



SMART MOBILITY: ROAD INCIDENT MONITORING SYSTEM FOR URBAN TRAFFIC MANAGEMENT

Movilidad Inteligente: Sistema de Monitoreo de Incidentes Viales para la Gestión del Tráfico Urbano

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ABSTRACT

This article describes the process, tools, and technological platforms used to implement a computer system that collects, processes, transforms, stores, and analyzes real-time traffic incidents. This system, fed by data from the Waze application accessed through the Waze for Cities program, aims to support decision-making in urban traffic management. Its implementation uses a spiral methodology that generates evolutionary deliveries, progressing towards more complete versions. The architecture, components, and data flow are detailed, allowing to get interactive and summarized views of the information, including filters, analysis, summaries, statistics, and maps. An application case is presented in the city of Bogotá, where the Secretariat of Mobility uses the real-time traffic incident monitoring system and integrates it with other information systems to identify incidents, congestion, or roadblocks, anticipating problems and planning strategies focused on optimizing mobility in the city. The system can collect and process large amounts of information, perform advanced data analysis to identify mobility patterns, anticipate critical points, and predict contingencies such as accidents or blockages. This information facilitates a more agile and accurate response by transport authorities and strengthens evidence-based decision-making, contributing to more efficient, safer, and citizen-centered traffic management.

Keywords: geospatial big data; incident analysis; real-time data; smart mobility; traffic management; traffic optimization.

RESUMEN

Este artículo describe el proceso, las herramientas y las plataformas tecnológicas empleadas para implementar un sistema informático que captura, procesa, transforma, almacena y analiza incidentes viales en tiempo real. Dicho sistema, alimentado por datos de la aplicación Waze, a los que se accede a través del programa Waze for Cities, busca apoyar la toma de decisiones

en la gestión del tráfico urbano. Su implementación se efectúa usando una metodología en espiral que se caracteriza por generar entregas evolutivas, que van progresando hacia versiones más completas. Se detallan la arquitectura, los componentes y el flujo de datos, que permiten obtener como resultado vistas interactivas y resumidas de la información, incluyendo filtros, análisis, resúmenes, estadísticas y mapas. Se presenta un caso de aplicación en la ciudad de Bogotá, donde la Secretaría de Movilidad utiliza el sistema de monitoreo de incidentes viales en tiempo real y lo integra con otros sistemas de información con el objetivo de identificar incidentes, congestiones o bloqueos viales, anticipar problemas y planificar estrategias enfocadas a la optimización de la movilidad en la ciudad. El sistema tiene la capacidad de recolectar y procesar grandes volúmenes de información, para realizar análisis de datos avanzados que permitan identificar patrones de movilidad, prever puntos críticos y anticiparse a eventualidades como accidentes o bloqueos. Esta información facilita una respuesta más ágil y precisa por parte de las autoridades de transporte y fortalece la toma de decisiones basadas en evidencia, lo que contribuye a una gestión del tráfico más eficiente, segura y orientada a las necesidades de los ciudadanos.

Palabras clave: análisis de incidentes; datos en tiempo real; datos masivos geoespaciales; gestión del tráfico; movilidad inteligente; optimización de tráfico.

MOBILIDADE INTELIGENTE: SISTEMA DE MONITORAMENTO DE INCIDENTES VIÁRIOS PARA A GESTÃO DO TRÁFEGO URBANO

RESUMO

Este artigo descreve o processo, as ferramentas e as plataformas tecnológicas utilizadas para implementar um sistema computacional que captura, processa, transforma, armazena e analisa incidentes de trânsito em tempo real. Esse sistema, alimentado por dados do aplicativo Waze, acessados por meio do programa Waze for Cities, visa apoiar a tomada de decisões na gestão do tráfego urbano. Sua implementação segue uma metodologia em espiral, caracterizada por entregas evolutivas que avançam para versões mais completas. São detalhados a arquitetura, os componentes e o fluxo de dados, permitindo obter visualizações interativas e resumidas da informação, incluindo filtros, análises, resumos, estatísticas e mapas.

É apresentado um caso de aplicação na cidade de Bogotá, onde a Secretaria de Mobilidade utiliza o sistema de monitoramento de incidentes viários em tempo real e o integra com outros sistemas de informação para identificar incidentes, congestionamentos ou bloqueios nas vias, antecipar problemas e planejar estratégias focadas na otimização da mobilidade urbana. O sistema é capaz de coletar e processar grandes volumes de dados, realizar análises avançadas para identificar padrões de mobilidade, prever pontos críticos e antecipar contingências como acidentes ou bloqueios. Essas informações facilitam uma resposta mais ágil e precisa por parte das autoridades de transporte e fortalecem a tomada de decisões baseadas em evidências, contribuindo para uma gestão do tráfego mais eficiente, segura e centrada no cidadão.

Palavras-chave: dados massivos geoespaciais; análise de incidentes; dados em tempo real; mobilidade inteligente; gestão do tráfego; otimização do tráfego.

1. INTRODUCTION

Urban mobility is one of the main challenges in large cities due to historical, geographical, social, and political factors such as rapid population growth, urban sprawl, and lack of adequate infrastructure to manage traffic [1]. The increasing concentration of people in urban areas increases the demand for transport, resulting in congestion, long waiting times, and growing environmental pollution [2]. The lack of efficient and accessible public transport systems in many cities forces residents to rely on private cars, exacerbating traffic problems, increasing carbon emissions, and affecting the citizens' quality of life [3].

