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Original Article

Design of Machine Learning-Based Software for Transportation Optimization and Accident Reduction

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Abstract - *Traffic congestion and accidents have been critical problems in urban environments, especially in cities with limited infrastructure and a lack of updated data. This work presented the conceptual design of an application aimed at optimizing routes, improving urban mobility, and contributing to the reduction of road incidents. The methodology used was Design Thinking, which allowed for the identification of user needs and the proposal of innovative solutions through the integration of technologies such as Flutter, Firebase, and TensorFlow Lite. The proposed design included algorithms capable of analyzing real-time data from sensors, cameras, and GPS devices, with the goal of anticipating traffic patterns and generating more efficient routes. Additionally, functionalities such as a scoring system to evaluate driver behavior and an administrative dashboard for managing alerts and traffic analysis were proposed. It was concluded that the conceptual design exhibited significant potential to improve road safety in high-congestion areas and promote more efficient mobility. Future research suggested the development or implementation of this design, in addition to expanding the system's geographic coverage and evaluating its impact on the sustainability of urban transport.*

Keywords - *Software design, Machine Learning, Transportation optimization, Accident reduction, Prototype.*

1. Introduction

Traffic congestion and high accident rates in modern cities have posed significant challenges due to a lack of integration and efficient transport management [1]. Furthermore, the absence of real-time data hampered route and schedule optimization, resulting in long travel times and increased road safety. An international analysis even highlighted traffic congestion trends in cities such as Manila, Philippines, and Bengaluru, India, where average travel times were observed to reach extremely high levels, with typical routes lasting between 23 and 25 minutes [2]. Specific studies found that traffic congestion had reached critical levels, with cases recorded where 10-kilometre routes were taking up to 24 minutes. Furthermore, financial losses related to these problems were estimated to exceed S/. 2 billion [3]. Factors such as environmental pollution and poor infrastructure were also found to significantly worsen the situation. The use of Machine Learning (ML) in urban transport optimization has proven to be an effective strategy for addressing mobility-related problems. In this context, ML-based technologies were used to analyze large volumes of real-time data from sensors, cameras, and GPS devices. These technologies facilitated the detection of traffic patterns and potential risks, enabling dynamic decision-making aimed at route optimization, reducing accidents, and improving urban transport efficiency. The study addressed the problems associated with inefficient traffic management and the lack of effective accident prevention tools in highly congested urban environments. The lack of integrated and predictive solutions significantly limited the response capacity to risk situations, affecting road safety and citizens' quality of life. Faced with this problem, he proposes a conceptual software design based on ML techniques aimed at optimizing urban transportation and contributing to the reduction of traffic accidents. The design includes the analysis of real-time data from cameras, sensors, and GPS devices, with the aim of identifying congestion patterns and potential risks. Although this is an initial proposal, it is hoped that this initiative will motivate future research focused on developing and implementing technological solutions to address traffic congestion and improve road safety in urban environments.

The contribution of this study lies in the development of an innovative technological solution that combines the use of ML with a user-centered design approach. The methodology applied was Design Thinking, which allows the identification of viable solutions to urban transportation problems [4]. Unlike previous studies, this study emphasizes the application of lightweight ML models integrated into a platform developed with Flutter and TensorFlow Lite, which allows for easy implementation on various devices. The contribution of this study lies in the proposal of an innovative technological solution that combines the use of ML with a user-centered design approach. The Design Thinking methodology was employed, which allowed for the identification of relevant problems in the field of urban transportation and the proposal of viable solutions. Unlike previous research, this study stood out for its emphasis on the conceptual design of ML, integrated into a platform designed with Flutter and TensorFlow Lite, which facilitates its potential adaptation to various devices. It should be noted that the research was limited exclusively to the design proposal, excluding practical implementation stages. This article is structured into five chapters. First, the background to the problem and the objective of the study are presented. Second, a comprehensive review of the literature on the topic is offered. Third, the methodology used is described based on Design Thinking to focus the greatest rigor on the user impact. Fourth, the results obtained are presented, including prototype graphics that reflect the progress made in the development of the objective. Fifth, the discussions, comparing the results obtained with previous studies. Finally, the conclusion is presented and emphasizing recommendations for future research.

