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Smart Traffic Management for Sustainable Development in Cities: Enhancing Safety and Efficiency

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ABSTRACT

The emergence of smart cities as a solution to the challenges posed by urbanization and population growth has paved the way for the integration of information and communication technology with traditional infrastructure. This research explores the integration of smart city concepts, particularly the Internet of Things and Big Data, in traffic control systems to enhance safety and sustainability. The study focuses on the role of intelligent traffic systems, including traffic lights, in smart cities and the potential impact of self-driving cars on traffic safety. The paper highlights the importance of traffic lights in reducing emissions and easing traffic congestion in urban areas. Additionally, the research discusses the human element in traffic control and provides suggestions for enhancing the capabilities of traffic workers to adapt to the modern smart city environment. Overall, this paper aims to provide insights into the applications and impact of smart cities on traffic safety and sustainable development.

Keywords: Smart cities - self-driving cars - traffic accidents

1 Introduction

Urbanization is a rapidly growing phenomenon, with the majority of the world's population expected to live in cities by 2030 [1]. As a result, there is a heightened demand for services, particularly transportation, which is critical to any society's economic, social, and political dimensions. With the transport and communication sector occupying a substantial portion of government expenditure in developed and developing countries, it is essential to consider how best to meet the increasing demand for mobility without adversely affecting existing natural resources.

The rise in urbanization, coupled with the significant increase in the number of cars in the past three decades, has led to a steady demand for mobility, resulting in traffic congestion, accidents, and poorly designed roads. To address these issues, the concept of smart cities has emerged, which leverages innovative traffic control tools, intelligent transportation services, and road design concepts to promote safety and improve mobility [2] .

The growth and evolution of cities have resulted in increasingly challenging issues related to traffic management and safety. To address these issues, smart city technologies are being developed and implemented with the aim of improving traffic control and reducing the negative impact of transportation on the environment. This literature review examines previous studies on safe traffic control in smart cities and its applications, with a focus on the impact of these technologies on sustainable development.

In 2019, Tan et al. [3] conducted a study that examined the role of smart city technologies in promoting sustainable transportation and reducing the negative impact of transportation on the environment. The study found that the use of these technologies can significantly improve transportation efficiency, reduce emissions, and improve air quality. The authors emphasized the importance of taking a holistic approach to smart city development, which incorporates various technologies and policies to promote sustainable transportation.

Figueiredo et al. [4] conducted a study on the use of intelligent transportation systems in managing traffic flow in smart cities. The study found that these systems can significantly reduce traffic congestion, improve safety, and reduce emissions. The authors concluded that the use of intelligent transportation systems is a critical component of safe traffic control in smart cities.

Another study by Zhang et al. [5] focused on the use of connected and autonomous vehicles in improving road safety. The study found that these vehicles can significantly reduce the number of accidents and fatalities on the road, particularly through the use of vehicle-to-vehicle and vehicle-to-infrastructure communication. The authors emphasized the potential of these technologies in promoting sustainable transportation and improving road safety.

Liu et al. [6] explored the use of advanced traffic management systems in improving traffic flow and reducing emissions in smart cities. The study found that such systems can significantly reduce congestion and improve the efficiency of transportation, leading to reduced emissions and improved air quality. The authors emphasized the importance of these systems in achieving sustainable transportation in smart cities.

In another study by Wang et al., [7] the authors examined the impact of smart transportation systems on reducing energy consumption and greenhouse gas emissions. The study found that the use of smart transportation systems, such as intelligent transportation systems and advanced traffic

management systems, can significantly reduce energy consumption and emissions, particularly through the promotion of public transportation and the use of alternative modes of transportation.

These studies demonstrate that smart city technologies, such as intelligent transportation systems, connected and autonomous vehicles, and advanced traffic management systems, can significantly improve traffic control, promote sustainable transportation, and reduce the negative impact of transportation on the environment. A holistic approach to smart city development, incorporating various technologies and policies, is crucial for achieving these goals.

In this paper, we will explore the challenges of managing traffic in growing cities and the increasing importance of implementing smart city technologies to address these issues. We will review previous studies on traffic control in smart cities, focusing on the use of intelligent transportation systems, advanced traffic management systems, and connected and autonomous vehicles. Specifically, we will examine the impact of these technologies on traffic flow, safety, and emissions reduction, as well as their potential to promote sustainable transportation. Finally, we will discuss the need for a holistic approach to smart city development that incorporates various technologies and policies to address the negative impact of transportation on the environment.

