الجمهورية الجزائرية الديمقراطيـة الشعبيــة
People's Democratic Republic of Algeria
وزارة التـعليــم العالــي والبحــث العلمــــي
Ministry of higher education and scientific research
جامعة عين تموشنت بلحاج بوشعيب
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End-of-studies project
As part of Ministerial Decree 008-1275
« A diploma, a startup/micro-enterprise, or a patent »
To obtain Master's degree
Sector: Telecommunications
Specialty: Telecommunications Networks

RouteGuard: Design and Implementation of an intelligent system for the prevention of automobile accidents in urban areas

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Academic Year: 2024/2025

Dedication

To the memory of my father,

Who instilled in me the values of perseverance, courage, and integrity.

Although you are no longer here to witness the completion of this work, your presence continues to live in everything I do.

This thesis is dedicated to you, with all my love and eternal gratitude.

Acknowledgments

First and foremost, I thank Allah for granting me the strength, patience, and guidance throughout this journey. Without His blessings, none of this would have been possible.

I extend my deepest gratitude to my family, especially my mother, whose unwavering support and prayers have always been my greatest source of motivation, and to my sisters and my brother, for their constant encouragement and love.

I would also like to express my sincere appreciation to my supervisors **Mr. MERADI Abdelhafid**, **Ms. Benhaddou Amel** and **Ms. Gherbi Sabah** for their invaluable guidance, constructive feedback, and continuous support throughout the development of this project.

I would also like to express my sincere thanks to the jury members for agreeing to evaluate this work.

Abstract

This thesis presents RouteGuard, an innovative system designed to improve road safety in urban environments. In light of the increasing number of traffic accidents, especially those involving light vehicles, RouteGuard offers a proactive solution based on the intelligent exchange of information between drivers.

The system enables real-time tracking of user movements and issues alerts in case of potential collision risks. It combines an embedded device with a mobile application to deliver a smooth and user-friendly experience for drivers.

This work explores the challenges of urban road safety, reviews existing preventive systems and their limitations, and outlines the development of a more responsive and adaptable solution. RouteGuard aims to contribute to the reduction of road accidents by enhancing driver awareness and supporting real-time decision-making.

Keywords: road safety, accident prevention, smart system, urban mobility, RouteGuard.

الملخص

تقدم هذه الأطروحة نظام RouteGuard ، وهو نظام مبتكر مصمم لتحسين السلامة المرورية في المناطق الحضرية. في ضوء تزايد حوادث المرور، وخاصة تلك التي تشمل المركبات الخفيفة، يقدم RouteGuard حلاً استباقيًا قائمًا على التبادل الذكي للمعلومات بين السائقين .

يتيح النظام تتبعًا آنيًا لحركات المستخدمين، ويُصدر تنبيهات في حال وجود مخاطر تصادم محتملة. يجمع النظام بين جهاز مدمج وتطبيق جوال لتوفير تجربة سلسة وسهلة الاستخدام للسائقين.

يستكشف هذا العمل تحديات السلامة المرورية في المناطق الحضرية، ويستعرض أنظمة الوقاية الحالية وحدودها، ويوضح تطوير حل أكثر استجابة وقابلية للتكيف. يهدف RouteGuard إلى المساهمة في الحد من حوادث الطرق من خلال تعزيز وعي السائقين ودعم اتخاذ القرارات الفورية.

الكلمات المفتاحية: السلامة المرورية، الوقاية من الحوادث، النظام الذكي، التنقل الحضري، RouteGuard.

Résumé

Cette thèse présente RouteGuard, un système innovant conçu pour améliorer la sécurité routière en milieu urbain. Face à l'augmentation du nombre d'accidents de la route, notamment ceux impliquant des véhicules légers, RouteGuard propose une solution proactive basée sur l'échange intelligent d'informations entre les conducteurs.

Le système permet de suivre en temps réel les déplacements des usagers et d'émettre des alertes en cas de risque de collision. Il combine un dispositif embarqué et une application mobile pour offrir une expérience utilisateur fluide et intuitive aux conducteurs.

Ce travail explore les enjeux de la sécurité routière urbaine, examine les systèmes préventifs existants et leurs limites, et propose le développement d'une solution plus réactive et adaptable. RouteGuard vise à contribuer à la réduction des accidents de la route en améliorant la vigilance des conducteurs et en les aidant à prendre des décisions en temps réel.

Mots-clés : sécurité routière, prévention des accidents, système intelligent, mobilité urbaine, RouteGuard.

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List of Abbreviations:

ADAS	Advanced Driver Assistance Systems
BDS	BeiDou Navigation Satellite System
BLE	Bluetooth Low Energy
CPU	Central Processing Unit
DGSN	Direction Generale de Sûreté National
ESA	European Space Agency
GPRS	General Packet Radio Service
GLONASS	GLObal Navigation Satellite System
GPS	Global Positioning System
HTTP	Hypertext Transfer Protocol
IDE	Integrated Development Environment
LoRa	Long Range
MQTT	Message Queuing Telemetry Transport
RF	Radio Frequency
SDK	Software Development Kit
SIM	Subscriber Identity Module
SMS	Short Message Service
TCP/IP	Transmission Control Protocol / Internet Protocol
USDOD	United States Department of Defense
VANET	Vehicle Ad-hoc NETwork
WHO	World Health Organization

Wi-Fi	Wireless Fidelity

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General Introduction

General Introduction:

Road safety remains one of the most critical challenges in modern urban environments. The growing number of vehicles, combined with the complexity of city traffic and human factors such as distraction or excessive speed, continues to cause a high rate of accidents. Despite ongoing awareness campaigns and the development of various preventive technologies, accidents in urban areas persist, leading to significant human and economic losses.

Urban intersections, in particular, are frequently the scene of collisions due to high vehicle density, poor visibility, and unpredictable driver behavior. While existing solutions such as traffic lights, radars, or high-end vehicle systems contribute to reducing risks, they are often limited by cost, accessibility, or technical constraints — especially in developing regions.

In response to this reality, and as part of this academic research, I have designed and developed RouteGuard: an innovative and original system aimed at enhancing road safety through real-time collision prevention. RouteGuard combines a mobile application with a lightweight embedded device, enabling drivers to detect nearby vehicles, receive alerts, and make safer decisions in real time. The system is intended to be low-cost, easy to use, and compatible with all types of vehicles, making it accessible to a wide range of users.

This thesis is structured into three chapters:

- The first chapter addresses the causes, consequences, and prevention strategies of road accidents in urban areas.
- The second chapter presents the fundamental principles of GPS technology and its applications in real-time geolocation systems.
- The third chapter details the design, implementation, and testing of RouteGuard as an original solution to enhance road safety.

Chapter I: Urban Road Accidents: Causes, Impacts, and Prevention Strategies

I.1 Introduction

Urban areas, with their dense population, complex road networks, and heavy traffic, are contexts where road traffic accidents, particularly at intersections, occur with high frequency. These events have profound repercussions on human well-being, economic life, and social dynamics, influencing quality of life and public safety. This chapter presents a comprehensive analysis of urban road traffic accidents, exploring their context, etiology, characteristics, consequences, prevention strategies, evolving trends, and multidisciplinary responses. Tables, figures, and diagrams are used to present important data and ideas, including examples from national and international contexts. This analysis lays the foundation for the following chapters, which will examine emerging solutions.

I.2 Context of automobile accidents in urban areas

I.2.1 Definition and characteristics of urban areas

An urban area is essentially characterized by the complex relationships of heterogeneous elements: populations, buildings, winding avenues, and congested intersections. Automobiles are omnipresent; however, their dense traffic and constant interactions between drivers make them a breeding ground for accidents, particularly at intersections. In Algeria, the anarchy that reigns in congested urban centers perfectly illustrates these contradictions. Similarly, major metropolises around the world, equipped with advanced transportation systems, are also exposed to these problems. [1]

I.2.2 Road accident statistics

Globally, road traffic accidents are an endemic tragedy that occurs daily. The World Health Organization (WHO) report published in 2023 reveals that approximately 1.19 million people die each year as a result of road traffic accidents, representing more than 3,200 deaths daily. It is important to note that 30% of deaths occur among people traveling in cars or comparable light four-wheeled vehicles. A significant percentage of fatal accidents occur in urban areas, known for their heavy traffic, complex intersections, high speeds, and, sometimes, faulty traffic signals. [2]

I.2.3 Case study in Algeria

In Algeria, increasing traffic congestion, combined with often inadequate road infrastructure, has led to a sharp rise in road accidents at urban intersections according to DGSN between 2022 and 2024. This increase is also accompanied by an increase in the number of deaths, mainly due to inadequate signage, speeding and reckless behavior, such as failure to comply with priority instructions. [3]

The following table presents statistical data on the incidence of accidents in Algeria over the past three years, as well as the variation in the number of deaths and number of injured.

Year	Number of accidents	Number of deaths	Number of injuries
2022	17 186	720	20 575
2023	17 045	665	20 601
2024	18 881	780	22 979

Table I.1: Report on car accidents in Algeria (2022-2024)

As illustrated in the table, there is a general trend towards a decline in road safety measures, due to factors that we will discuss in the next section.

I.3 Causes of car accidents in urban areas

The causes of road accidents at urban intersections are numerous and complex, dependent on the interaction between human behavior, geometry, environmental conditions, and sociocultural conditions. In this section, we will conduct a qualitative analysis of the factors that cause accidents.

I.3.1 Human factors

Worldwide, between 90 and 92% of road accidents are attributed to human factors as the primary cause [2]. Drivers, with their moments of weakness, are often at the heart of the problem. Too often, we see drivers holding their phones, making calls, sending messages, or watching videos, which causes inattention while driving. Speed is poison: some people floor the accelerator, forgetting urban boundaries, and find themselves stuck facing an obstacle, especially at night, when the roads seem clearer but just as treacherous. Fatigue steals attention: an exhausted driver, after a long day, may miss a sign or a turn and, of course, lose attention to the vehicle in front of them. There are also those who drive like they're racing, swerving without respect for the rules, a scourge on congested streets. Finally, novices, still clumsy in urban areas, make costly mistakes.

The following figure shows the percentage of factors that cause accidents.