2. Literature Review

Recent research has explored innovative transport optimization and accident reduction approaches in urban environments. Studies using data from GPS sensors, accelerometers, and connected vehicle systems were analyzed, highlighting the use of route classification and prediction algorithms as key tools for improving urban mobility. These approaches have proven effective in reducing travel times and associated risks, significantly contributing to road safety. Technical challenges related to the integration and reliability of data sources were also identified, which limited the implementation capacity in certain environments. The reviewed research agreed on the need to develop proposals geared toward technological adaptation, prioritizing conceptual designs over practical development stages. These findings provided a solid framework for future exploration of solutions that strengthen transportation management and optimize the quality of life in modern cities.

In Ireland, several machine learning models were evaluated to predict the duration of motorway incidents. The results showed that Support Vector Machines were most effective for short and medium duration incidents, while Artificial Neural Networks excelled in cases of prolonged incidents [5]. On the other hand, another study addressed the lack of automation in identifying travel phases in public transport, proposing a GPS-based model that classified trip stages with high accuracy, thus improving the efficiency of urban transport planning [6]. On the other hand, in the Latin American context, a study carried out in Peru proposed the application of data science techniques aimed at optimizing mass transit routes. This proposal significantly reduced waiting times by 66% and minimized the number of transfers by 69%, which represented a relevant advance in public transport management [7]. Together, these studies provided evidence on the positive impact of integrating advanced techniques in urban mobility, underscoring the importance of designing solutions that contribute to traffic optimization and road safety. It should be noted that the reviewed research is limited to conceptual design proposals, not including development or practical implementation stages.

On the other hand, [8] examined the optimization of the Quality of Service (QoS) in urban vehicular networks, focusing on the prediction of key metrics such as bitrate and packet loss in ITS-G5 and 5G technologies. Furthermore, [9] proposed an intelligent transportation system based on connected vehicle networks, highlighting its capacity to improve traffic management and the detection of anomalies in the vehicular network. This system achieved an accuracy of 99.05% in traffic classification. Complementarily, in Lisbon [10], the estimation of passenger drop-off stops in single-access fare collection systems was investigated using smart card data. This approach achieved an accuracy of 92.84%, surpassing traditional methods by 11 percentage points. Together, these investigations evidenced the importance of proposals that seek to optimize traffic, increase the efficiency of public transport and improve data-driven urban planning. It should be noted that such research was limited to conceptual design, not including development or practical implementation stages.

Several studies have addressed challenges related to the accurate identification of transport modes in urban environments. One study [11] proposed a model based on GPS, accelerometers and heart rate data, achieving 95% accuracy in predicting bicycle trips and 65% for public transport. On the other hand, efficient public transport management requires analyzing large volumes of data generated by sensors and fare control systems. In this context, another study [12] employed specialized algorithms to identify demand patterns, highlighting the importance of standardizing data sources and fostering interdisciplinary collaboration between scientists and transport specialists.

In a different field, a study carried out in Cuenca, Ecuador, developed a model based on classification techniques to analyze geolocation data obtained from mobile devices. This approach achieved high accuracy in categorizing mobility patterns, suggesting its potential usefulness for optimizing urban dynamics and promoting sustainability in transportation [13]. These contributions demonstrated the relevance of conceptual proposals aimed at designing innovative solutions that improve traffic planning and management in modern cities. Finally, [14] analyzed the difficulty of classifying transport modes and accurately calculating waiting and access times to public transport stops in Rome, Italy. To address this problem, an algorithm based on data from mobile devices and machine learning models was developed. The methodology included the collection of user trajectories and the implementation of a random forest model together with a convolutional neural network. The main results showed that the random forest model obtained an accuracy greater than 95% in predicting walking times, while the neural network reached approximately 81% in classifying transport modes. These findings demonstrated the effectiveness of the proposed models in improving the understanding of mobility patterns in urban environments, favoring the optimization of public transport.