2 Smart Cities

The concept of smart cities is complex to define, yet they are cities that utilize information and communication technology to offer innovative solutions that facilitate and enhance the quality of life for their residents. The need for smart cities stems from the challenges that ordinary cities face, making it crucial to understand the issues faced by cities and apply intelligent solutions to address them. It is important to note that innovative city solutions cannot be replicated across different countries as each location faces unique problems [8] .

There exist different types of smart cities, including those with advanced communication networks and integrated technologies that require significant investments to build. However, not all cities can be developed in this way, necessitating the use of communication and information technologies to transform them into smart cities.

The city of Pittsburgh in the United States provides a successful model of a smart city by utilizing big data to analyze car routes and numbers, reducing traffic congestion and carbon dioxide emissions by 20%. In addition, the city of San Francisco experimented with an intelligent parking system between 2011 and 2014, which generated an annual revenue of 2 million dollars [9]. Similarly, the city of Barcelona in Spain developed an intelligent system for street lighting, saving the city 37 million dollars annually.

2.1 Foundations of smart cities

Smart cities rely on several essential pillars, including:

- Having a well-defined vision and strategy for implementing smart city initiatives.
- Developing an open data platform that benefits all segments of the city, including researchers, investors, and small business owners.
- Creating an environment that encourages and supports innovation in smart city technologies.
- Establishing a robust and efficient communication infrastructure that can accommodate modern technologies.

These pillars serve as a foundation for successful smart city development, ensuring that cities can leverage technology to provide innovative solutions that enhance the quality of life for their residents. By adopting these principles, cities can create an ecosystem that supports the growth and adoption of intelligent technologies, enabling them to address the unique challenges they face.

2.2 Areas of smart cities

Smart cities encompass various areas of focus, such as smart transportation, innovative energy, smart waste management, smart homes, smart tourism, innovative governance, wise health, and smart educational services.

Smart homes represent a critical aspect of smart cities, characterized by reduced energy consumption and the presence of intelligent devices that facilitate daily activities. For instance, homes equipped with Internet of Things (IoT) technologies enable refrigerators to communicate with shops, or the use of lights that only illuminate rooms when occupied. Additionally, the adoption of solar panels enables homes to produce electricity sustainably, further reducing energy consumption. These technologies contribute to a more efficient and sustainable use of energy, enabling smoother and faster daily activities.

2.3 Big data and artificial intelligence for smart cities

Smart cities rely on various advanced technologies, including big data, the Internet of Things (IoT), and artificial intelligence (AI). Big data refers to vast and diverse datasets collected from numerous sources. These datasets are analyzed to provide new insights that support decision-making processes, such as identifying optimal locations for schools, factories, and other institutions based on data-driven analysis.

AI is another critical technology used in smart cities. It involves analyzing data to generate the best possible outcomes. For instance, ride-sharing applications like Uber use AI techniques to determine the locations of cars and calculate the most efficient routes and fares for transportation services.

Therefore, the development of smart cities requires a comprehensive and ongoing effort, including a clear vision, strategic planning, and effective implementation. By leveraging these advanced technologies, smart cities can benefit from data-driven insights and optimize their resources to improve the quality of life for their residents [10].

3 Self-Driving Cars

Self-driving cars are considered to be one of the most significant technological advancements that the world is expected to experience in the near future. These cars are defined as vehicles that can fully sense and understand their surrounding environment through the use of cameras and sensors that are controlled by a controller or an electronic computer. This computer gives commands to control the speed of the car, its deviations, brakes, and all other tasks that a driver typically performs while driving. The experiments on self-driving cars have been ongoing for over five decades and have progressed through multiple stages, starting with simple tasks and progressing to complete autonomy.

The Society of American Automotive Engineers (SAE) has identified six levels of driving automation or the transformation towards self-driving cars, ranging from zero to five [11]. At level zero, the car has no control, and the driver has complete control. At level one, there is a partnership between the driver and the car, with the driver retaining control, but with the car providing assistance. At level two, the car controls the driving and steering, but the driver has control and follow-up on the road. At level three, the car intervenes in traffic fully and only needs the human element in case of a breakdown or failure of one of the systems or parts of the vehicle. At level four, the car is highly self-driving and does not require human intervention, except in some exceptional circumstances. At level five, the car is fully self-driving, and it can adapt to any surrounding environment or situation, even if some systems or parts fail [12].