In Latin America, cities such as Lima, Mexico City, and Bogotá face serious traffic problems due to rapid urbanization, lack of infrastructure, and increased use of private vehicles, leading to high congestion rates in the region, according to the TomTom traffic index [4]. Various strategies have been explored

to improve urban mobility, such as vehicle restraint [5], road pricing [6], enhanced public transport [7], [8], [9], bicycle and pedestrian infrastructure [10], [11], low emission zones (LEZs) [12], car sharing [13], [14], [15], electric vehicle infrastructure [16], urban planning with a '15-minute city' approach [17], teleworking [18], and the use of smart technologies for real-time traffic management [19].

Technological tools such as mobile apps, traffic sensors, big data analytics, and artificial intelligence have become essential to improve the efficiency and sustainability of urban mobility, supporting decision-making and the implementation of intelligent mobility systems.

The Waze application has gained prominence by providing real-time traffic information, including accidents, road works, and other obstacles, to offer alternative routes and improve navigation efficiency [20]. This tool enables user participation, both passively through automatic data sharing and actively by sending information about traffic conditions [21]. Data collected in real-time from applications such as Waze, sensors, and other sources is essential for efficient traffic management. It can reduce travel times, monitor roads, identify congestion patterns, and respond to incidents. Its integration into intelligent transport systems (ITS) improves decision-making and optimizes mobility [22].

This paper describes the implementation of a computer system that uses Waze data to collect, process, store, monitor, and analyze road incidents to support decision-making in urban traffic management in large or densely populated cities.

2. METHODOLOGY

Four of the most recognised and widely used software development methodologies were analysed for the implementation of the system for monitoring and analysing traffic incidents reported in Waze: Waterfall, RAD, Boehm's six-stage spiral model, and Scrum. The choice was made by considering the advantages of each approach in relation to certain key characteristics relevant to the project. [Table 1](#) compares the characteristics of each method concerning the aspects analyzed.

In summary, the six-stage adaptation of Boehm's spiral model is ideal for dynamic, high-risk projects such as the Waze traffic incident monitoring system because of its flexibility, risk management, continuous feedback, and incremental product delivery. This approach outperforms more rigid methods, such as the waterfall model and agile approaches that prioritise rapid delivery without detailed planning and explicit risk assessment.

Applying the six-stage adaptation of Boehm's spiral model to the development of the proposed system, four iterations were undertaken, allowing incremental improvements and functionality to be incorporated. This approach facilitated risk management, adaptation to change, and ensured that the final product was robust and fit for purpose. [Figure 1](#) illustrates the methodology used, highlighting each of the phases and iterations of the model.

Table 1. Comparative analysis of software development methodologies concerning critical aspects of the project lifecycle

Characteristic	Waterfall	RAD	Scrum	Boehm's six-stage spiral model
Flexibility and Adaptability	Rigid and sequential, making it difficult to incorporate changes once the project has started [23].	Offers more flexibility by focusing on prototypes and rapid delivery. However, it depends on available resources and tools [24].	It is very adaptable because it sprints, which makes it possible to keep adapting according to customer needs [25].	Combines structured planning with continuous risk assessment and feedback. This allows constant adjustments throughout the project [26]
Risk management	It is limited because it only addresses risks at the beginning of the project, making it difficult to manage them at later stages [23].	Although it allows for rapid adjustments, its rapid approach means it struggles to identify long-term risks [24].	With its iterative approach, it manages the risks in each sprint, but it may not provide a complete view of the long-term risks [25].	It is characterised by its ability to manage risks on an ongoing basis, allowing them to be identified, analysed, and mitigated throughout the project through a cyclical planning and evaluation approach [27].
Continuous Feedback and Communication	Limits feedback to certain stages, which can cause a delay in the identification of problems [23].	Allows for more frequent feedback. However, it focuses on specific functionality and may miss important details [24].	Ensures issues are addressed quickly by encouraging continuous feedback through short sprints, daily meetings, and retrospectives [28].	It allows for ongoing evaluation, continuous feedback, and fluid communication between stakeholders, adapting quickly to change and keeping the focus on the project objectives [26].
Error Correction and Continuous Product Improvement	It is the least flexible for error correction because errors are not identified until the end of each phase, which can delay corrections and hinder continuous improvement [23].	Allows for rapid error correction through prototyping and continuous feedback, but its accelerated approach may not allow for deep, long-term correction [24].	Encourage continuous improvement in short sprints, making it easier to identify and correct errors quickly [28].	With its cyclical approach and continuous evaluation, it allows early and continuous identification and correction of errors, ensuring continuous improvement in line with the project's objectives, thanks to constant feedback from stakeholders [26].

The tasks carried out in each phase were:

Communication: Ongoing communication was established with potential users to identify needs, define goals, and gather relevant information.

Planning: In each iteration, goals, specifications, time, and resources were defined, and components were adjusted and added to the system.

Risk Analysis: Each iteration evaluated potential risks, including technical challenges, tools, resources, and their availability.

Engineering: Performed component analysis and design, recording tasks in Azure DevOps for detailed progress tracking.

Build and Deploy: Software components were built and customized, tested, implemented, and integrated into the system, and related documentation was created.

Evaluation: Obtained feedback from users and experts, reviewed the product globally, and implemented improvements in subsequent releases.