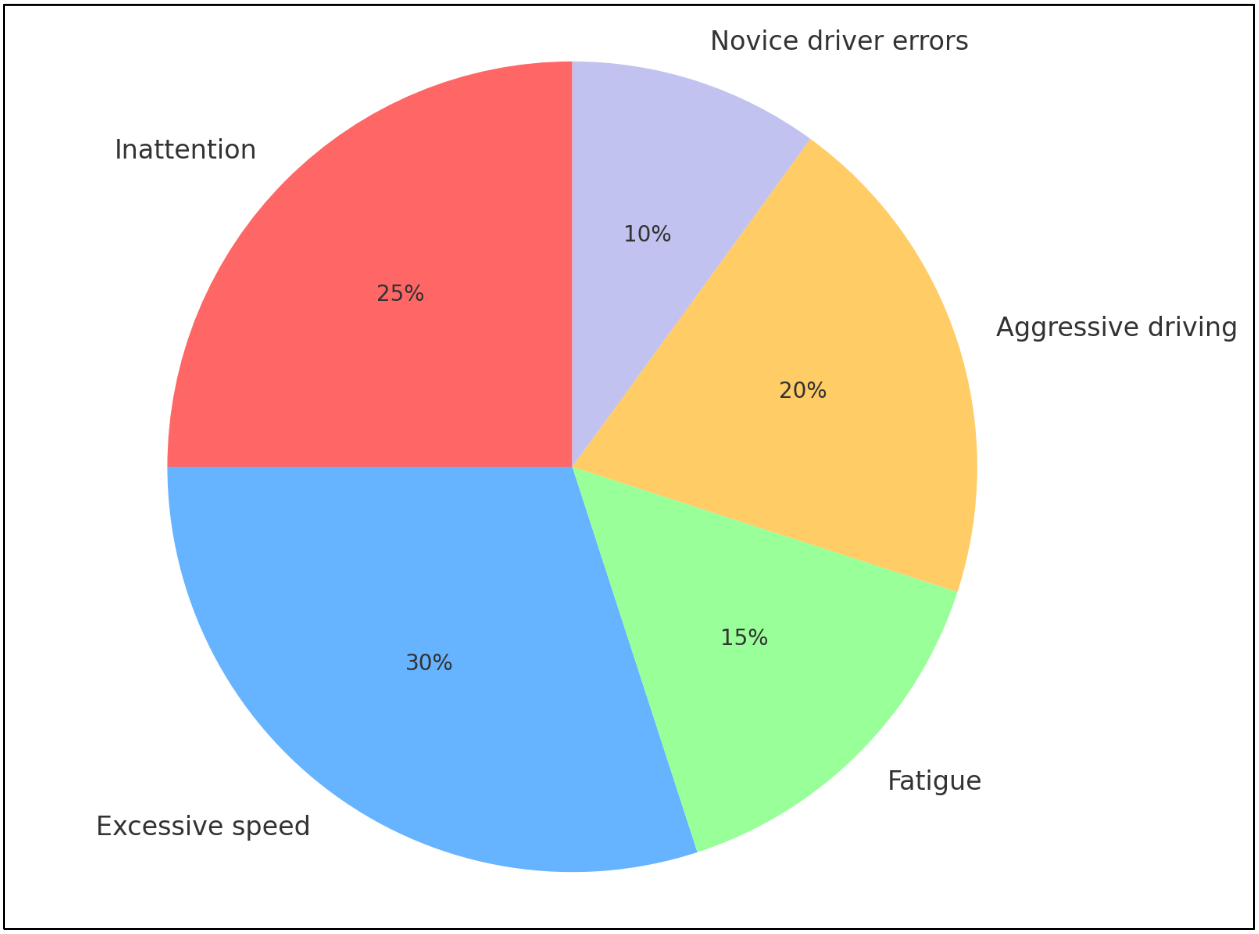

Figure I.1: Percentage of human factors in road accidents [2]

I.3.2 Infrastructure-Related Factors

The roads themselves sometimes betray drivers. In many cities, roadways are poorly designed: sharp turns, narrow lanes, abrupt transitions that surprise even the most seasoned drivers. Many urban roads bear the scars of a neglected past. Maintenance, or lack thereof, makes matters worse: potholes, faded road markings, and encroaching sidewalks force risky maneuvers. Lighting, when lacking, turns nights into ordeals, especially in poorly equipped neighborhoods. Congestion, a universal urban malady, creates traffic jams where patience evaporates, leading to risky lane changes or sudden stops. As for signs and lights, absent, defective, or poorly placed, they sow confusion, leaving drivers to their own devices. [4]

I.3.3 Environmental Factors

Nature complicates the situation. Heavy rain, thick fog, or snowfall can make an urban road nearly impassable, especially if drainage systems allow water to accumulate. Inclement weather puts drivers' nerves to the test. Moments of low light—dawn, dusk—or the glare of headlights at night blur vision, making every journey more uncertain. Winter, with its short days and slippery roads, is particularly dangerous. In polluted cities, particulate-laden air can cloud the road, disrupting both visibility and driver attention. [5]

I.3.4 Socio-cultural factors

Accidents aren't just a matter of roads or weather; they also reflect our societies. A certain carelessness with regard to the rules, crossing a limit, or jumping the right-of-way sometimes seems ingrained in our customs, as if the road were a space of freedom. Individualism can translate into selfish driving, where everyone seeks to save time at the expense of others. Driver education, often lacking, leaves too many drivers ill-prepared, a glaring problem in low-resource areas, but also in certain communities. Generations diverge: young people, thirsty for adrenaline, take unnecessary risks, while older people, sometimes less responsive, struggle to keep up with the urban pace. And then there is the idea, in many cultures, that accidents are inevitable, a stroke of fate against which nothing can be done—a belief that discourages efforts to be cautious. [6]

I.4 Car Collisions at Intersections

Intersections are the scene of numerous car accidents, places where the convergence of roads creates tricky intersections. These intersections come in different forms: intersections with signalized traffic, often poorly timed or out of order; roundabouts, where priorities are sometimes ignored; and intersections without signaling, where improvisation and chaos reign. Each type has its pitfalls; a signalized intersection can be paralyzed by a flashing amber light, forcing drivers to force their way through. At roundabouts, drivers often cut across each other's lanes, creating chain collisions. Intersections without signalized traffic, common in small towns, leave drivers guessing who goes first, a dangerous game amplified by speed or distraction. Rush hours (7 a.m.–9 a.m., 5 p.m.–7 p.m.) are the peak times for these tragedies, when fatigue and impatience take over.

Inadequate lighting, especially at night, makes the situation worse: a poorly lit intersection becomes an invisible trap.

I.5 Impacts of Car Collisions at Intersections

Collis at intersections don't just dent metal: they shatter lives, empty wallets, and weaken the social and environmental fabric. At busy intersections, every accident leaves deep scars, far beyond the asphalt. These multiple and interconnected impacts affect individuals, communities, and the entire economy.

I.5.1 Human Consequences

Intersection accidents have a catastrophic human toll. They kill, leaving behind grieving families and traumatized communities. Serious injuries, such as head trauma from violent impacts or broken limbs, disable victims for months, disrupting their daily activities. In 2023, a significant percentage of people seriously injured at intersections were drivers, many of whom were trapped in crashed cars. Post-traumatic stress is not uncommon, causing some survivors to dread getting back behind the wheel, tormented by the memory of a deadly intersection. Such tragedies have a considerable emotional and economic impact on families, who must provide costly care or cope with the loss of a loved one. [3]

I.5.2 Economic Consequences

Intersection collisions represent a significant cost to the Algerian economy. These expenses accumulate in several areas: medical care, which mobilizes resources for hospitalization and rehabilitation; vehicle repairs, often imported and costly; and lost productivity, when victims are no longer able to work. The congestion resulting from these collisions brings traffic to a standstill in congested cities, slowing down economic activities such as deliveries or business travel. Road traffic accidents represent 3% of global gross domestic product (GDP), a reality that has local repercussions [2]. In Algeria, the economic cost of road accidents exceeds 100 billion Algerian dinars per year, which is considered very significant [7]. These costs, generally underestimated, hamper the economic growth of cities. The escalating trend of both accident frequency and their corresponding economic burden over recent years is clearly illustrated in Figure 2, which demonstrates the urgent need for comprehensive intersection safety interventions to mitigate these mounting financial losses.

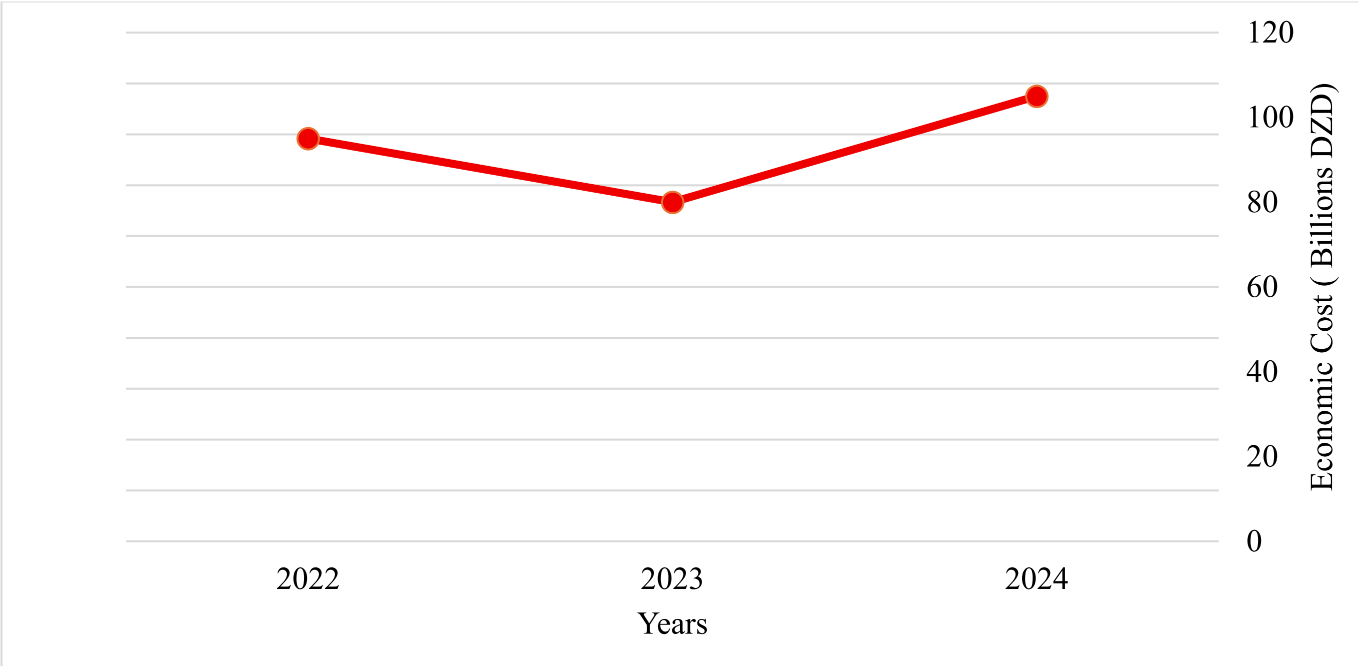

Figure I.2: Economic Costs of Urban accidents in Algeria (2022-2024) [3]

I.5.3 Social and Environmental Consequences

Intersections where accidents occur undermine drivers' confidence in the road network. Each accident reinforces the feeling of insecurity, leading some to reduce their travel or avoid dangerous intersections. In urbanized cities, media reports of accidents occurring in certain locations or frequent accidents at certain intersections increase collective distrust, harming quality of life and making daily travel stressful. From an environmental perspective, traffic jams caused by accidents worsen pollution. Stationary vehicles emit CO2 and fine particles, reducing air quality in an already polluted environment. A congested intersection can reduce an urban artery to a cloud of gas, with consequences for the health of local populations. These environmental and social impacts worsen the human toll of accidents. [8]

I.6 Policies and Measures to Prevent Vehicle Collisions at Intersections

The increase in accidents at Algerian intersections has led to the adoption of regulatory, infrastructural, educational, and technological measures. This section assesses their effectiveness and identifies barriers to their implementation in a context marked by logistical and financial constraints.

I.6.1 Regulations and Controls

The 40 km/h speed limit in urban areas is enforced to slow traffic around intersections and promote defensive driving. Penalties, including speeding tickets, are imposed to encourage compliance with speed limits. Roadside checks, carried out by patrols, aim to ensure compliance with speed limits. In addition, the installation of fixed speed cameras allows for the monitoring of driver behavior and the regulation of traffic in high-risk areas. [9]

I.6.2 Urban Development

Intersection designs are currently being optimized. Smart traffic lights, which automatically adjust their activation based on traffic, are being implemented in some cities to improve traffic flow and minimize the risk of accidents. Modern roundabouts, equipped with visible signage, are designed to efficiently manage vehicle flows. Road rehabilitation, such as repairing potholes and adding visible lines, improves lane readability. Intersection lighting improves nighttime visibility, thus promoting safe driving.