Overall, the reviewed literature highlighted the potential of data-driven approaches to transform transportation management, from route improvement to mode classification and incident prediction. However, persistent challenges were identified, such as integrating multiple data sources and needing more robust models applicable to diverse urban environments. This research provided a solid theoretical framework for the conceptual design of solutions aimed at improving urban mobility and road safety. It should be noted that the reviewed studies were limited to design proposals, not including practical implementation stages.

3. Methodology

For the development of the application, a hybrid approach of the Design Thinking (DT) methodology was used, a human-centered approach to problem solving.

3.1. Design Thinking

Design Thinking was widely recognized as a human-centered innovation methodology for its effectiveness in developing technological proposals focused on optimizing experiences and solving specific problems. This approach was characterized by its systematic structure, which allowed for a deep understanding of the challenges posed, fostering the generation of viable solutions aligned with user needs.

3.2. Phases of the Methodology

The Design Thinking approach is particularly well-suited to this study, as it allows us to address problems from a human-centered perspective. Its structure is organized into six phases, divided into three main categories, as illustrated in Figure 1.

3.2.1. Understand

Empathize

In this phase, the needs and problems of end-users, including drivers and pedestrians in Lima, who face traffic congestion and high accident rates on a daily basis, are analyzed [15]. Tools such as surveys, interviews, and observational studies are considered for this analysis. These techniques allow the collection of relevant information on users' experiences, perceptions, and expectations regarding urban mobility [16]. This approach favors a deep understanding of their concerns and the impact of traffic on their quality of life, thus laying the foundation for the design of a solution focused on their specific needs.

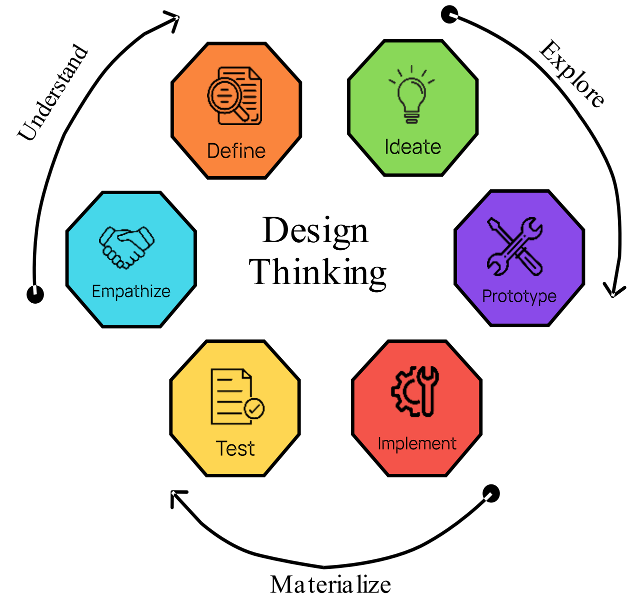

Fig. 1 Design thinking methodology

Define

In this phase, the collected data were analyzed and organized in order to establish a direct relationship with the main objective to be addressed [16]. In the context of Lima, traffic congestion and the high accident rate constituted critical challenges for urban mobility. A precise definition of the problem made it possible to guide the design of viable solutions, such as the development of an application based on machine learning techniques that optimizes traffic and contributes to improving road safety [17].

3.2.2. Explore

Ideation

During this phase, potential solutions are proposed to mitigate the negative effects of traffic and accidents [18]. To this end, an innovation team was formed to generate viable ideas aligned with the project objectives. Additionally, advanced technologies such as machine learning, real-time data analysis, and route optimization systems were explored, which allow the generation of predictive models capable of anticipating congestion scenarios and critical risk points [19].

Prototype

In this phase, a functional prototype of an application aimed at improving urban mobility is built [20]. This solution integrates features such as real-time congestion prediction, data analysis for alternative route suggestions, and customized geolocation tools. To ensure its effectiveness, the prototype has been evaluated by users, allowing for the identification of opportunities for improvement in its design and functionality and making the necessary adjustments according to the detected needs [21].