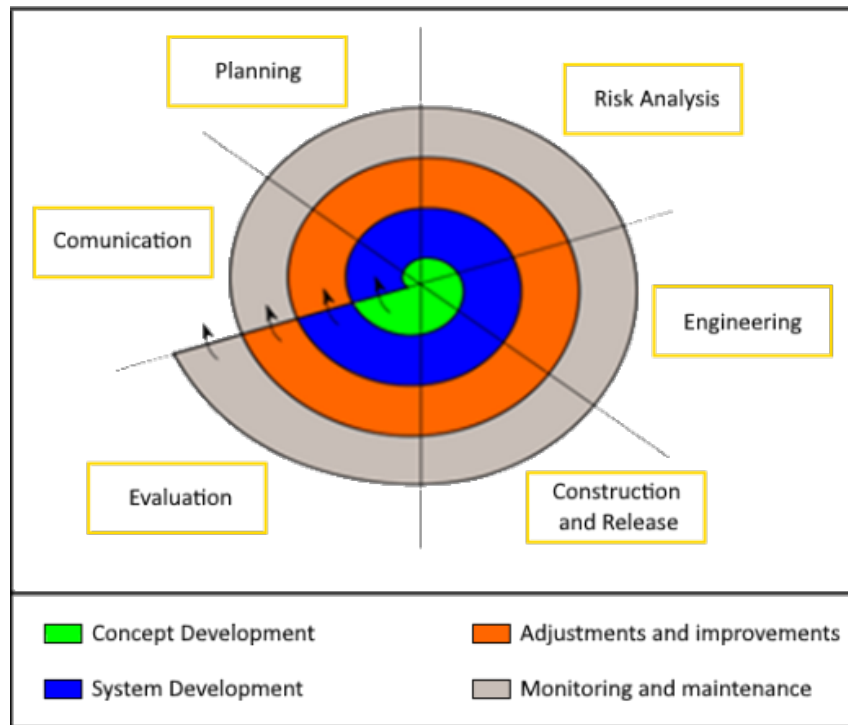


Figure 1. 6-stage extended spiral model adaptation (Modified from the Stages and Activities diagram of the Six Region Spiral Model available at Ana Guevara website [29]).

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3. RESULTS

3.1 System Architecture

The architecture of the road incident monitoring system is composed of multiple integrated layers to ensure an efficient data flow. First, the information is collected in real-time through the Waze mobile application, which, as part of the Waze for Cities program, is responsible for enriching and exposing the data in JSON or XML formats through web services Scripts written in Python read, cleanse and debug this information before it is integrated into ArcGIS GeoEvent Server and then stored in the ArcGIS Spatio-Temporal Big Data Store. ArcGIS Online accesses this repository to create geographic layers and maps. Finally, visualization and analysis are performed using tools such as ArcGIS Dashboards and Geographic Viewers, which provide interactive functionalities to monitor incidents, identify patterns, and support decision-making in urban traffic management. [Figure 2](#) shows the architecture of the implemented system and the interaction of the different components involved.

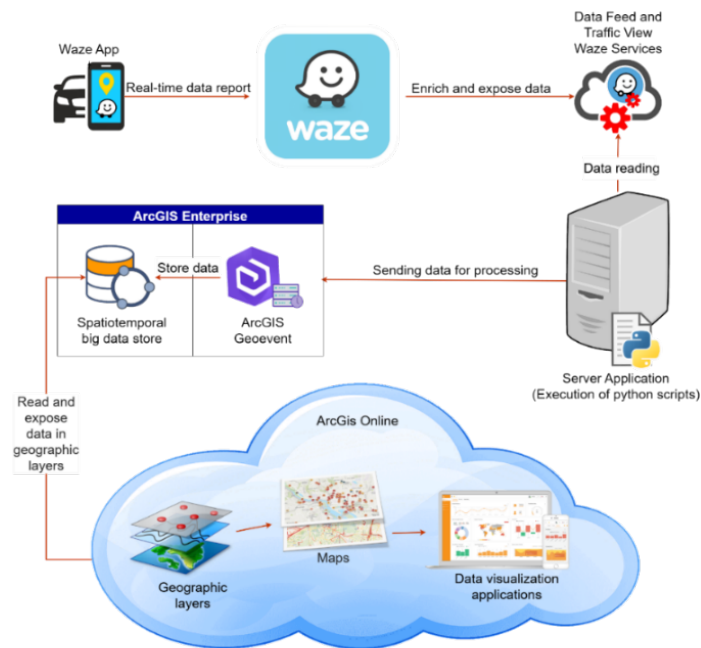


Figure 2. Architecture of the system for monitoring and analyzing incidents reported in Waze.

3.2 System Components

The components of the real-time road incident monitoring system work in an integrated and automatic manner. Data flows through each element sequentially as shown in [Figure 3](#).