I.6.3 Driver Awareness

Campaigns aim to ensure right-of-way compliance. Public posters and radio spots emphasize the need to avoid distractions, such as mobile phone use while driving. Youth programs, broadcast in schools and on social media, encourage the adoption of good behavior from an early age. Dramatic visual campaigns, such as accident reenactments, aim to educate drivers of all ages about caution.

I.6.4 Technology Integration

Urban areas, characterized by high traffic density and complex user interactions, require advanced technological solutions to enhance road safety. In this section, we will analyze key technologies deployed in cities.

- **<u>Speed enforcement cameras:</u>** Fixed or mobile, speed enforcement cameras, which measure vehicle speed with radar or laser devices and record violations with cameras, are used to secure urban spaces by targeting high-risk traffic areas (near schools, pedestrian crossings) and speed limits (30 km/h). In Paris, for example, compact speed cameras are installed in each of the central arrondissements. These devices help limit speeding and, consequently, the number of fatal accidents.

- **Smart sensors for traffic lights**: Sensors, incorporating magnetic loops or cameras, can collect real-time traffic data to dynamically adjust traffic light cycles. In Amsterdam, an example is the FLOW system, which optimizes the operation of the busiest intersections in terms of vehicle traffic. These systems help to smooth traffic flow, reduce the risk of congestion, and limit reckless behavior at intersections.

- **Advanced Driver Assistance Systems (ADAS)**: ADAS (Advanced Driver Assistance Systems), such as automatic emergency braking, use radar or cameras to detect obstacles such as pedestrians or other equipped vehicles to intervene in the event of danger. It is installed in newer-generation vehicles (Tesla, Volkswagen, Mercedes). In urban environments, they prevent collisions at low speeds, their performance being dependent on good road conditions.

I.7 Future Trends and Challenges

In the previous section, we analyzed the technologies available to ensure road safety in urban areas, but these technologies face challenges. In this section, we will identify the most common challenges encountered by these technologies.

I.7.1 Impact of New Technologies

Latest-generation vehicles containing intelligent systems capable of navigating intersections without human error remain out of reach for some people due to their high cost and the lack of local road infrastructure information in some countries. Artificial intelligence systems, such as collision prediction, require reliable data, which is rarely available. Sensors connected to traffic lights show potential, but their adoption is hampered by power outages. These technologies, although promising, must be adapted to a context where the majority of accidents are attributable to human error.

I.7.2 Urban Growth

Ongoing rehabilitation is placing road infrastructure under increasing pressure. Intersections, designed to handle low traffic volumes, are becoming saturated. Intersections located in rapidly expanding areas, once very quiet, have become high-risk areas. Urban planning that anticipates strong growth is a must, but delays in the execution of infrastructure projects are exacerbating the consequences.

I.7.3 Climate Change

In light of ongoing climate change, beyond signage developments, climate information infrastructure is essential to warn residents about the effects of these phenomena. Extreme weather events are becoming increasingly frequent, compromising road safety where, with non-existent or inadequate drainage systems, rains pour down. When sandstorms aren't grappling with the molasses of dry desert regions, they systematically provoke the ire of motorists whose visibility is often zero. These contemporary climate phenomena find their solutions in modern infrastructure, such as draining roads and suitable signage, but investments take too long to come to fruition.

I.8 Interdisciplinary Perspectives

Despite the availability of solutions that can reduce the problem of accidents in urban areas, they are limited due to various factors (economic, technological, environmental, etc.). In this section, we will attempt to propose interdisciplinary perspectives for rethinking road safety, taking into account local specificities and user behaviors.

I.8.1 Urban Planning Approach

The reconstruction of road infrastructure is a fundamental lever for reducing accidents. Modern roundabouts, by smoothing traffic flow and eliminating conflict points, significantly reduce the risk of collisions. However, their widespread adoption is hampered by their cost. Furthermore, smart traffic lights, capable of optimizing traffic flows in real time, are extremely promising, but their high cost limits their use. Rigorous urban planning, with clear road markings and defined lanes, remains essential to reduce incidents.

I.8.2 Psychological Approach

Human error, responsible for a high percentage of accidents, deserves special attention. Stress management training for drivers in complex situations such as intersections is not yet widely practiced. Simulators reproducing high-risk intersection situations are being implemented by some driving schools, thus facilitating the acquisition of defensive driving techniques. The widespread adoption of these interventions can prevent human error. Targeted awareness campaigns, particularly on the risks of distraction (such as cell phone use, excessive speeds, and dangerous maneuvers), are particularly important, especially for new drivers.

I.8.3 Technological Approach

The use of advanced technologies offers considerable potential for identifying and protecting dangerous intersections. Analyzing traffic information received by GPS systems or cameras makes it possible to map risk areas. Pilot programs, such as the real-time adjustment of traffic lights based on traffic volume, have shown promise; However, their effectiveness is sometimes compromised by technical issues. Moreover, the integration of networked sensors, capable of quickly alerting drivers of imminent threats, can significantly improve road safety. However, the effective implementation of such systems depends on the availability of a stable digital infrastructure, which is often lacking in many contexts.

I.9 Conclusion

This chapter provides a detailed overview of urban road accidents, with a particular focus on intersections, analyzing their context, causes, impacts, and prevention strategies. Statistical data, particularly in Algeria, reveal a persistence of accidents due to human, infrastructural, environmental, and sociocultural factors. Preventive measures, including regulations, urban planning, awareness raising, and advanced technologies, while promising, face logistical and financial constraints. Interdisciplinary perspectives, combining urban planning, psychology, and technology, offer avenues for rethinking road safety. This analytical framework serves as the foundation for the following chapters, which will explore innovative solutions to reduce the incidence of accidents in urban areas.

Chapter II: Fundamentals and Applications of GPS Technology

II.1 Introduction

The first chapter presents an analysis of urban road accidents, their prevalence at intersections, and the multiple threats they pose to road safety. In this context, emerging technologies offer innovative solutions to reduce these accidents. The global positioning system (GPS) stands out in particular for its potential to improve traffic control and accident prevention. This chapter explores the operating principle of GPS, its civilian applications, and its integration with communication technologies. This study attempts to identify the ways in which GPS improves road safety in congested urban environments, thus expanding on the discussions discussed in the previous chapter.

II.2 Definition of GPS

GPS (Global Positioning System) is a U.S. government satellite navigation system. It currently consists of at least 24 satellites. GPS works in all weather conditions, anywhere in the world, 24 hours a day, with no subscription or installation fees. Initially, the U.S. Department of Defense (USDOD) put satellites into orbit for military use, but they were made available to civilians in the 1980s. [10]

II.3 GPS History

GPS was originally a reconnaissance system for the U.S. Armed Forces. It was launched in the late 1960s at the request of President Richard Nixon. Its design was entrusted to Ivan A. Getting, who conceived the principle of a group of inter-ring satellites emitting UHF radio waves picked up by GPS receivers.

It builds on previous programs, including SECOR, a series of satellites used to perform geodetic measurements.

The first satellite was launched in 1978. By 1995, deployment of the 24 operational satellites (plus 4 in reserve) was complete. The system also became operational.

In 1983, following the deaths of the 269 passengers of Korean Air Lines Flight 007, President Ronald Reagan proposed that GPS technology be made available to civilians free of charge once operational. Another series of satellites was launched in 1989 to build up a sufficient coverage area.

By 1995, the number of available satellites allowed GPS to operate continuously on Earth, with an accuracy limited to about 100 measurements for mercenary use. In 2000, President Bill Clinton confirmed the technology's value for mercenary purposes and authorized the unrestricted broadcast of GPS signals, allowing an accuracy of about 10 measurements and the widespread distribution of the technology to the general public starting in the mid-2000s.

The United States continued to develop its system by replacing and adding satellites and providing new GPS signals, which were more accurate and required less power to avoid bias. An interoperability agreement was also signed between the GPS and Galileo systems, allowing both systems to use the same frequency and ensuring courtesy. Two other systems were developed by Russia, GLONASS from 1980, and by China, Beidou, launched in 2000. [11]

II.4 Types of navigation systems

II.4.1 GLONASS System

GLONASS (GLObal Navigation Satellite System) is a Russian navigation system equivalent to the American Global Positioning System (GPS). Today it is used in combination with the American system (GPS) to obtain precise location. [12]

II.4.2 GALILEO System

Galileo is a satellite positioning (radionavigation) system set up by the European Union (EU) through the European Space Agency (ESA). The Galileo program consists of the establishment of a global infrastructure made up of thirty satellites, a vast network of ground stations distributed worldwide and two control centers in Europe. [13]

II.4.3 BDS System

BDS (BeiDou System) is a Chinese satellite navigation and positioning system. Like GPS, Galileo, and GLONASS systems, BeiDou satellites send two types of signals: the first is only usable by the military, while the second, providing a less precise position, is usable for civilian applications. [14]

II.5 Composition of the GPS system [15]

The GPS system is divided into three sectors, each playing a crucial role in its operation.

II.5.1 Space Segment

The space segment consists of a constellation of satellites in medium Earth orbit, at an altitude of about 20,200 kilometers and with an orbital period of 12 sidereal hours. Composed of 24 to 32 units, it is spread over six different orbital planes to ensure complete global coverage.

The space segment consists of a constellation of satellites in medium Earth orbit, at an altitude of approximately 20,200 kilometers and with a rotation period of 12 sidereal hours. Composed of 24 to 32 satellites, it is distributed across six different orbital planes to ensure complete global coverage.

The different generations of satellites that have followed are called Blocks, and six of these are called Block Satellites.

Block I: Eleven satellites were launched into orbit between 1978 and 1985. They were planned by Rockwell International for an average mission duration of 4.5 years and a lifespan of 5 years, but the average lifespan was 8.76 years. One of them had been in service for 10 years. Their main task was to examine the various concepts of GPS systems. There are no Block I satellites in operation today.

Block II: These represent the first operational satellites in the GPS system. These satellites have many improvements over previous versions, particularly in terms of autonomy. They can remain without contact with the ground segment for 14 days while still maintaining sufficient accuracy. Between 1989 and 1990, nine satellites were launched. They had a lifespan of 7.5 years, but most of them had been in operation for over a decade. Today, there are three Block II satellites.

Block IIA: Since 1990, Block IIA satellites have supported improved versions of the first Block II satellites. They were equipped to operate for civilians in degraded mode. They are equipped with two cesium atomic clocks and two rubidium clocks. They marked the beginning of the GPS operational phase, starting in 1993. As of 2010, 11 Block IIA satellites are active.

Block IIR: With greater autonomy, these satellites, launched in 1996, can transmit messages to each other without any ground contact, allowing system operators to communicate with spacecraft that would otherwise be inaccessible to them through direct communication. They are equipped with three rubidium atomic clocks. Fifteen Block IIR satellites have been launched, the last on

November 17, 2006; all are active. The last three are designated IIR-M because they transmit a new civil code (L2C) and a new military code (M).

Block IIF: The Block IIF (Follow-On) satellites built by Boeing will be launched starting in 2007. The program aims to achieve a constellation of 33 satellites.

Block III: The first ten Block III satellites are built by Lockheed Martin Corporation. They transmit a new civil signal (L1C) on the L1 frequency. The first Block III satellite was launched on December 23, 2018, and their goal is to prolong GPS operations until 2030 and beyond.

II.5.2 Control Segment

The control segment is the system's operational center that oversees and ensures the operation of the satellite constellation. Through a network of ground stations, including the main control station in Colorado and several tracking stations around the world, this segment participates in the continuous monitoring of the satellites' position, velocity, and general status. It adjusts their orbits to counter gravitational disturbances, synchronizes their atomic clocks to provide accurate time, and corrects navigation data, such as ephemeris and atmospheric corrections, transmitted to the satellites. This task requires advanced technologies, supercomputers, and secure communications, but is threatened by cyberattacks, geopolitical restrictions on station locations, and high upgrade costs.