One of the critical components of a self-driving car is the presence of high-quality sensors and sensors that enable cars to draw environmental maps. The types, use, and sophistication of sensors in self-driving cars vary depending on the level at which they operate. Maps are also crucial for self-driving cars to ensure that they can navigate from one point to another. GPS is one of the most famous mapping applications used in self-driving cars. The absence of human intervention in self-driving cars also presents new challenges for designers, such as reducing the weight of the car and developing a highly sophisticated infrastructure to minimize potential problems. This technology requires significant investment, but it offers several advantages, including enhanced safety and efficiency.

4 Traffic Engineering Applications in Smart Cities

The objective of Smart Transportation Services is to mitigate traffic congestion, enhance traffic flow, and offer diversified transportation options such as bicycles and motorcycles. Intelligent transportation services deployed in some smart cities incorporate the use of sensors in the streets to gather data on the number of cars present at intersections and rearrange traffic flow accordingly based on time and day. Intelligent traffic lights also play a critical role in optimizing the movement of vehicles. Additionally, the use of self-driving cars has been proven efficient in enhancing reaction time in comparison to human response, which is an essential aspect in reducing the number of accidents. Another vital aspect is reducing emissions of pollutants and gases, specifically carbon dioxide, to protect the environment and promote sustainable development by utilizing hybrid or electric cars. These efforts and other factors contribute to the development of smart cities through the activation of intelligent transportation services [13].

4.1 Intelligent traffic lights

Intelligent traffic lights have garnered significant attention in recent years in smart cities, utilizing artificial intelligence techniques and big data to regulate traffic flow. In Changwon, South Korea, intelligent traffic lights have been developed to increase the operational time of the traffic signal when pedestrians pass by, ranging from 5 to 10 seconds, if detected by the system's artificial intelligence program. This was launched under the slogan "Protecting children while walking and crossing the road," and plans are in place to expand these signals to other cities.

In Khobar, Saudi Arabia, around 10 interactive traffic lights were launched in 2020, which continue to operate if pedestrians do not cross, ensuring safe passage for the highest number of pedestrians while maintaining vehicular traffic flow.

A system of intelligent traffic lights has been implemented in a Canadian city to synchronize the red and green signals with actual traffic flow, reducing wait times for motorists. The Center for Intelligent Transportation Systems and civil engineering professors claim that this technology could save millions of dollars in gas emissions.

In the Netherlands, research is ongoing on how to optimize traffic signals to facilitate ambulance movement by allowing them to pass through the signals using a communication unit, sending text signals via phone or devices in passenger cars to inform them of the ambulance's need to cross. This complex study is currently being tested.

In Germany, ideas have been implemented to regulate tram speed by adjusting it at previous stopping stations to arrive when the signal is green, reducing fuel consumption by approximately 20%. However, the real challenge in designing traffic lights in various cities worldwide remains the

communication network's capacity and the availability of information and big data, along with the economic costs required to activate these systems. [14]

5 Analysis of Traffic Accidents

Traffic accidents refer to incidents that occur spontaneously and involve one or more vehicles, pedestrians, animals, or objects on public or private roads, resulting in damages and injuries that range from minor to severe, leading to death or permanent disability.

Road accidents are a growing public health issue that severely impacts road users, with thousands of people being injured or dying daily, including men, women, and children while walking, riding cars, or bicycling. Women are affected the most, accounting for over half of the victims. The age range of those who die in road accidents is between 11 and 44 years. Furthermore, low- and middle-income countries suffer a significant economic burden, with road accidents consuming between 4% and 2% of their gross national product, exceeding the total development aid they receive.

Accident analysis involves scrutinizing accident data to determine their root causes, which should be addressed to mitigate the likelihood of future accidents [15].

5.1 The Objectives of Traffic Accident Analysis

The analysis of traffic accidents serves the following purposes:

- Identifying high-risk locations where accidents are frequent.
- Conducting a thorough assessment of these sites to determine the underlying causes of the high number of accidents.
- Compiling statistics that reveal patterns and common causes of accidents.
- Developing methods to identify potential accident-prone areas before accidents occur.
- Identifying the causes of accidents to create awareness programs and improve the licensing process.

5.2 Reasons for Conducting Traffic Accident Analysis

The analysis of traffic accidents is carried out to achieve the following goals:

- Identifying the most common types of accidents.
- Estimating the economic cost of accidents.
- Developing support services such as ambulance and emergency services.
- Improving emergency services in hospitals.
- Evaluating the performance of traffic police officers and the effectiveness of existing plans.