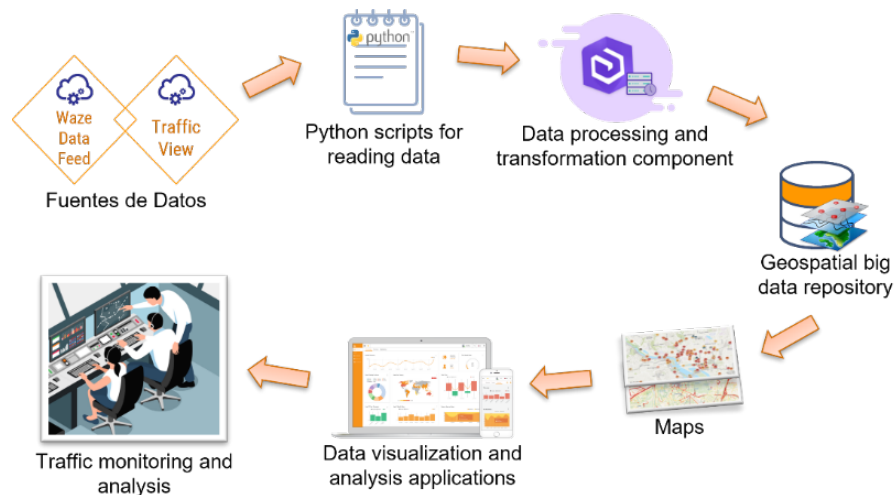


Figure 3. Components of the system for monitoring and analyzing incidents reported in Waze.

Data sources: The traffic incident monitoring system uses information from Waze’s Waze Data Feed and Traffic View services, accessed through the Waze for Cities partnership. These services provide accurate, real-time information on traffic, incidents, and congestion, among other relevant factors.

Waze data feed service: Waze reports on traffic congestion and incidents using reports from users and external sources. The data is updated every 2 minutes and distributed via a GeoRSS feed with coordinates in XML or JSON format [30]. The Waze data feed service provides the following information:

- **General data:** Date, time of archiving, and geographical area of the data.
- **Traffic alerts:** User-reported traffic incidents.
- **Traffic congestion:** Information about traffic congestion generated by the service based on the user’s location and speed.
- **Unusual traffic (irregularities):** Traffic alerts and congestion affecting an unusually large number of users.

The description of the attributes included in the Alerts, Jams, and Irregularity datasets can be found in the “Waze Data Feed Specifications” document available on the Waze Partner Help website [30].

Traffic View Service: Provides real-time traffic information for specific areas and routes within the approved polygons for each partner in the Waze for Cities program. The data is updated every 2 minutes and is provided in GeoRSS format (XML or JSON) [31]. The Traffic View service includes the following information:

- **General data:** Date, time of submission, geographical area from which the data was obtained, and number of users in congestion.
- **Users in congestion:** Number of users per level of congestion.
- **Congestion length:** Total length of congestion in the bounding box by congestion level (indicates how congested the area is).

- **Routes:** Roads or groups of road segments set up for monitoring in Waze.
- **Irregularities (also known as unusual traffic):** A list of routes with high ETAs compared to historical ETAs, identifying 'unusual traffic events'. The data included is the same as for routes in general.

Figure 4 shows the general structure of the information displayed by the Waze Data Feed and Traffic View services in JSON format, with an example of real data.

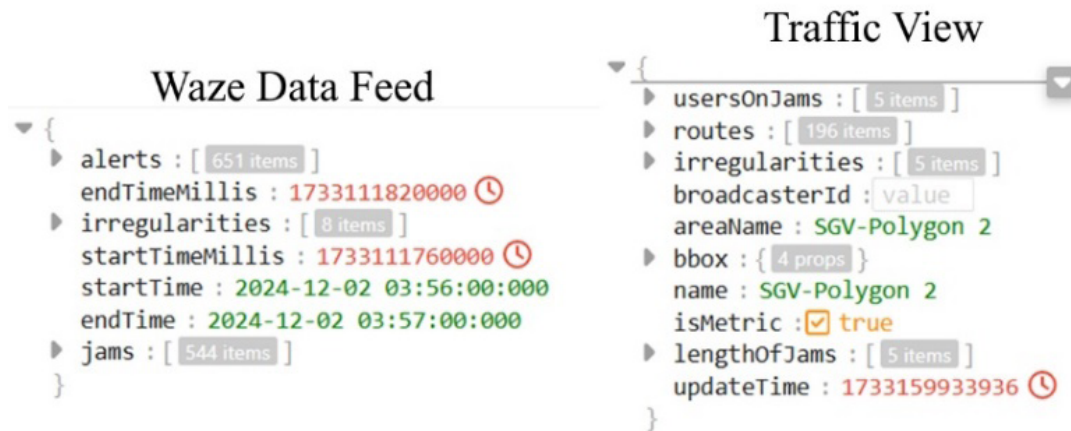
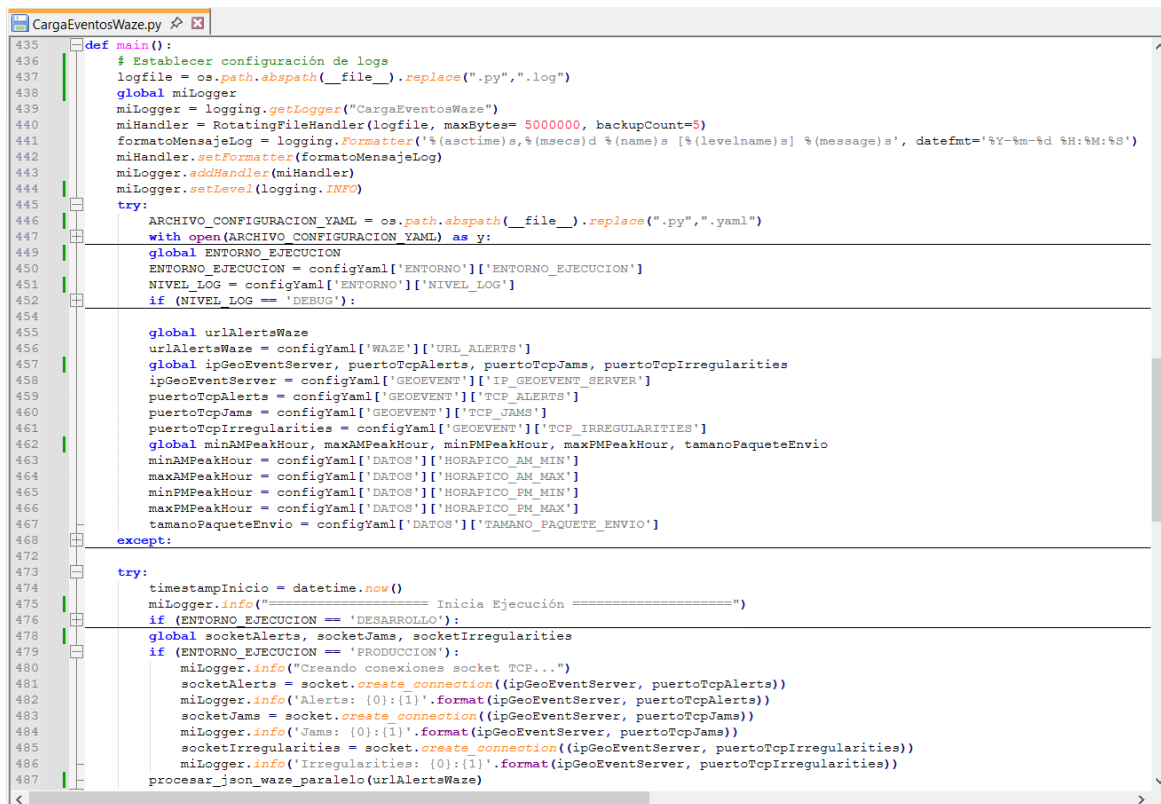