II.5.3 User Segment

The user segment encompasses the countless GPS receivers used around the world, smartphones, and military guidance systems. These devices capture satellite signals, calculate distances to multiple satellites using trilateration, and determine precise positioning in latitude, longitude, and altitude. Applications are vast, ranging from road and flight navigation to telecom network synchronization, scientific research, and military operations. However, their low signal strength makes them susceptible to obstacles such as buildings or jamming, while the global reliance on GPS raises concerns about outages or attacks.

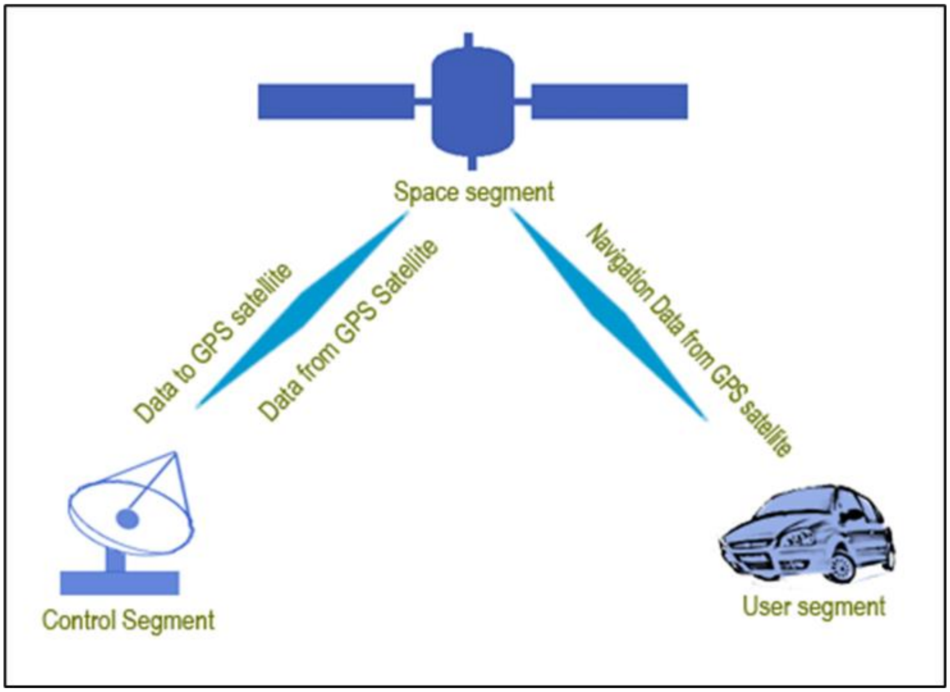

Figure II.1: GPS segments

II.6 How GPS works [16]

GPS works by calculating the distance between a GPS receiver and several satellites. Since the information needed to calculate the satellites, positions are regularly transmitted to the receiver, the receiver can determine its coordinates by knowing the distance between the satellites. In the next section we will determine the most needed calculations of GPS system

II.6.1 Position calculation

The GPS system determines the three-dimensional position of a receiver on the Earth's surface using signals emitted by a constellation of orbiting satellites. This system is essentially based on the principle of trilateration, which consists of calculating the receiver's position from the distances measured between it and at least four satellites.

Each GPS satellite transmits a signal containing two essential pieces of information:

- The position in space expressed as $(\boldsymbol{X_i}, \boldsymbol{Y_i}, \boldsymbol{Z_i})$ in a geocentric frame of reference
- The exact time of the signal's emission, obtained using an onboard atomic clock.t_i

When the receiver picks up the signal, it notes the time of reception t_r. The difference $t_r - t_i$ is used to calculate the propagation time of the signal, denoted Δt_i . By multiplying this time by the speed of light $c \approx 3 \times 10^8$ m/s, we obtain the pseudodistance D_i between the receiver and the satellite:

$$\boldsymbol{D_i = c \cdot \Delta t_i} \qquad \textit{(II.1)}$$

The unknown position of the receiver is noted (X, Y, Z) and the equation that expresses the actual geometric distance to the satellite i is as follows:

$$\boldsymbol{D_i = \sqrt{(X - X_i)^2 + (Y - Y_i)^2 + (Z - Z_i)^2} + c \cdot \delta t} \qquad \textit{(II.2)}$$

Where:

- $\boldsymbol{D_i}$ **: is** the pseudodistance measured
- $(\boldsymbol{X_i}, \boldsymbol{Y_i}, \boldsymbol{Z_i})$ **:** are the coordinates of the satellite i
- $\boldsymbol{\delta t}$ **:** is the synchronization error between the receiver clock and the satellite clock.

Once the coordinates $(\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{Z})$ are determined in the geocentric system, other calculations performed use geodetic formulas to obtain the geographic coordinates (Latitude, Longitude, Altitude)

- **Latitude:** represents the angle between the point and the equator (horizontal plain) denoted by ϕ it is obtained with the following equation:

$$\boldsymbol{\phi = arctan\ \frac{Z + e'^2\ a\ sin^3(\theta)}{\sqrt{X^2 + Y^2} - e^2\ b\ cos^3(\theta)}} \qquad \textit{(II.3)}$$

Where:

- $\boldsymbol{a}$ **:** Semi-major axis of the ellipsoid (equatorial radius).
- $\boldsymbol{b}$ **:** Semi-minor axis of the ellipsoid (polar radius).
- $\boldsymbol{e^2}$ **:** First squared eccentricity $\left(1 - \frac{a^2}{b^2}\right)$

- $\boldsymbol{e'^2}$ **:** Second squared eccentricity $\left(\frac{a^2-b^2}{b^2}\right)$
- $\boldsymbol{\theta}$ **:** Intermediate angle (Bowring parameter)

- **Longitude:** represents the angle between the point and the Greenwich meridian (vertical axis) denoted by λ, obtained according to the following equation:

$$\boldsymbol{\lambda = arctan\left(\frac{Y}{X}\right)} \qquad \textbf{\textit{(II.4)}}$$

- **Altitude:** represents between a point and an altimetry referent, most often the sea level, denoted by h obtained according to the following equation:

$$\boldsymbol{h = \frac{\sqrt{X^2+Y^2}}{cos(\phi)} - N(\phi)} \qquad \textbf{\textit{(II.5)}}$$

Where $\boldsymbol{N(\phi)}$ is the radius of curvature in the vertical plane at latitude $\boldsymbol{\phi}$ and is given by:

$$\boldsymbol{N(\phi) = \frac{a}{\sqrt{1-e^2 \cdot sin^2(\phi)}}} \qquad \textbf{\textit{(II.6)}}$$

Once the geographical position of the receiver (latitude, longitude and altitude) has been calculated, this information can be used for various applications in real time. They are usually integrated with navigation or mapping software so that the current position can be displayed on a digital map. It can also be transmitted via communication networks to remote servers for vehicle tracking, traffic management, or asset monitoring. At the same time, other algorithms can calculate trajectories, speeds or motion anomalies, thus providing added value in areas such as logistics, road safety and intelligent transport.

II.6.2 Determine distances

Geographic coordinates, typically expressed in latitude and longitude, are the primary basis for determining the distance between two features in the context of geolocation systems. After obtaining these coordinates, mathematical models adapted to the spherical shape of the Earth can be used to estimate the distance between these two points.

Geographic points defined by coordinate pairs (latitude, longitude) are provided by GPS positioning. Since calculations based on Euclidean distance (in a straight line) are inappropriate for spherical space, the curvature of the Earth's surface must be taken into account to determine the distance between two known positions.

Haversine's formula is commonly used to determine the great circle distance, which is the shortest distance between two points on the surface of a sphere. It is expressed according to the following equation:

$$d = 2R \cdot arcsin\left(\sqrt{sin^2\left(\frac{\Delta\varphi}{2}\right) + cos(\varphi_1) \cdot cos(\varphi_2) \cdot sin^2\left(\frac{\Delta\lambda}{2}\right)}\right) \quad (II.7)$$

Where:

- d **:** represents the distance between the two points (in meters)
- R **:** this is the radius of the earth (6,378 km)
- φ_1 **et** φ_2 **:** are the latitudes of the two points
- $\Delta\varphi$ = φ_2 **-:** φ_1 is the difference in latitude
- $\Delta\lambda = \lambda_2 - \lambda_1$ **: is** the difference in longitude

This method has the advantage of being both simple to implement and accurate enough for the majority of practical applications, including embedded systems, mobile navigation applications, or driver assistance solutions.

II.6.3 Determine the speed

The GPS system measures a user's speed in addition to their geographical location. The use of the Doppler effect on the radiofrequency signals emitted by satellites makes it possible to make this estimate accurately.

In the event of a difference in relative speed between the two, the GPS receiver will perceive a signal emitted by the satellite at the frequency at a different frequency. The Doppler effect, which states that the frequency received varies according to the relative speed between the transmitter (the satellite) and the receiver (the user), explains this discrepancy. Specifically, the frequency increases as the receiver gets closer to the satellite and decreases as it moves away from it. $f_0 f_r$

The Doppler frequency shift is given by the following equation:

$$f_{D_i} = \frac{\left(\vec{v}_{s_i} - \vec{v}_r\right) \cdot \vec{u}_i + c \cdot \dot{\delta}}{c} \cdot f_0 \qquad \textit{(II.8)}$$

Where:

- f_{D_i} **:** represents the Doppler Shift (Hz), measured for the satellite
- $\vec{v}_{s_i}$ **:** this is Satellite velocity i (m/s)
- $\vec{v}_r$ **:** this is the receiver speed
- $\vec{u}_i$ **:** represents Satellite-receiver direction unit vector
- c **:** this is the value of the celerity of light ($3 \times 10^8\ m/s$)
- $\dot{\delta}$ **:** this is the derivative of the clock error
- f_0 **:** represents the nominal frequency of the signal (Hz)

Once the calculations are performed, the measured Doppler shifts (e.g. of 4 satellites) are used to form a system of linear equations. This system, solved by a matrix approach, makes it possible to determine the speed of the vehicle as well as the clock bias. The resulting speed, expressed in meters per second, can be converted to kilometers per hour by multiplying by 3.6, providing accurate information for navigation applications, such as tracking or displaying real-time speed on a GPS device.

II.7 The different civilian applications of GPS [10]

II.7.1 Real-time navigation

Real-time navigation is one of the main uses of GPS in the Civil Domain. The GPS receiver can know its precise position and speed in relation to a terrestrial reference point at any time, regardless of the vehicle that is equipped with it. All this information makes it possible to follow a route, detect traffic jams and calculate the best route, improving the safety and efficiency of travel.

II.7.2 Cartography

The mapping industry can benefit from the use of GPS technology during the survey and implementation phases. The real-time GPS approach is especially suitable for this task, it is commonly used in cadastral projects, the construction of roads or railways, as well as in the monitoring of performance in precision agriculture.

II.7.3 Transport and logistics

The GPS feature allows for efficient management of en-route transport and logistics fleets. Vehicles equipped with a GPS receiver will send their real-time location where they are at all times and at all times to a central system. Officials will know where the car is from and which road it will be passing on to allow tracking. The use of Geolocation to track this road device allows the optimization of its route as well as traffic due to the road. The GPS system will synchronize routes with road and traffic conditions. Deliveries will also be regulated according to time constraints.

II.7.4 Safety and urgency

GPS is also extremely crucial during emergency response because it allows the exact location of victims or accidents to be determined quickly and accurately.