3.2.3. Materialize

Implementation

In this phase, the solution was integrated and deployed in a controlled or real environment, based on the previously validated prototype [22]. The application incorporates functionalities such as real-time congestion prediction, data analysis for the recommendation of alternative routes and customized geolocation tools.

The implementation allowed observing [23] the behavior of the system under real conditions, facilitating the identification of possible failures, performance improvements and adjustments necessary for its future scalability.

Evaluate

Finally, in this phase, the application has been tested with real users, who provide feedback on its accuracy, ease of use, and ability to reduce travel times and accident risks [24]. This evaluation has been crucial to identify possible improvements before its large-scale implementation. This process analyses aspects such as user acceptance, performance under various conditions, and the impact on urban mobility [25].

3.3. Tools for Design

For the development of the application focused on traffic optimization and accident reduction in Lima, various tools are considered to ensure efficient integration between technologies, ensuring an intuitive and accessible interface for users.

3.3.1. Figma

It is a cloud-based design and prototyping tool used to create interactive user interfaces. Its collaborative functionality allows multiple users to work simultaneously on the design of screens, facilitating early validation of the interaction flow [26]. In this project, Figma has been used to develop the interfaces that would show optimized routes and traffic alerts, allowing the simulation of the navigation of drivers and administrators within the application [27].

3.3.2. MongoDB

For real-time data management, such as GPS location and traffic logs, NoSQL databases have been used, notable for their ability to store unstructured information and synchronize it efficiently [28].

3.3.3. PostgreSQL

It has been used to manage structured data, such as user profiles and historical records of routes and accidents. Its ability to perform advanced geospatial queries facilitates analyzing traffic patterns and identifying high-risk areas [29]. In addition, its use allows for flexibility in data management, optimally adapting to the dynamic needs of the application [30].

3.3.4. Flutter

It has been used as the main framework for development, enabling the creation of a single code base for applications on Android and iOS. Its widget-based architecture guarantees the implementation of complex graphical interfaces, such as optimized route maps and real-time alerts [31, 32].

3.3.5. TensorFlow Lite

For the integration of the machine learning model in charge of route optimization, this tool is implemented, which allows running artificial intelligence models on mobile devices with high performance, ensuring real-time processing of traffic data and road conditions [33, 34].

3.3.6. Firebase Cloud Firestore

It has been used to enable offline-online synchronization, allowing users to access relevant information without an internet connection [35]. Data is stored locally and automatically synchronized when a connection is available [36].

3.3.7. Firebase Authentication

A secure authentication system is implemented for access management, protecting user data and ensuring security in traffic optimization [37]. Encryption protocols are also integrated to protect information in transit and at rest [38].

3.3.8. Google Cloud

The application is deployed on cloud infrastructure, allowing automatic scaling based on the number of users. These platforms ensure high performance, integrating directly with database, storage, and machine learning services, facilitating comprehensive system management [39, 40].

4. Results

This section presents the results obtained from the application design, developed using the Design Thinking methodology, for the development of a technological solution aimed at optimizing traffic and reducing accidents. The proposal includes an application designed to improve urban mobility by integrating smart tools that facilitate safe and efficient navigation. The results include the planned addition of key features, such as a mapping module with optimized routes, a road safety module, and an administrative dashboard. Additionally, the implementation of a traffic and accident alert system was planned, allowing users to receive immediate notifications about congestion or hazardous situations. A user interface prototype was also designed using Figma, and a preliminary usability analysis predicted an intuitive and user-friendly experience. This approach seeks to ensure that the proposed solution effectively addresses the city's mobility needs, promoting the use of technological tools to improve road safety and traffic efficiency. The user interface prototype focused on developing an intuitive navigation system that prioritizes safety and efficiency in urban mobility. Figure 2 illustrates the prototype, showing an interactive map with key landmarks and optimized routes, highlighted in blue for ease of viewing. A conceptual route calculation algorithm was designed to provide step-by-step directions with accurate estimated times for each segment of the journey. Additionally, the system was designed to offer real-time updates at 6- to 8-minute intervals, ensuring that users receive up-to-date information throughout their journey.