Figure 4. General structure of Waze Data Feed and Traffic View Services JSON format.

Data reading scripts: To read the data exposed in the Traffic View and Waze Data Feed services, a configuration file is created that sets the general execution parameters and two Python scripts that are responsible for periodically retrieving the data from the endpoints exposed by Waze in JSON format and then sending it to the ArcGIS Gevent tool for processing and transformation. The data retrieval scripts use threads to process each type of data in parallel to improve efficiency. After extracting the data, new fields are calculated and added based on the incident information (alerts, congestion, irregularities). Text strings representing each incident are then created and sent via TCP socket to ArcGIS GeoEvent Server. The process is recorded in trace files, and a scheduled task runs the scripts every two minutes to read the data from Waze. Figure 5 shows a partial view of one of the Python scripts implemented to read road incidents from Waze.

Data processing and transformation component: ArcGIS GeoEvent Server is used to receive and transform data. TCP input connectors are configured to process event data formatted as delimited text. GeoEvent services take the input data and transform it into geographic elements (points and lines), which are then sent via output connectors to the geographic layers in the ArcGIS Enterprise spatio-temporal big data store.

Geospatial Big Data Repository: Stores and geo-referenced Waze data in geographic layers inserted through the ArcGIS Gevent Server output connector. The information is organised into the following layers (Table 2).



```

435 def main():
436     # Establecer configuración de logs
437     logfile = os.path.abspath(__file__).replace(".py", ".log")
438     global miLogger
439     miLogger = logging.getLogger("CargaEventosWaze")
440     miHandler = RotatingFileHandler(logfile, maxBytes= 5000000, backupCount=5)
441     formatMensajeLog = logging.Formatter('%(asctime)s, %(secs)d %(name)s [%(levelname)s] %(message)s', datefmt='%Y-%m-%d %H:%M:%S')
442     miHandler.setFormatter(formatMensajeLog)
443     miLogger.addHandler(miHandler)
444     miLogger.setLevel(logging.INFO)
445     try:
446         ARCHIVO_CONFIGURACION_YAML = os.path.abspath(__file__).replace(".py", ".yaml")
447         with open(ARCHIVO_CONFIGURACION_YAML) as y:
448             global ENTORNO_EJECUCION
449             ENTORNO_EJECUCION = configYaml['ENTORNO']['ENTORNO_EJECUCION']
450             NIVEL_LOG = configYaml['ENTORNO']['NIVEL_LOG']
451             if (NIVEL_LOG == 'DEBUG'):
452                 global urlAlertasWaze
453                 urlAlertasWaze = configYaml['WAZE']['URL_ALERTS']
454                 global ipGeoEventServer, puertoTcpAlerts, puertoTcpJams, puertoTcpIrregularities
455                 ipGeoEventServer = configYaml['GEOEVENT']['IP_GEOEVENT_SERVER']
456                 puertoTcpAlerts = configYaml['GEOEVENT']['TCP_ALERTS']
457                 puertoTcpJams = configYaml['GEOEVENT']['TCP_JAMS']
458                 puertoTcpIrregularities = configYaml['GEOEVENT']['TCP_IRREGULARITIES']
459                 global minAMPeakHour, maxAMPeakHour, minPMPeakHour, maxPMPeakHour, tamanoPaqueteEnvio
460                 minAMPeakHour = configYaml['DATOS']['HORAPICO_AM_MIN']
461                 maxAMPeakHour = configYaml['DATOS']['HORAPICO_AM_MAX']
462                 minPMPeakHour = configYaml['DATOS']['HORAPICO_PM_MIN']
463                 maxPMPeakHour = configYaml['DATOS']['HORAPICO_PM_MAX']
464                 tamanoPaqueteEnvio = configYaml['DATOS']['TAMANO_PAQUETE_ENVIO']
465     except:
466         pass
467     try:
468         timestampInicio = datetime.now()
469         miLogger.info("===== Inicia Ejecución =====")
470         if (ENTORNO_EJECUCION == 'DESARROLLO'):
471             global socketAlerts, socketJams, socketIrregularities
472             if (ENTORNO_EJECUCION == 'PRODUCCION'):
473                 miLogger.info("Creando conexiones socket TCP...")
474                 socketAlerts = socket.create_connection((ipGeoEventServer, puertoTcpAlerts))
475                 miLogger.info('Alerts: {0}:{1}'.format(ipGeoEventServer, puertoTcpAlerts))
476                 socketJams = socket.create_connection((ipGeoEventServer, puertoTcpJams))
477                 miLogger.info('Jams: {0}:{1}'.format(ipGeoEventServer, puertoTcpJams))
478                 socketIrregularities = socket.create_connection((ipGeoEventServer, puertoTcpIrregularities))
479                 miLogger.info('Irregularities: {0}:{1}'.format(ipGeoEventServer, puertoTcpIrregularities))
480                 procesar_json_waze_paralelo(urlAlertasWaze)