When an emergency call is made, GPS can accurately determine the caller's position even if he/she has no idea where he/she is.

This information is passed on to emergency response teams, such as ambulances and fire departments, to guide them on the most efficient route to the scene of the incident.

When a natural disaster occurs, GPS technology can be used by governments to organize the rescue process and track the spread of the disaster so that resources can be allocated and victims can be recovered more efficiently.

II.7.5 Meteorology

GPS is the most frequently used system today in all types of locations. In addition, many new applications can be provided from the analysis of GPS data in meteorology. This is based on investigations into the propagation of GPS signals from satellites to receivers, climate change and atmospheric refraction affecting the atmosphere. Convection phosphorus disorders, the cause of GPS errors, are rich data for meteorologists.

II.8 Integration of Transmission Technologies for GPS Geolocation

After the GPS module has determined the location (latitude, longitude, altitude, speed), this information must be sent to an external system, such as a mobile phone, a remote server, or an integrated app. This transmission is based on the use of communication technologies, selected according to the specific needs of the application: range, energy efficiency, data transfer rate and reliability. In the following section, we will specify some of the technologies that can be used in this context. The overall performance of the geolocation system and its suitability for the environment of use depend on the judicious choice of technology.

II.8.1 Communication technologies

- **Bluetooth Low Energy (BLE)**

BLE is a wireless communication technology, which works at short range, ideal for GPS embedded systems. This technology makes it possible to efficiently transmit geographic data to smartphones with low battery consumption. The protocol used, GATT, organizes exchanges in the form of services and features, facilitating integration into mobile applications. [17]

- **Wi-Fi**

Wi-Fi enables high-speed wireless communication, often used to connect an on-board GPS system to a local network or the Internet. Using protocols such as HTTP, MQTT or WebSocket, GPS coordinates can be sent in real time to a web server, application or database. This solution can be used for the management of GPS data for short and long needs. [18]

- **Cellular networks**

These cellular technologies allow an on-board GPS system to transmit data through a mobile network, using a module such as the SIM800L or SIM7600, GPS data can be sent remotely via HTTP, MQTT, TCP/IP or even SMS. This system ensures worldwide coverage, as long as a mobile signal is available. [19]

- **Lora**

LoRa is a long-range radio technology, perfect for embedded GPS systems located in rural areas or without internet infrastructure. Combined with a module such as the RFM95, it allows GPS coordinates to be sent over several kilometers with very low energy consumption. LoRaWAN protocol or a custom protocol can be used. LoRa is suitable for low-power networks and connected objects in isolated areas. [20]

- **RF (Radio Frequency)**

RF modules such as the nRF24L01 or 433 MHz modules allow for simple, point-to-point communication with limited throughput. By combining a GPS, the coordinates can be transmitted to a remote receiver without the Internet, via a basic serial protocol. It is an economical solution, easy to implement for simple uses over short or medium distances. [21]

The following table compares the different communication modules that can be integrated into a GPS embedded system. This comparison takes into account several essential criteria such as range, power consumption, data throughput, as well as the advantages and limitations of each technology.

Communication Module	Scope	Energy consumption	Throughput	Benefits	Bounds
BLE	10-30 m	Very Low	Low to medium	Low power, good mobile integration, simple to use	Limited range, moderate throughput
Wi-Fi	50-100 m	Medium to High	High	Broadband, direct connection to the Internet	Dependence on a local network, high consumption
Cellular networks	Global coverage	Medium	High	Real-time tracking, accessible mobile network	Need a SIM card, expensive subscription
Lora	2 to 15 kilometers	Very Low	Weak	Very long range, low power consumption	gateway or private network required
RF	50 to 500 meters	Weak	Very Low	Cost-effective, simple to implement	Insufficient flow

Table II.1: Comparison of Communication Technologies for GPS Systems

II.8.2 Criteria for choosing communication technology for a GPS embedded system

The choice of the communication module to be integrated into a GPS embedded system is based on several technical and contextual criteria. Among the most important are:

- **Reach**: maximum broadcast distance depending on the project need (local, urban or rural)
- **Throughput**: it is necessary to choose a technology that transmits GPS data without disturbances
- **Power consumption:** This is especially important for systems that are battery-powered
- **The communication protocol**: use of a simple, available and compatible protocol
- **The cost**: including the price of the module, the operating costs and the implementation costs.

Thus, depending on the environment of use (area covered, frequency of sending, mobility of the object, access to the network), each technology has specific advantages.

II.9 Conclusion

This chapter highlighted the functioning of the GPS system, its essential components, as well as its decisive role in modern geolocation. In addition to providing accurate position, distance, and speed data, GPS integrates effectively with various communication technologies to meet the growing needs for mobility, safety, and efficiency. These capabilities make it an indispensable tool in many civilian fields such as navigation, logistics and emergency management. This understanding serves as a foundation for developing an innovative solution to improve road safety, which will be presented in the next chapter.

Chapter III: Implementation of RouteGuard

III.1 Introduction

After an in-depth study on the causes and impacts of vehicle accidents in urban areas in the first chapter and the exploration of GPS technology in the second chapter, which represents a starting point for the realization of a system that has the goal of reducing vehicle accidents in cities, it is to realize RouteGuard to achieve the desired objective

In this chapter, we present the RouteGuard project, a wearable and connected solution that uses GPS and Bluetooth Low Energy (BLE) to detect and prevent the risk of collisions between road users.

III.2 Problem statement

Statistics showing that the majority of accidents in urban areas are caused by humans with a percentage of 92% [2], the main causes are often related to excessive speed, maneuvering errors, failure to respect priorities, sudden changes of direction and driver inattention. These actions, combined with the complex infrastructure of the streets that create dangerous situations and collisions become frequent

Despite the availability of vehicle traffic organization means such as road signs and traffic lights, the number of accidents continues to increase precisely in high-traffic areas and intersections.

It is becoming essential to implement a simple, intelligent and compatible solution that allows drivers to better anticipate the presence of other vehicles and prevent accidents.

III.3 Existing solutions

In order to reduce vehicle accidents, several technologies have been implemented over the years, some are integrated into recent vehicles, and others in the form of mobile applications, in the next part we will present the main existing systems that are intended to reduce road accidents.

- **ADAS (Advanced Driver Assistance Systems)**: is an on-board system installed in modern vehicles, it consists of sensors, radars, cameras and software that allows surveillance insideand outside the vehicle and notifies drivers when abnormal situations are present, it is considered an excellent technology that allows to alert drivers against abnormal situations. [22]

- **Mobile navigation apps**: Mobile apps like **Waze** provide real-time traffic data for users, they can be used in the context of road safety with manual hazard or accident signaling. [23]
- **VANET System (Vehicle Ad-hoc NETwork)**: is a technology that uses moving vehicles as a node, it allows vehicles to connect to each other wirelessly with a distance of 100 to 200 meters. The main goal of VANET is to provide road safety. Each equipped vehicle allows you to instantly share data such as position, speed, direction, or an event (emergency braking, obstacle, accident, etc.). This information is used to warn other drivers in good time and reduce the risk of collisions. [24]

III.4 The limits of existing solutions

Despite the notable advances in on-board road safety, current solutions have several technical, economic and practical limitations that limit their large-scale adoption and reduce their effectiveness, in this section we will present the limitations of each solution mentioned in the previous section

- **ADAS System:** [22]
  - Reserved for recent and high-end vehicles.
  - High cost of integration
- **Mobile Navigation Apps:** [23]
  - Do not allow real-time detection of the immediate vicinity of another vehicle.
  - Are based on manually reported data, so not instantaneous.
- **VANET system:** [24]
  - Require specialized on-board equipment on all vehicles involved
  - Not compatible with standard or older vehicles.
  - High cost of set-up and maintenance.

III.5 Initial Technology Approaches

Faced with the limitations identified in existing solutions, it is necessary to consider other technical approaches that are more accessible, flexible and efficient.

In this section, we present several technologies that can form a solid basis for the design of an accident prevention system.

III.5.1 GPS System - Wi-Fi

The first approach for the realization of the system was the use of an ESP32 microcontroller SoC that integrates the Wi-Fi module with a GPS module, which represents a strong combination for real-time communication between the GPS module and the connected user. But this solution had disadvantages that influence the operation of the system, such as high energy consumption.

III.5.2 SIM system – GPS

The second approach was to create the system with a GSM/GPRS module as (SIM800L) links with the GPS module, which allows the coordinates to be sent as an SMS message to a mobile phone or as http packets to a database. This system has drawbacks such as configuration complexity and additional subscription fees.

The first avenues considered to design the system quickly showed their limits in terms of performance, simplicity and autonomy that we had set for ourselves. These methods presented significant constraints in terms of energy, configuration and dependence on external infrastructures. To overcome these obstacles, we have chosen to move towards an alternative which is the GPS-BLE embedded system which has a low energy consumption, ideal for mobility and simple to integrate into mobile applications and all types of smartphones.

III.6 RouteGuard System Description

III.6.1 Definition

RouteGuard is an intelligent road accident prevention system, designed to improve driver safety in urban environments. It is a combination of on-board and mobile technologies to track the position of vehicles in real time and alert drivers to potential collision risks.

III.6.2 System composition

RouteGuard is composed of a hardware part (RouteGuard GPS) and the RouteGuard mobile application. In this part we will present the composition of the two subsystems, hardware and software

- **Hardware subsystem**

The embedded hardware is the physical basis of the system. It is installed on board each user vehicle and collects and transmits position data, it consists of three essential parts:

a. Central Processing Unit (CPU)

The CPU is the heart of the system, it is responsible for the analysis, recovery and transmission of GPS data

b. The GPS module

This module is used to capture the geographical position of the vehicle (latitude, longitude, speed) in real time. It allows the system to track movements accurately.

c. A power battery

The system is powered by a rechargeable battery providing sufficient runtime for extended operation without interruption.

- **Software subsystem**

a. Arduino IDE

It's an open-source software used to program electronic boards, we're going to use it to develop the code needed for our system, including the relationship between the GPS module and Bluetooth to ensure the connection with the smartphone. [25]

b. Flutter

The RouteGuard system mobile app was developed with Flutter, an open-source framework from Google, using the Dart language [26]. This technology creates a smooth and responsive interface that is compatible with Android and iOS. It manages the Bluetooth connection, the display of GPS positions on the map, and communication with the cloud. The development was done in the Visual Studio Code environment, making it easy to write and test the code.

c. Cloud Database Integration

A cloud-based real-time database is used to store, manage, and synchronize users' geolocation data. This enables continuous sharing and updating of position information across all connected users within the system.

d. Google Maps SDK

In the app, a Google map is displayed using the Google Maps SDK, a development kit provided by Google that allows interactive maps to be integrated into mobile applications. Which will track the user's location and displays nearby vehicles. [27]

III.6.3 Introducing the mobile app

- **Start screen**

When the user launches the app, a 3-second splash screen appears with a white background and the RouteGuard logo is centered.