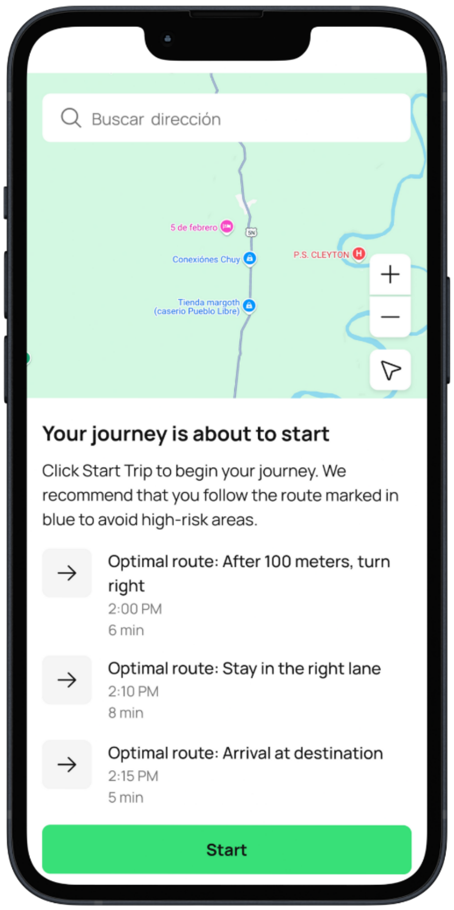

Fig. 2 Safe navigation map module

Figure 3 shows the development of the road safety module, which incorporates an ML-based scoring system that evaluates driver behavior in real time. This module analyzes four main metrics: safe driving (70%), speed (60%), phone use (50%), and harsh braking (40%). To do so, it utilizes device sensors and driving data, enabling the generation of personalized alerts.

Additionally, a high-risk zone detection system was implemented by analyzing historical data and predictive models, providing timely warnings to reduce accidents. Figure 4 presents the prototype welcome screen, which displays an interactive map at the top, followed by the user's location in the middle. Finally, a list of the generated route optimizations was included at the bottom, designed to facilitate navigation and improve the user experience.