```

Figure 5. Partial view of one of the Python scripts for reading Waze events. The image shows the reading of the configuration file and the creation of sockets for processing each type of data.

Maps: Integrate layers of information for more detailed analysis, incorporating complementary data that makes it easier to identify complex areas, apply filters, classify data, create summaries, and generate statistics. When combined with dynamic data from Waze, users can identify mobility patterns, plan alternative routes, and develop data-driven urban planning strategies.

Applications for data visualisation and analysis: Traffic incidents, once processed and transformed into thematic maps, are used to create applications, viewers, and dashboards. These allow real-time monitoring of traffic flow, congestion, speed, road conditions, and problem areas using Waze data. Base maps, sensor data, traffic lights, public transport, and cameras are integrated to enrich the information. ArcGIS Dashboard, ArcGIS Online, and Portal for ArcGIS create interactive dashboards and viewers that allow users to customise visualisation, apply filters, sort data, and generate statistics.

Below are some of the dashboards, maps, and applications designed to provide multiple views of data and help manage traffic in large cities using information from Bogotá.

Dashboard for exodus operation and return plan (monitored road corridors): This dashboard (Figure 6) monitors speeds during high mobility seasons (vacations, holidays, events) for exodus operation and return plan in Bogotá. Available publicly on the Secretariat of Mobility's ArcGIS portal or via URL [32], it allows filtering data by monitored section, date, and time. The split screen shows data for entering (top) and exiting (bottom) the city, with maps highlighting the monitored road corridors and arrow symbology indicating the direction of the road. It includes statistical graphs of average speeds by section and time of day for ingress and exits.

Comparative dashboard of speeds on monitored road sections: This dashboard (Figure 7) allows you to compare speeds on sections of road monitored by Waze. It has a general multi-select filter and filters in the left panel for date, day, and time ranges. One or more road sections can be selected for analysis, and the date range to be used for data comparison must be specified. The maps highlight the selected road corridors, and the lower part shows bar and line graphs of average speeds by road segment or hour. It is available to the public on the ArcGIS portal of the Bogotá Mobility Secretariat or via the URL [33].

Table 2. Geographical layers created for the registration of data obtained from Waze services

Layer Name	Geometry	Source	Description
Waze_Alerts	Point	Waze Feed	Data Contains traffic alert information reported by users through the Waze app.
Waze_Jams	Line	Waze Feed	Data Records traffic jam information based on location, speed, and Waze user alerts.
Waze_Irregularities	Line	Waze Feed	Data Log incidents or unusual events that affect traffic or driver experience on the road.
Waze_Routes	Line	Traffic View	Stores traffic data associated with a specific route, section, or road previously configured to be monitored in Waze.
Waze_Subroutes	Line	Traffic View	Contains the definition of sub-sections into which a monitored route is divided due to different levels of congestion.
Waze_LeadAlerts	Point	Traffic View	Corresponds to the alerts associated with the monitored routes, which are prioritized as the most important.
Waze_Recent_Alerts	Point	Waze Feed	Layers destined to register alerts, traffic jams, and irregularities generated in the last hour. They are used to optimize the visualization, consultation, and filtering of information in real-time monitoring applications.
Waze_Recent_Jams	Line	Waze Feed	
Waze_Recent_Irregularities	Line	Waze Feed	