- Measuring the effectiveness of traffic awareness and control campaigns and the response of road users to them.

6 Road Safety in Smart Cities

Measuring traffic safety directly is challenging, but it can be inferred by comparing the number of accidents to the number of vehicles. The objective of road safety in smart cities is threefold [16]:

- Reduce the number of traffic accidents.
- Reduce the severity of accidents that do occur.
- Decrease the likelihood of accidents happening.

Achieving these goals requires a multi-faceted approach that involves engineering solutions, designing roads and vehicles with safety in mind, educating drivers on safe driving practices, and providing medical services on the road. Additionally, safety measures should be employed to prevent the recurrence of similar accidents.

6.1 Aspects of Improving Traffic Safety

Improving traffic safety involves three main aspects:

- Reducing the recurrence of accidents by improving driver skills, developing training programs, and ensuring driving license exams are rigorous. Punishing drivers who repeatedly violate traffic laws or are involved in accidents is also necessary. Additionally, placing informative and ground signs in appropriate locations can guide drivers and reduce the risk of accidents [17].
- Reducing the severity of accidents by designing roads that provide enough space for drivers to avoid obstacles or dangers.
- Absorbing and mitigating the impact of accidents through vehicle design. The use of struts, shock-absorbing sponges, seat belts, and airbags can help reduce the force of impact on passengers.

6.2 Engineering Applications for Traffic Safety Control

The Haden matrix is a critical program in the field of traffic safety, aimed at reducing the number of traffic accidents. This matrix links three elements - the driver, the vehicle, and the road - and then connects them with the three stages that they pass through: the pre-accident stage, the accident stage, and the post-accident stage. As a result of this connection, the matrix includes nine squares in which the relationship between the elements of the traffic system in its different stages is summarized.

The following is an explanation of the squares of the Haden matrix:

Square 1: The driver before the accident. This stage focuses on awareness and training programs, as well as controlling intoxicants and improving licensing procedures.

Square 2: The driver during an accident. This stage is concerned with educating the driver on using safety methods, such as the seat belt, during the accident.

Square 3: The driver after the accident. This stage is similar to the first square, with the added focus on developing ambulance and rescue services.

Square 4: The vehicle before the accident. This stage is concerned with the safe design of the vehicle, improving brake systems, and maintaining tires and driving devices.

Square 5: Vehicles during an accident. This stage focuses on safety systems such as seat belts, airbags, padded seats, headrests, and shock absorbers.

Square 6: Vehicles after the accident. This stage focuses on reinforcing the fuel tank and fuel lines to protect them from the force of the shock and ensuring that there are no flammable materials.

Square 7: The road before the accident. This stage is concerned with road maintenance, improving side lighting, clarifying signs, making ground marks, and sidelines.

Square 8: The road during the accident. This stage involves the use of side barriers, executing traffic signs, and ensuring the distances of bridge pillars from the edge of the road.

Square 9: The road after the accident. This stage involves improving and deploying ambulances on the road, training ambulance staff, deploying emergency telephones on the roadside, improving rescue tools, and repairing traffic control tools.

6.3 Considerations for Improving Traffic Safety in Smart Cities

In order to improve traffic safety in smart cities, several factors need to be taken into consideration:

- Regulations: The planning of roads and intersections should include measures to limit speed, establish traffic laws, determine parking lots, and establish the direction of car movement, among other things.
- Traffic signs: The installation of signs, signals, ground signs, alerts, lighting, and other traffic-related features should be considered.
- Changes in planning: Efforts should be made to widen roads, eliminate choke points, improve entrances to bridges and tunnels, remove traffic obstacles, and pave roads.
- The public: The needs of the public should be taken into account, including the establishment of fast and slow traffic lanes, convenient car parks, bus stops, final stops for buses, and the setting of bus itineraries.

- Other factors: Considerations such as the presence of traffic police, car detection technologies, traffic courts, and public assistance programs should also be taken into account.

