph of total vehicle delay as a function of blocking time.

6 Conclusion

Looking for the best solution to hazardous cargo 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) The smartphone does not require vehicle embedded systems installation.
b) There are many application development platforms where custom solutions can be built through low-cost hacker marathons
c) Smartphone uses recent data transmission technology and has a more economical evolution for future technologies, with the consolidation of fifth-generation networks; smartphones can have new mission-critical functions that require low latency.
d) The smartphone is an available technology; it dispenses fleet adaptation or replacement as VANETs do.
e) Smartphones have powerful hardware, and several possibilities of sensors application, which brings flexibility and feasibility to adapt to legacy government systems.

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