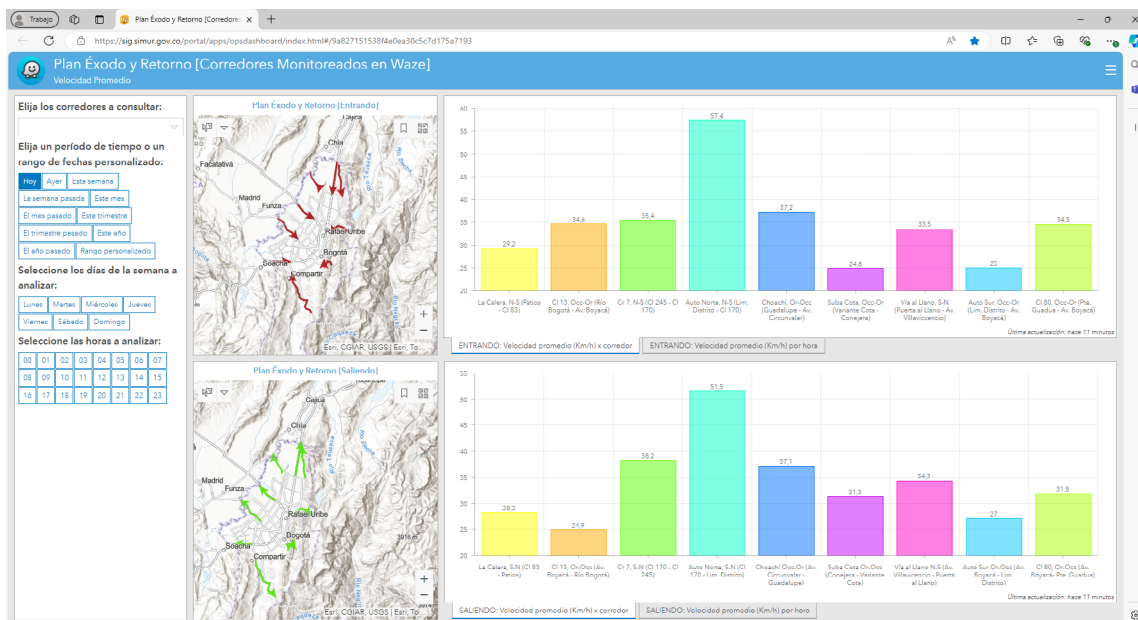


Figure 6. Exodus operation and return plan dashboard (monitored road corridors) in Bogotá. The red lines on the upper map represent the roads entering the city, and the green lines on the lower map represent the roads leaving the city. Statistical graphs with average speeds per road corridor are included [32].



Figure 7. Comparative dashboard of speeds on monitored road sections in Bogotá. This view shows a comparison of average speeds per hour, for the road section 'AUTONORTEdeCL168aCL100', on the dates 06/01/2025 (left map, green line) and 13/01/2025 (right map, blue line) [33].

Congestion analysis dashboard: This tool monitors and evaluates congestion levels in real time for the city. The congestion level displayed indicates the percentage of the road network reported by Waze as congested (speeds between 0 and 20 km/h). Two classification maps are presented, one by Transport Analysis Zones (TAZ) and one by localities, the conventions of which are shown in the left panel. Bar charts showing the level of congestion by location and road corridor are included. This dashboard (Figure 8) is available via URL at [34].

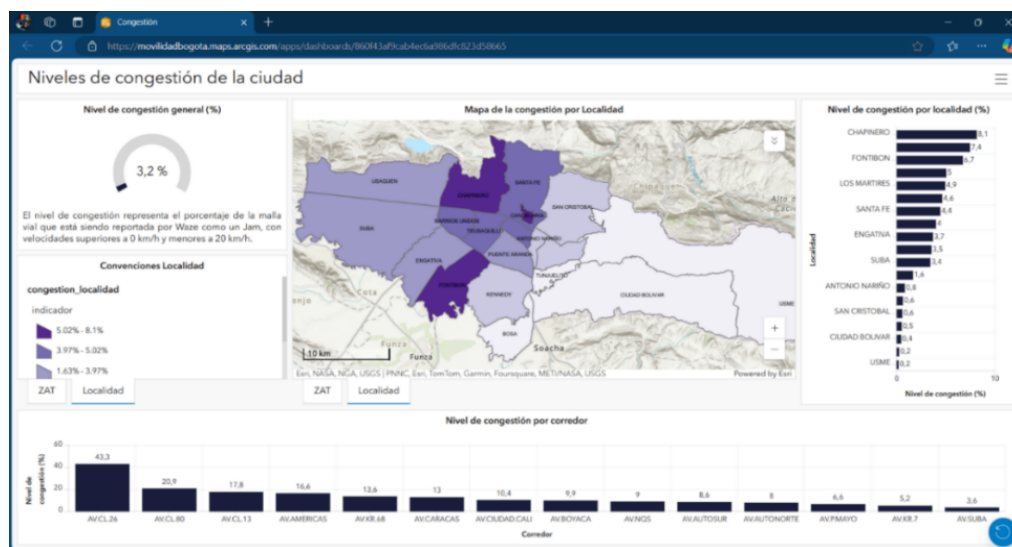


Figure 8. The congestion levels dashboard in Bogotá. In this case, it shows an overall congestion level of 3.2%. The map and graph on the right show that the localities with the highest congestion levels are Chapinero, Candelaria, and Fontibon. The graph below lists the most congested road corridors in descending order of reported congestion levels [34].

4. DISCUSSION AND CONCLUSIONS

The use of real-time data for urban traffic management is a growing trend worldwide. The works and information systems that have been developed to support this task vary widely in complexity, coverage, and operational approach. Systems such as that of the City of Singapore described in its ITS (Intelligent Transport Systems) report [35], the SCATS system developed by the New South Wales (Australia) Government's Main Roads Department [36], and the ATSAC system in Los Angeles [37] focus on integrating data from multiple sources, such as real-time sensors and cameras, to optimise traffic flows through adaptive traffic signal control. These systems are highly centralised and operate within a robust public infrastructure, intending to maximise urban traffic efficiency on a large scale.