7 Raising the efficiency of the human resources to control traffic in smart cities

- Preparing workers - practically and technically - to work in the field of traffic engineering and city planning, introducing them to the traffic law, traffic rules and etiquette, licensing procedures and problems, and practically training them on how to conduct a technical examination.
- Preparing cadres for road traffic management and training them on how to deal with traffic accidents, how to inspect them, and the procedures that are followed in the event of injuries or deaths, as well as the proper ways to raise the accident.
- Training workers on the use of modern positioning systems and raising awareness of smart traffic devices such as smart transportation, smart traffic lights, and others.
- Communicating with educational bodies and universities to give intensive courses for workers in the field of traffic on how to estimate and analyze traffic accidents

8 Smart City Traffic Control: Egypt and Global Summary

1. Smart city traffic control systems rely on technology such as intelligent transportation systems, connected and autonomous vehicles, big data analytics, and machine learning algorithms to optimize traffic flow and reduce congestion.
2. Smart cities around the world are implementing various traffic control measures, including intelligent traffic signals, electronic road pricing, automated traffic surveillance and control, and platooning to reduce congestion and improve traffic flow.
3. Singapore is a leading example of a smart city with advanced traffic control systems, including electronic road pricing, that have significantly reduced traffic congestion.
4. In the United States, Los Angeles has implemented a smart traffic management system called Automated Traffic Surveillance and Control (ATSAC) that adjusts traffic signals in real-time to reduce congestion and improve traffic flow.
5. Egypt faces significant traffic congestion problems in major cities like Cairo and Alexandria. The country has implemented measures such as expanding public transportation and building new roads to tackle the issue, but traffic congestion remains a major problem.

In numbers, according to a 2019 report by the TomTom Traffic Index, Cairo ranked as the most congested city in the world, with drivers spending an average of 149 hours a year stuck in traffic. Alexandria also ranked high, at 13th place globally. To address this, the Egyptian government has invested in a number of transportation infrastructure projects, including the construction of new

highways, metro lines, and a high-speed train between Cairo and Alexandria. Additionally, the government is working to implement intelligent transportation systems and other smart city technologies to manage traffic flow more efficiently.

The Global Status Report on Road Safety 2021, published by the World Health Organization (WHO), provides an overview of road safety in Egypt. Here are some key points:

Egypt has a high rate of road traffic deaths, with 17.4 deaths per 100,000 population in 2019. This is higher than the global average of 18.5 deaths per 100,000 population (Figure1) [18].

The majority of road traffic deaths in Egypt are among vulnerable road users, including pedestrians, motorcyclists, and bicyclists.

Speeding is a major contributor to road traffic crashes and fatalities in Egypt. Other factors that contribute to road traffic crashes in Egypt include driving under the influence of alcohol, not wearing seat belts or helmets, and poor road infrastructure.

Egypt has implemented some measures to improve road safety, including the adoption of a national road safety strategy and action plan, the introduction of stricter penalties for traffic violations, and the installation of speed cameras and other safety devices on some roads.

However, more needs to be done to improve road safety in Egypt. The WHO recommends that Egypt strengthen its legislation and enforcement of traffic laws, improve its road infrastructure, and invest in road safety education and awareness campaigns.

Smart cities and smart transportation systems can play a significant role in improving road safety in Egypt and reducing the number of road traffic accidents and fatalities. Here are some ways in which they can contribute:

Intelligent Transportation Systems (ITS): Smart transportation systems can use advanced technology to provide real-time information about traffic flow, congestion, and accidents to drivers and traffic management authorities. This information can help drivers to plan their routes, avoid congested areas, and drive more safely, thereby reducing the risk of accidents.

Smart Traffic Management: Smart cities can use intelligent traffic management systems to optimize traffic flow, reduce congestion, and improve safety on the roads. For example, the use of smart traffic lights that can adjust their timing based on traffic volume and real-time conditions can help to reduce the risk of accidents caused by traffic congestion.

Connected and Autonomous Vehicles (CAVs): The deployment of connected and autonomous vehicles can help to improve road safety in several ways. CAVs can communicate with each other and with traffic management systems to avoid collisions, reduce traffic congestion, and improve the overall efficiency of the transportation system.

Pedestrian and Cyclist Safety: Smart cities can use advanced technology to improve the safety of vulnerable road users, such as pedestrians and cyclists. For example, smart traffic lights can be equipped with sensors that detect the presence of pedestrians and cyclists and give them priority at crossings.

Data Analytics: Smart cities can use data analytics to monitor traffic patterns, identify accident hotspots, and develop targeted interventions to improve road safety. This can include the use of predictive analytics to identify areas with a high risk of accidents and take preemptive measures to reduce the risk.

Smart cities and smart transportation systems have the potential to significantly improve road safety in Egypt by using advanced technology to optimize traffic flow, reduce congestion, and improve the safety of vulnerable road users. By implementing these technologies and strategies, Egypt can reduce the number of road traffic accidents and fatalities and create a safer and more efficient transportation system for all.