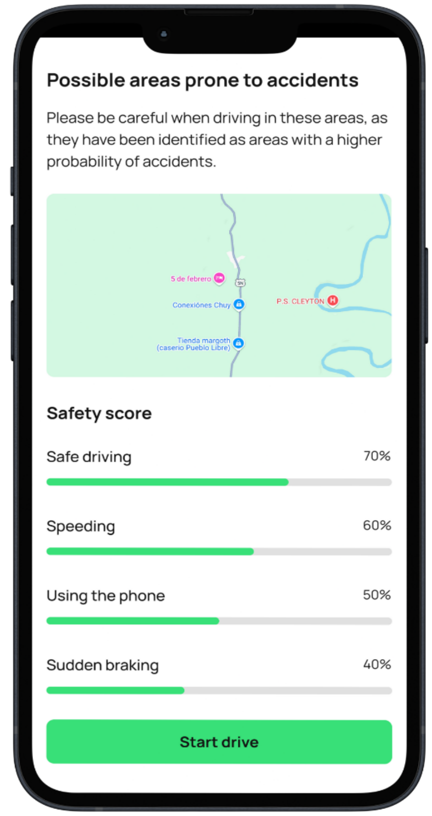

Fig. 3 Safety module with driver behavior scoring

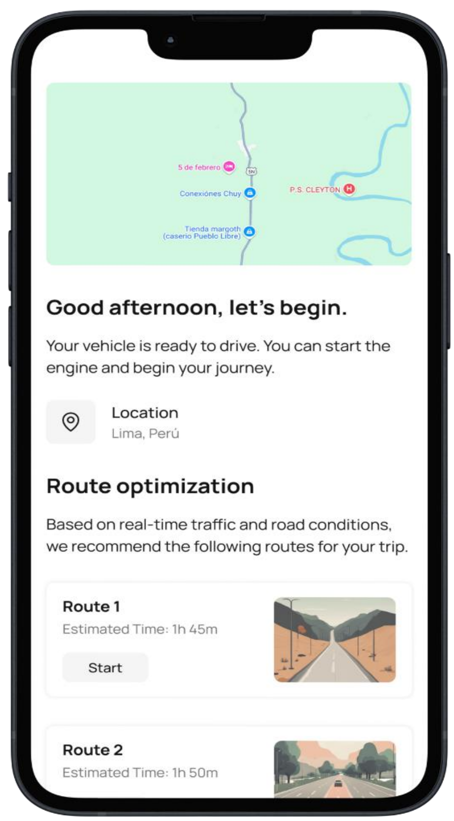

Fig. 4 Alternative welcome module

Figures 5 and 6 present a prototype administrative dashboard designed to provide a comprehensive view of real-time traffic. This prototype included key metrics such as the number of active routes (3,324), traffic conditions (98% efficiency), and incident alert detection. Through interactive visualizations, it was proposed that administrators could monitor the system and make

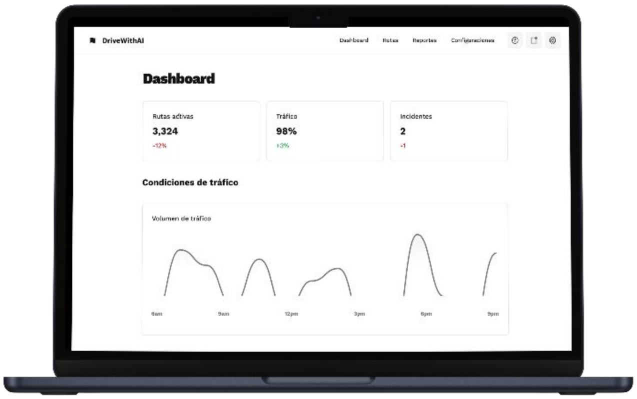

Fig. 5 Dashboard view on a laptop

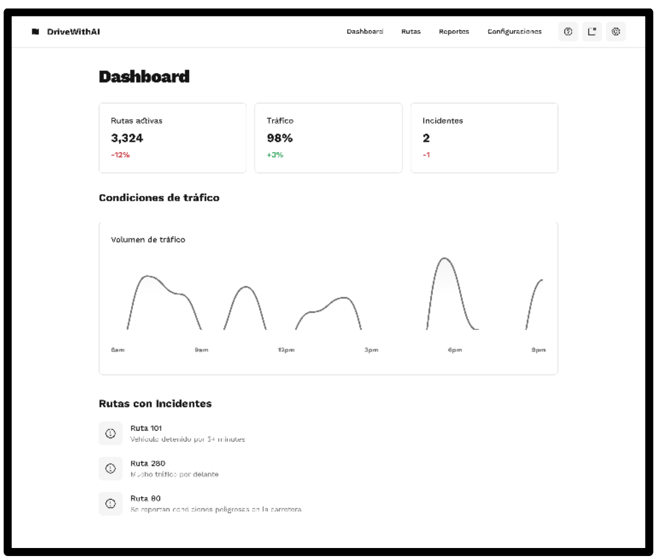

Fig. 6 Dashboard with traffic graph and incident alerts in the system

Although the results were limited to developing a prototype proposal, they demonstrated the feasibility of creating a software-based system that combines real-time navigation, driver behavior analysis, administrative monitoring, and traffic prediction. Such a system could significantly improve urban mobility, facilitating informed decision-making and reducing accidents and traffic congestion.

5. Discussion

The development of this proposal identified several limitations that could impact future implementations of intelligent systems for urban mobility. One of the main constraints was the lack of specialized databases containing geospatial information and real-time traffic, which would have been key to enriching predictive models and improving the accuracy of identifying traffic incidents. Furthermore, the absence of tools such as heat maps to represent areas of high user interaction was evident, limiting the analysis of usage patterns and optimizing the navigation experience within the proposed interface.