Similarly, proposals such as that of Yisheng, Lv et al. [38] and Mohamed Abdel et al. [39] use adaptive control and predictive algorithms to manage traffic more accurately by making automatic adjustments based on the analysis of large amounts of data. These approaches are designed for rigorous and centralised control, allowing long-term planning and continuous optimisation of the transport infrastructure.

Real-time traffic management systems in Brazil and Barcelona are characterised by the integration of different technologies and data sources, both infrastructure and user data, to monitor and optimise urban traffic. Barcelona [10] uses real-time information on vehicle flows and public transport to improve mobility, while Brazil [40] focuses on planning and operational efficiency by analysing large amounts of data. These approaches prioritise local coordination, technological interoperability, and strategic planning, but require large investments in infrastructure and efficient data integration to be effective.

In contrast, platforms such as Waze, which allow users to report traffic incidents in real time, offer a more decentralised and collaborative approach. While not relying on the centralised infrastructure of the aforementioned systems, Waze relies on the active collaboration of users to share information about accidents, road closures, and congestion. This community feedback enables a more agile response to unexpected traffic events, although its effectiveness depends largely on the volume of active users and the accuracy of the reports. In contrast to centralised traffic management systems, Waze relies more on the democratisation of information, allowing flexibility for rapid response, but with less control over data quality and accuracy.

In summary, traffic systems such as SCATS, ATSAC and those implemented in Singapore, Barcelona and Brazil, as well as those proposed by Yisheng, Lv et al. [38] and Mohamed Abdel et al. [39], are characterised by their ability to handle large amounts of data in a controlled manner and with global optimisation goals. However, real-time data sharing, as facilitated by the Waze for Cities programme, offers a more distributed and cost-effective alternative, allowing users to generate real-time traffic information, but relying more on community input. Both approaches have their advantages and limitations, depending on the specific needs of cities and the infrastructure available.

The Waze for Cities program demonstrates how public-private partnerships can improve the ability of local governments to address the challenges of limited infrastructure and high traffic density. Through the use of mobile technology and collaborative data analysis, traffic management can be more agile and effective.

This partnership has been used in a variety of ways in several Latin American cities. In Mexico, for example, the collaboration with Waze has enabled city authorities to receive real-time data on traffic congestion, helping to make traffic management decisions, especially in areas of high congestion [41]. In Buenos Aires, Waze has facilitated the collection of information on accidents and road closures, allowing

drivers to choose alternative routes in real time, contributing to the decongestion of the city, particularly on the main road network [42]. In São Paulo, the system has worked closely with the government to improve mobility planning and reduce the environmental impact of transport, with a particular focus on promoting sustainable mobility and integration with other public transport platforms [43]. Meanwhile, Chile has used Waze to optimise traffic management in Santiago, integrating real-time data with public transport decisions to improve traffic flow during peak hours [44].

In Bogotá, the traffic incident monitoring system uses information from Waze for Cities to improve real-time traffic management. Continuous data analysis identifies patterns that allow for better urban planning and preventive measures. Since its implementation, traffic distribution and incident response have been optimised. In addition, the Mobility Secretariat shares advanced information on closures and events, helping to reduce congestion and improve the driver experience, as well as reducing congestion caused by unforeseen events [45]. Some of the applications and dashboards created with data from Waze are shared on the Mobility Observatory website (<https://observatorio.movilidadbogota.gov.co/>), in the Integrated Regional Urban Mobility Information System SIMUR (<https://www.simur.gov.co/>), and others are available at the Bogotá Transit Management Center (CGT), which ratifies their relevance for incident monitoring, decision making and knowledge building in the mobility sector. Similarly, with the large amount of information collected, studies are being carried out to generate congestion indices [46] and analyze the road accident situation [47].

The use of the Waze incident monitoring system for urban traffic management has important practical and theoretical implications. On the practical side, it allows for real-time data collection and improved decision-making to optimise vehicle flow and incident response. On the theoretical side, it raises challenges about data accuracy, as it relies on user participation, and opens up new lines of study on collective intelligence and its application in urban traffic. Questions also arise about the scalability of the system and its integration with emerging technologies such as autonomous vehicles and intelligent transport systems.

On the other hand, interpreting the results of the traffic incident monitoring system provides an interesting picture of real-time traffic dynamics. Data collected from Waze users, including reports of accidents, congestion, obstructions, and adverse weather conditions, provides a detailed and up-to-date view of road conditions. By analysing these incidents, problem areas can be quickly identified, allowing traffic authorities to take appropriate action. However, relying on user reports also presents challenges in terms of accuracy and coverage, as not all incidents are reported, and the information may be subject to bias or delays. Nevertheless, the results generated by this system are a valuable tool for improving urban traffic management, providing dynamic information that can be used to reduce congestion and improve road safety.

The prospects of the IT system for collecting, processing, storing, monitoring, and analysing data on road incidents reported on Waze open up a wide field for innovation and the development of new solutions in traffic management and intelligent mobility. Among the most promising lines of research are the incorporation of artificial intelligence to predict traffic patterns, the development of advanced interactive analysis tools, and the integration with public transport and micro-mobility platforms to promote a more sustainable and efficient ecosystem for cities and their inhabitants.

AUTHOR CONTRIBUTIONS

Sulma-Rocío Pedraza-Farías: conceptualization, formal analysis, investigation, software, validation, visualization, writing – original drafts

Gustavo Cáceres-Castellanos: project administration, supervision, writing – review & editing.

Jorge-Enrique Quevedo-Reyes: project administration, supervision, writing – review & editing.

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