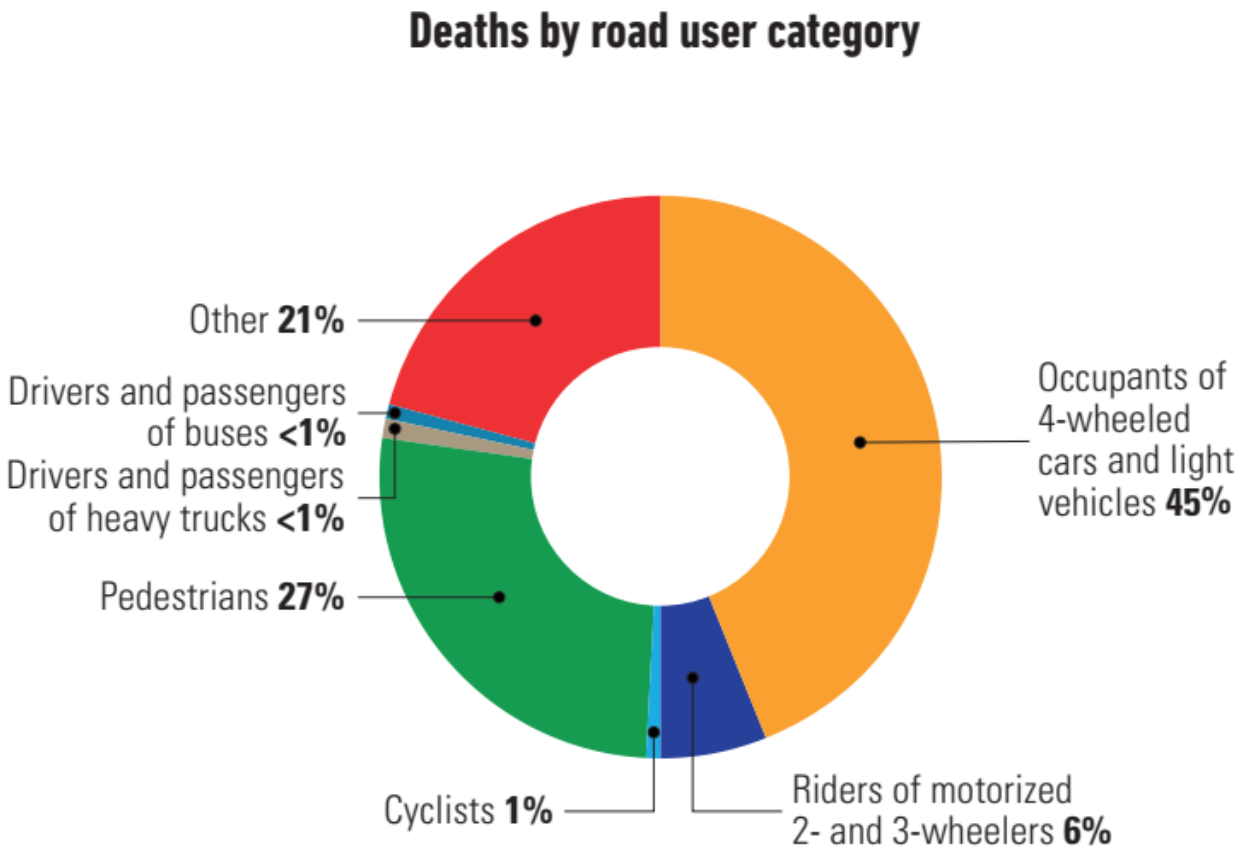

Figure 1

9 Conclusion

In conclusion, the concept of Smart Cities is a complex and evolving subject that requires a clear vision and practical strategies to reap its benefits. This paper focused on achieving traffic safety in Smart Cities, highlighting the importance of innovative traffic services such as intelligent traffic lights and self-driving cars. Furthermore, reducing emissions of pollutants and gases through hybrid or electric cars was identified as a critical factor in sustainable development. Engineering applications in traffic safety control, such as the Haden Matrix, were also discussed as a means of reducing traffic accidents. The paper also emphasized the importance of considering regulations, traffic signs, planning changes, and other factors to improve traffic situations in Smart Cities. Finally, a comprehensive plan with six axes was presented to reduce traffic accidents in the light of Smart Cities, including education for road users, vehicle safety, traffic control, technical and engineering improvements to roads, emergency response, and injury management. By implementing such strategies, Smart Cities can achieve efficient and safe transportation services, leading to a better quality of life for its citizens.

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