These limitations highlighted the need to incorporate more advanced analytical tools and broader methodological approaches in future iterations of the system. The project's results consisted of prototypes developed in Figma that demonstrated the feasibility of machine learning-based software design for transport optimization and road accident reduction. These prototypes represented a first step toward integrating advanced technologies into urban mobility solutions.

Comparing the findings with previous studies, it was observed that machine learning-based algorithms proved to be effective in predicting road incidents in various contexts. In a study conducted in Ireland [5], the performance of different models for predicting the duration of accidents on the M50 motorway was evaluated, finding that Support Vector Machines offered greater accuracy for short and medium duration events, while Artificial Neural Networks stood out in the prediction of long duration incidents. Similarly, the presented proposal contemplated the use of neural networks in transport mode classification and event prediction tasks, highlighting their applicability in complex urban contexts.

In addition, a research project developed in Lisbon implemented a model based on trip chaining [10], density clustering, and data mining, achieving a 92.84% prediction rate for passenger drop-off stops. The approach adopted in this work combined advanced data analysis techniques with the aim of improving public transport planning. This approach integrated multiple methodologies to optimize vehicle flow and facilitate urban mobility.

The prototypes developed in Figma demonstrated the potential of machine learning-based systems to generate solutions aimed at optimizing transportation and reducing road accidents. This proposal represents a significant contribution to the conceptualization of innovative tools for mobility management, laying a solid foundation for future research.

Other studies have also highlighted the importance of using real-time data for transport optimization. In a particular case in Cuenca, Ecuador, an algorithm was developed that classified transport modes using geolocation data obtained from smartphones. This approach was similar to the present study, considering GPS and sensor data to identify mobility patterns and optimize routes [12]. Similarly, in Rome, random forest and convolutional neural network models were implemented, which classified transport modes and calculated waiting times, achieving an accuracy greater than 95% in predicting walking times [14]. Along these lines, the designed prototypes showed consistent results in terms of conceptualizing predictive tools, demonstrating that the adopted approach is aligned with effective practices already validated in the academic field.

Overall, the analysis confirmed that the combination of technologies such as Flutter, TensorFlow Lite, and Firebase represents a viable option for designing intelligent applications focused on real-time traffic management and accident prevention. However, a need was identified to explore more diverse scenarios, including rural areas and diverse geographic areas, as well as to refine the models using more advanced neural networks. Furthermore, it would be relevant to evaluate the impact of these tools on transport sustainability, particularly their ability to reduce carbon emissions and adapt to urban environments with greater levels of complexity, thus ensuring system scalability.

The prototypes developed in Figma served as a proof of concept to demonstrate the feasibility of a software design based on machine learning algorithms. This proposal offered a solid approach to the use of smart technologies to address current challenges related to urban mobility and road safety, and paves the way for future research focused on the effective implementation of these types of systems.

6. Conclusion

The design proposed in this study demonstrated the feasibility of a system using machine learning algorithms to optimize urban traffic and reduce road traffic incidents. Through the development of a conceptual architecture and the development of interface prototypes in Figma, key functionalities were integrated, such as the recommendation of optimized routes, accident prediction based on historical patterns, and real-time monitoring of relevant variables. These functionalities were conceived to improve road safety, particularly in high-congestion areas, and provide useful information to both users and traffic managers.

The proposal addressed current issues related to urban mobility and highlighted the potential of integrating real-time data into transportation planning processes. It was identified that, in future research, expanding the geographic coverage of the system and refining the models through the use of more complex neural networks could increase the accuracy of predictions and their applicability in diverse contexts. Furthermore, evaluating the impact of these types of solutions on the sustainability of urban transportation would allow for the development of strategies aimed at reducing emissions and ensuring the efficient use of road infrastructure.

Together, the conceptual design and prototypes generated represented a significant step forward in the development of technological solutions focused on smart mobility. This work established a solid foundation for future research in urban transportation, where machine learning and the integration of emerging technologies continue to be fundamental pillars for addressing the challenges of safety, efficiency, and sustainability. Thus, it is hoped that future work can take this proposal as a starting point for the development and implementation of functional systems capable of empirically validating the impact of machine learning on urban mobility.

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