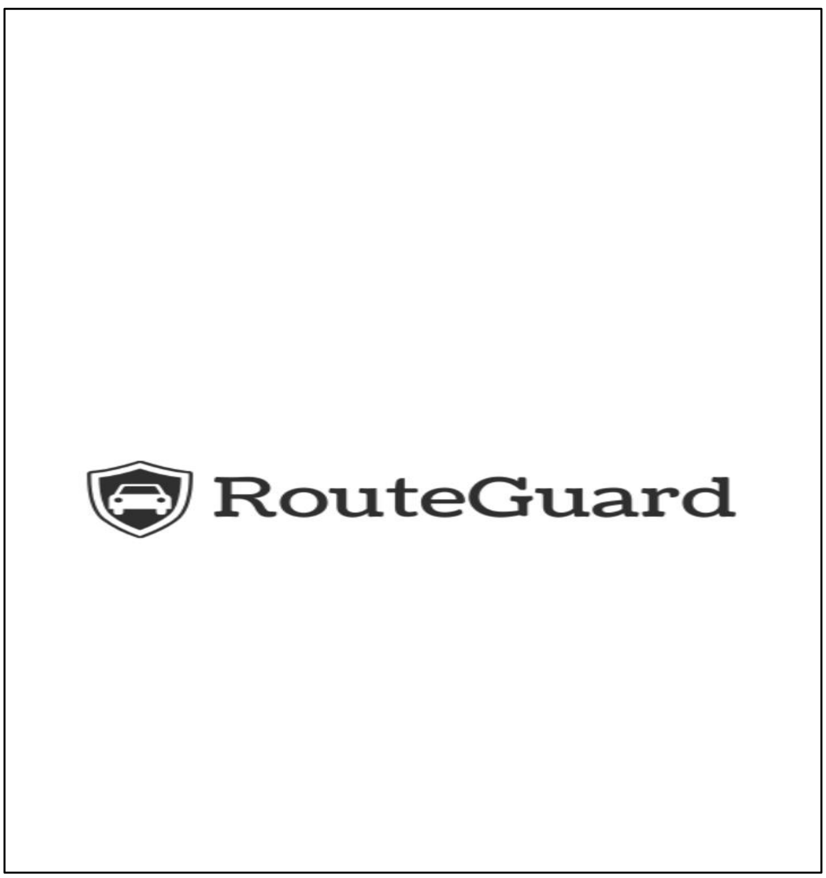

Figure III.1: Start Screen

- **Authentication screen**

User authentication is performed using Google Sign-In to retrieve a unique user ID, which is stored in the database to enable user identification and management within the system.

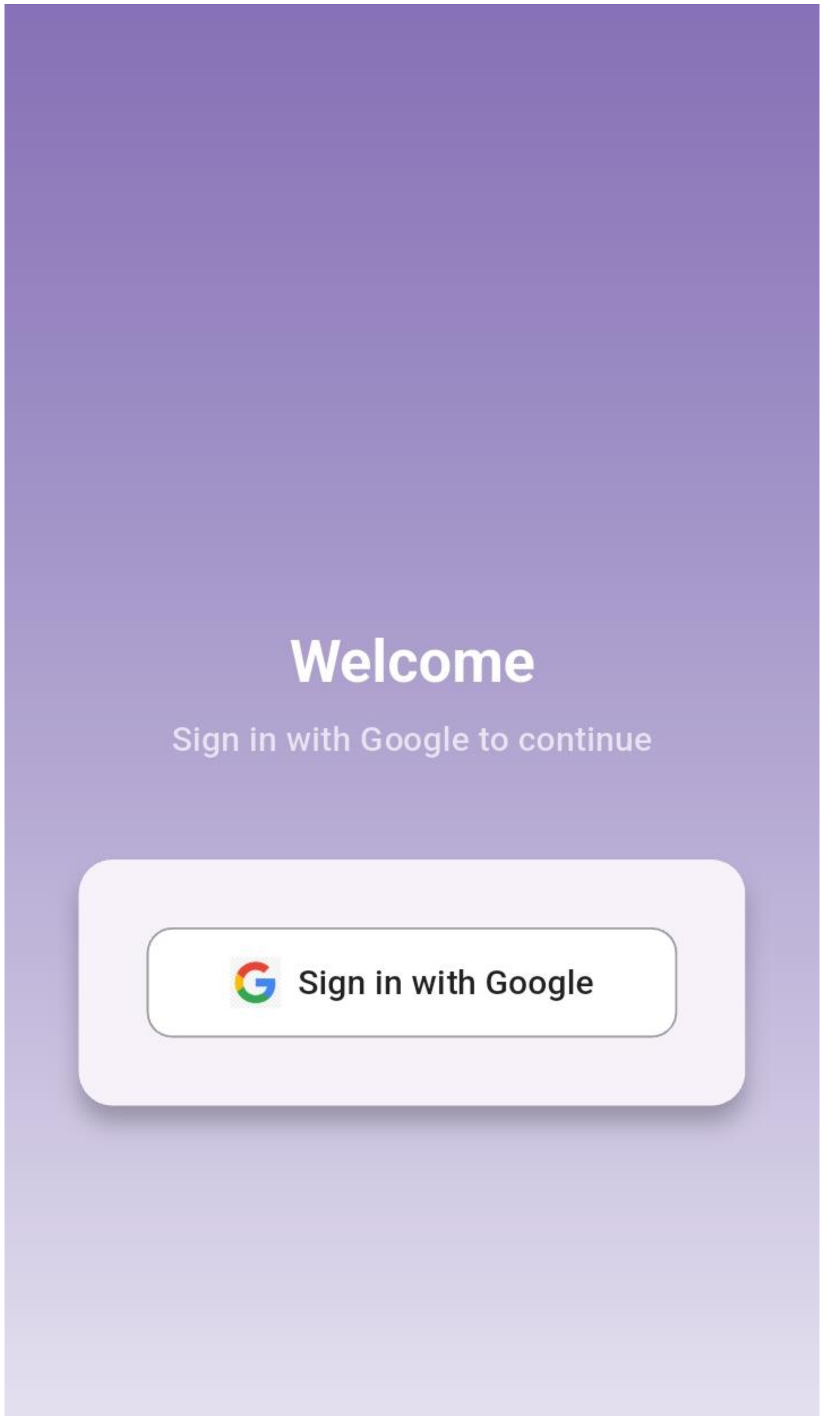

Figure III.2: Login screen

- **Main screen**

After a successful connection, the user will be transferred to the main screen which contains a navigation bar at the bottom to navigate to the three screens (Map, Bluetooth, settings)

- **App screens**

The app is divided into three screens:

- **Map Screen**: This screen contains a Google map, to display the user's position and other positions, also display second-by-second movement and display the user's speed, and you can see an audible warning of probable collision.

Figure III.3: Map screen

- **Bluetooth Connection Screen**: This screen is dedicated to connecting to the GPS device, it only displays the devices that are called RouteGuard GPS and connect them.

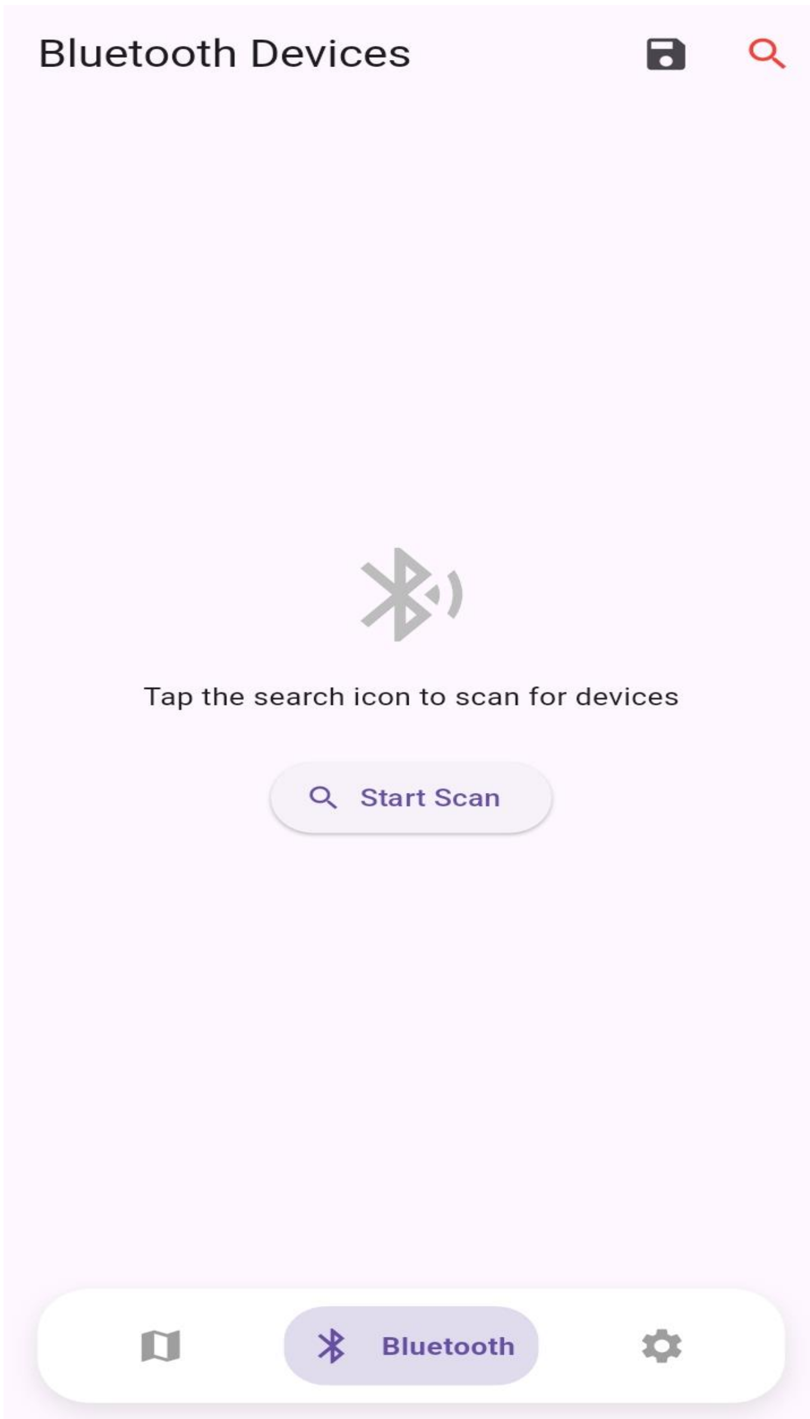

Figure III.4: Bluetooth Devices Screen

- **Settings screen**: in this screen the user can adjust the app's preferences according to its conformability, so we find:
    - **Profile**: which allows the user to save their name and car model to store at the database.
    - **Display theme**: The user can choose the dark or light theme according to their preference.
    - **Language**: the user can choose the language that suits him, there are three languages (French, English, Arabic).
    - **Logout button**: A button used to log out of the app.

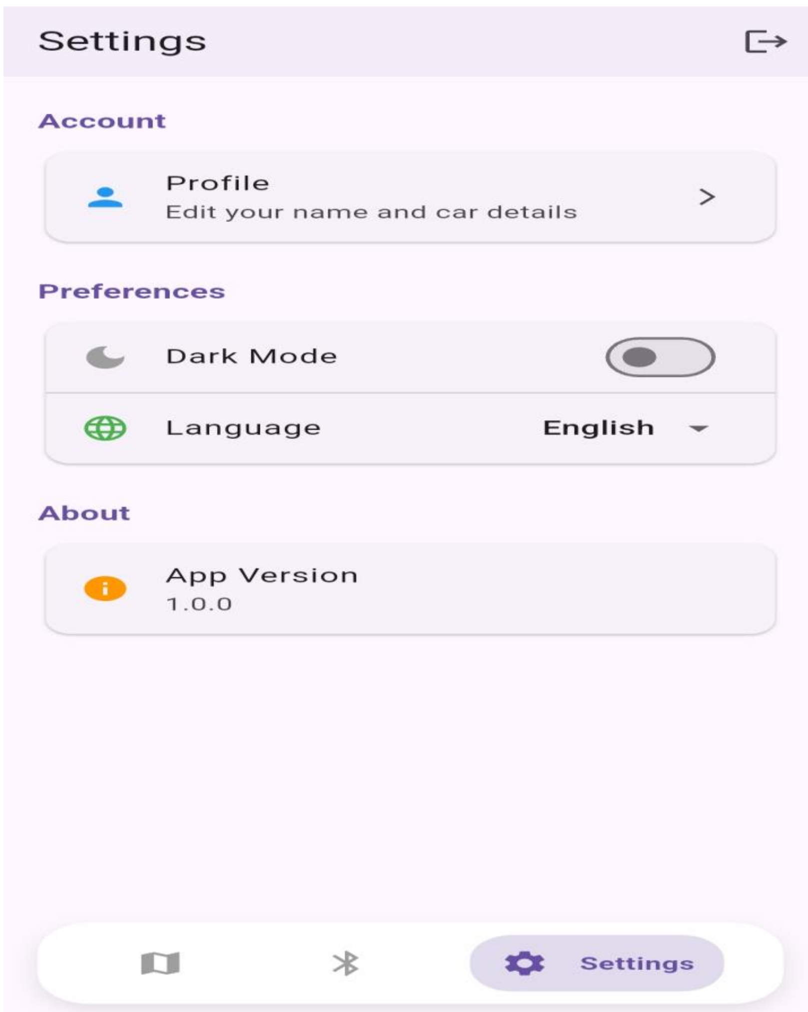

Figure III.5 : Settings Screen

III.6.4 The operating principle

The RouteGuard system works by following a coordinated chain of operations between the on-board hardware and the mobile app. The GPS module integrated into the RouteGuard device captures the vehicle's position in real time. This position is transmitted to the microcontroller, which then sends it via Bluetooth to the mobile application installed on the user's smartphone, and then these coordinates are sent to the online database, which allows the continuous synchronization of geographical positions and to share them with users, in the map screen the user can see the vehicles nearby. An intelligent analysis system continuously monitors distances and speeds. A visual and audible alert is automatically triggered if two conditions are met: another vehicle is at a distance of 50 meters or less, and the vehicle's speed exceeds 50 km/h, which allows the driver to be warned of a danger, thus enhancing collision avoidance.

III.7 The Benefits of RouteGuard

- **Reduced road accidents:** RouteGuard allows drivers to track the position of other vehicles equipped with the system in real time, which reduces the risk of collisions in areas with low visibility (bends, intersections, etc.)
- **Real-time alert:** The app displays alerts in the event of danger in a quick way to allow drivers to react faster.
- **System mobility:** The driver can use his RouteGuard GPS device in any personal vehicle, i.e. RouteGuard GPS is not fixed with a permanent installation.
- **Simplicity and compatibility:** RouteGuard is a simple system to install and use for all people even if they have no idea about the technology, and compatible with all types of vehicles.
- **Autonomous and sustainable power supply:** The device is equipped with a rechargeable battery, which allows it to operate autonomously without the need for vehicle electricity, due to the low power consumption, the battery can be keep the system running for a long time.
- **Collaborative and supportive driving:** By sharing their location and being alert to others' alerts, drivers become more responsible and aware of their surroundings, creating a safer and more supportive driving community.

III.8 Comparison of RouteGuard with available systems

In the following table, we will make a comparison between RouteGuard and the available road safety systems, this comparison that will push vehicle users to choose our system thanks to conditions that will be represented in the table above.

System / Characteristics	RouteGuard	ADAS	Waze
Cost	Affordable	High	Free
Real-time alert in case of danger	✅	❌	❌
Accessibility	Accessible in all types of vehicles	Limited to modern cars	Application accessible
System Type	Hybrid system (app + device)	Sensor-based embedded system	Application
Technology used	Bluetooth, GPS	Camera, radar	GPS

Table III.1: Comparison Between RouteGuard and available Systems

III.9 Testing and validation

The last step in the realization of our system is to perform a series of tests in order to validate the proper functioning of the main features of RouteGuard, in this part, I will present the tests we have carried out to verify the functionalities of RouteGuard:

- **Connection test**: Connectivity between the RouteGuard GPS device and the mobile app is tested
- **Position display test**: after successful connection with the device, we will test if the user's position is displayed in the map screen.

- **Testing the display of nearby vehicles**: We will check if the application is able to display the positions of other RouteGuard users located nearby. This test will evaluate the detection of surrounding vehicles and the real-time update of their positions.
- **Collision alert test**: When the collision probability conditions (distance and speed) are satisfied, we will test whether an alert is triggered automatically. This test will make it possible to validate the proper functioning of the alert system under realistic conditions.

III.10 Conclusion

This chapter introduced RouteGuard, a simple and smart system designed to reduce road accidents in cities. Unlike existing solutions that are expensive or limited to modern vehicles, RouteGuard is affordable, easy to use, and works with any car. By combining GPS and Bluetooth, it allows drivers to see nearby vehicles in real time and receive alerts to avoid collisions. Tests have shown that the system is effective, reliable, and ready to support safer and more responsible driving in urban areas.

General Conclusion

General Conclusion:

This thesis addressed the persistent problem of road accidents in urban areas, highlighting the limitations of existing preventive systems. In response, we designed RouteGuard, an intelligent, affordable, and easy-to-use system that combines a mobile app and an embedded GPS-Bluetooth device to alert drivers of potential collisions in real time.

Unlike existing high-cost or limited-access solutions, RouteGuard is compatible with all vehicle types and promotes safer driving through real-time awareness and alerts. Testing confirmed its reliability and effectiveness in urban settings.

In addition to reducing accident risks, RouteGuard fosters a more collaborative driving culture by sharing positional data among users. Its lightweight design and low energy consumption make it ideal for large-scale deployment, especially in developing regions. Future improvements could include AI-based risk prediction and integration with smart city infrastructure.

Overall, RouteGuard offers a practical and scalable approach to improving road safety and sets the stage for future advancements in connected mobility.

Annexes

الجمهورية الجزائرية الديمقراطية الشعبية

وزارة التعليم العالي والبحث العلمي

جامعة عين تموشنت بلحاج بوشعيب

حاضنة الأعمال عين تموشنت

ملحق نموذج العمل التجاري

BMC Annexes

Project Data Sheet — ■ *البطاقة التقنية للمشروع*

BOUIZEM Mohammed El Mehdi	**الاسم و اللقب** **Your first and last Name**
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+213662088324	**رقم الهاتف** **Your phone number**
Routeguard.dz@gmail.com	**البريد الالكتروني** **Your email address**
Ain Temouchent	**مقر مزاولة النشاط (الولاية- البلدية)** **Your city or municipality of activity**

Nature of project — ■ *طبيعة المشروع*

المنتوج ذو طابع إنتاجي - خدماتي

(Hybrid production-service system)

RouteGuard

المشكلة المراد حلها وتكون مدعمة بالبيانات (إحصائيات إن وجدت)

I. Problem:

Road safety remains a major issue on a global scale. Despite awareness campaigns, advances in infrastructure and changes in automotive equipment, road accidents continue to cause thousands of deaths and tens of thousands of injuries each year. According to the World Health Organization, more than 1.19 million people lose their lives on the roads every year. In Algeria, in 2024, more than 1,000 people died on the road, and thousands more were seriously injured. (DGSN,2024)

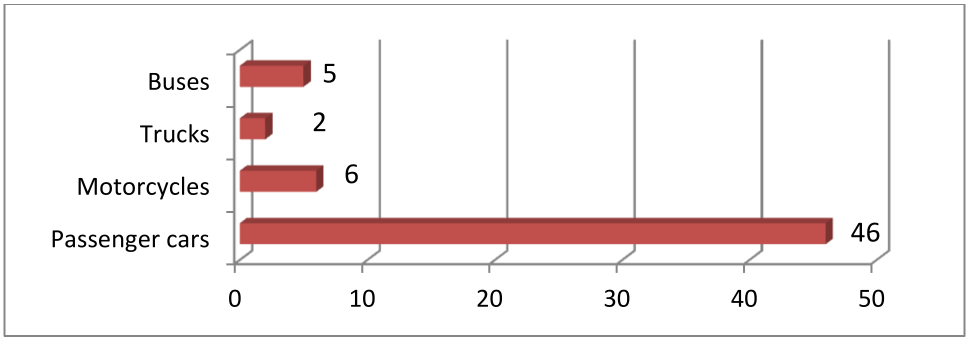
The majority of these accidents are linked to human factors: inattention, excessive speeds, lack of responsiveness, poor anticipation of the behavior of other users, or the inability to detect danger in time. For example, in urban or suburban areas, traffic density, blind spots, unexpected lane changes or priority crossings are all risky situations. In these contexts, a simple delay in reaction or a misperception of the environment can lead to a serious accident.

Today, some high-end cars are equipped with advanced driver assistance systems (ADAS) such as proximity radars, 360° cameras, collision warnings, or automatic emergency braking. However, these technologies remain expensive and are mainly accessible to recent vehicles. A large part of the vehicle fleet on the road, especially older vehicles or motorized two-wheelers, does not benefit from this type of assistance. There is therefore a real technological divide in terms of road safety.

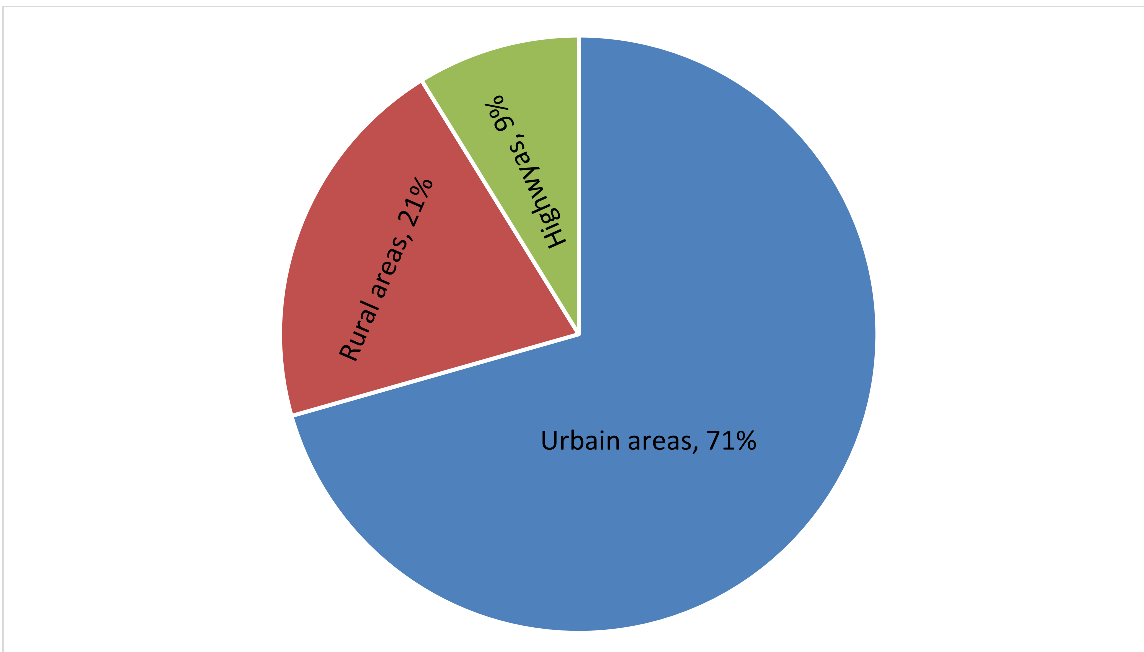
It is in this context that the idea of RouteGuard was born: a mobile, collaborative solution, accessible to all road users, which harnesses the power of real-time geolocation to create a safer driving environment, with the aim of reducing vehicle accidents in urban areas. The goal is simple but ambitious: to allow every driver to see other nearby vehicles on their smartphone and receive automatic alerts in the event of potential danger without the need for heavy infrastructure, complex sensors or state-of-the-art vehicles. By connecting users to each other, RouteGuard turns every phone into a safety sensor and every driver into a preventative player.

- The work team conducted a survey of 80 road users to collect their perceptions of everyday driving conditions, the causes of accidents, as well as the effectiveness of technological solutions. Preliminary results show that:

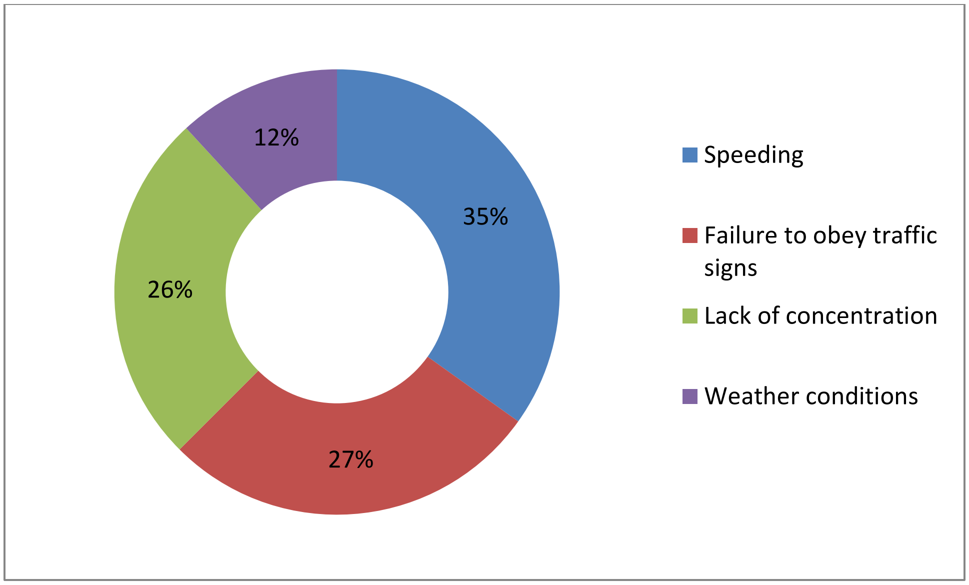
86% of those surveyed have a driver's license, and 70% have a vehicle, broken down as follows:



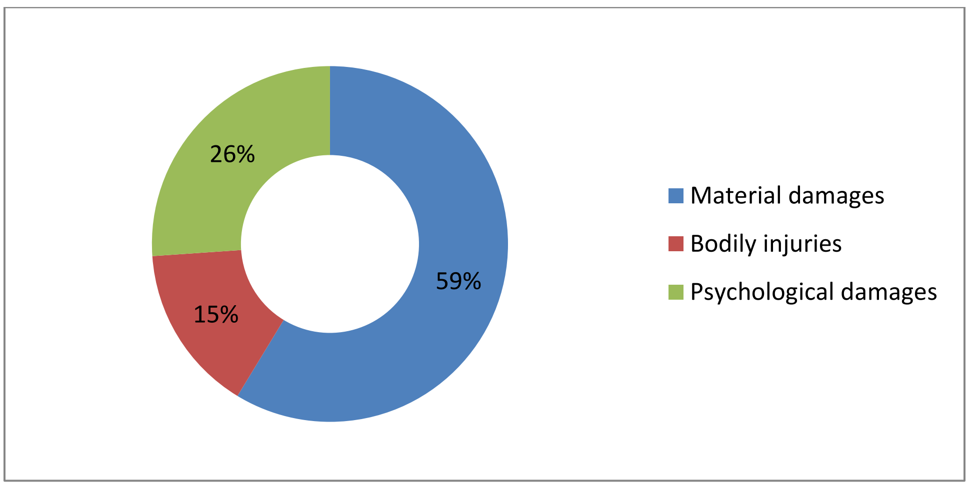
As far as daily driving time is concerned, 50% of drivers say they spend between 1 and 3 hours behind the wheel each day. With regard to driving contexts, respondents said that they mainly circulate:



Regarding the experience of road accidents, 65% of participants said they had been involved in previous accidents, including 40% in minor accidents, and 25% in moderate or severe accidents. The main causes identified by the sample are the following:



Persons involved in traffic accidents, either minor or serious, confirmed to have suffered various damages, which will be presented in the following circle:



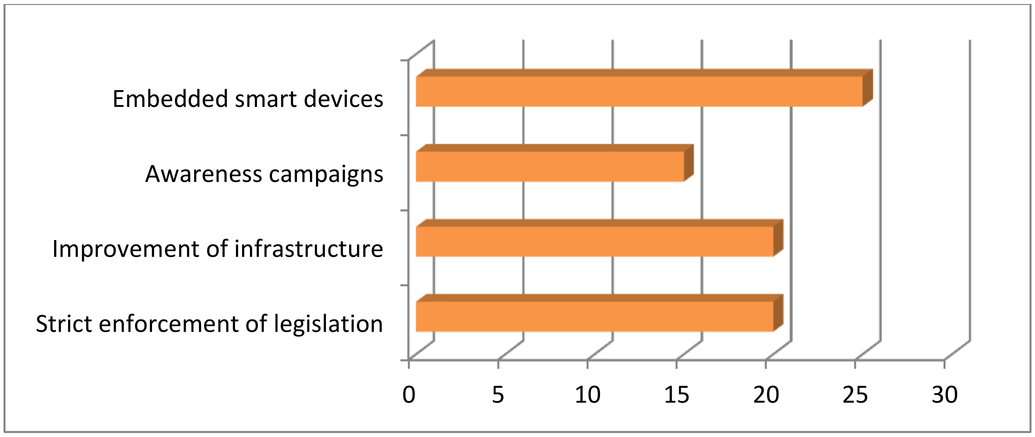
The most prone areas to accidents, according to drivers, are:

- Intersections and roundabouts (35%)
- Downtown (30%)
- Motorways (30%)
- Residential areas (5%)

Regarding the role of technology, 62% of respondents believe that smart solutions (such as in-vehicle warning and warning systems) could play a significant role in reducing accidents.

In addition, 70% of respondents say they are willing to buy a smart device to improve their driving, provided it is affordable and offers concrete benefits.

As for the means proposed to improve road safety, the suggestions are as follows:



1- Value proposition:

1- القيمة المقترحة:

ما القيمة التي نقدمها للزبون؟

كيف نساعد الزبون على حل مشكلاته؟

ما طبيعة هذا الحل للمشكلة هل هي قيم نوعية أو كمية؟

1/1- القيمة التي نقدمها للعميل:

1) Value Proposition

RouteGuard is a mobile and accessible road safety system designed to alert drivers in real-time of potential hazards on the road, reducing the risk of accidents in urban areas. This system offers significant value for customers as it allows:

Reduced time to detect hazards: Using geolocation technology and real-time vehicle-to-vehicle communication, RouteGuard instantly alerts drivers to potential hazards, allowing for better risk anticipation.

Real-time road safety monitoring: RouteGuard offers continuous monitoring of the position of other vehicles and the user's proximity

Active accident prevention: The system identifies collision risks at an early stage, reducing the likelihood of serious accidents. The app allows drivers to react in time to avoid dangerous situations, such as sudden braking or unexpected entry into a bend.

Portable and accessible solution: RouteGuard requires no complex installation or expensive equipment. It can be used on any vehicle with a simple smartphone, making it accessible to a wide audience.

Convenient and cost-effective solution: The app is easy to use and set up, and the necessary hardware is inexpensive, making this safety technology available to everyone, including those who do not own vehicles equipped with the latest safety technology.

Full support for proper use: Sales, installation and delivery services are offered to ensure optimal use.

System runtime: Built-in rechargeable battery for extended use without frequent recharging

Powerful protection at an affordable price: Thanks to its optimized engineering and a controlled production line, RouteGuard guarantees a high level of security equivalent to international standards, while being offered at a much more affordable price than its competitors. It is the ideal solution to combine performance, reliability and economy.

Emotional and societal values:

- Sense of security: RouteGuard reassures drivers by providing real-time monitoring.
- Peace of mind: The user can concentrate on the road stress-free, knowing that intelligent assistance is active.
- Improved public safety: By detecting dangerous situations in time, the app contributes to a safer road environment
- Collective awareness: RouteGuard promotes global awareness of the importance of responsible driving, it encourages a change in societal behavior in terms of road safety.

2/1-ما هي المشاريع الأخرى التي استهدفت نفس المشكلة والتي جرى تنفيذها؟

Competitive Products

- **Waze**: It is considered an indirect competitor, a community-based GPS navigation mobile application that provides optimized routes and alerts by user reports.

- **ADAS**: is considered a direct competitor, is an in-vehicle system that assists the driver through sensors and software to prevent accidents and facilitate driving.

Competitor comparison with RouteGuard.

Product	Key Benefits	Disadvantages	Dedicated hardware	Price
Waze	• Reduces travel times by avoiding known risk areas • Alerts on accidents, traffic jams, speed cameras, roadworks (thanks to the community)	• Not designed to prevent collisions in real time • Highly dependent on user reports (untrustworthy without an active community)	No	Free
ADAS	• Prevents collisions in real time with on-board sensors (radar, lidar, cameras) • Can significantly reduce accidents due to inattention	• High cost (reserved for modern or high-end vehicles) • Requires regular maintenance and calibration	Yes	High
RouteGuard	• Immediate alerts in case of danger • Portable solution compatible with all vehicle models	Still young solution (to be tested to scale)	Yes	Affordable

✓ SWOT analysis of direct competitors

○ ADAS

Strength:	Weakness:
• Improves safety by reducing accidents related to human error. • Improves driving comfort with features like adaptive cruise control. • Supported by increasing global regulations. • Expanding market thanks to demand	• Surrealism of systems can lead to driver distraction. • Limited performance in poor weather or road conditions. • High costs increasing vehicle prices.
Opportunity:	**Threat:**
• Supports the development of fully autonomous vehicles. • Expansion into affordable vehicle segments. • Enables data-driven system improvements through connectivity.	• Risky behaviors of drivers due to perceived safety. • Rapid emergence of competing solutions due to the rapid evolution of technology. • Dependence on quality infrastructure and connectivity.

2- **Customer segments**:

2- شرائح العملاء

- من أهم عملاؤنا؟ لمن نوجه القيمة؟ (حدد بالتفصيل)

نحاول تحديد عدد العملاء من خلال استبيان أو سبر أراء إن وجد. بهدف تحديد السوق المحتمل. أو كيف العمل لتحديد سوق مستهدف.

- Individual Drivers (B2C): This category represents RouteGuard's primary market, drivers especially in traffic-dense urban areas and complex intersections under daily stress, want safety alerts to avoid the unexpected situations.

- Car rental companies and transportation companies (B2B): Allows the managers of these companies to protect their fleet and empower drivers.
- Car manufacturers (B2B): are interested in innovations to differentiate themselves and add value to their models.

3- Customer Relationships :

3- العلاقات مع العملاء:

كيف تجذب انتباه العملاء إلى منتجاتك أو خدماتك؟.

كيف تشجع العميل لشراء منتوجك أو خدمتك؟.

كيف يستفيد العميل من منتوجك أو خدمتك؟.

ما هي الطرق المستعملة لخدمة ما بعد بيع منتوجك أو خدمتك؟.

Ongoing Support:

- 24/7 call center for emergencies (defective kit, bug application).
- RouteGuard app: Updates, and reporting issues.

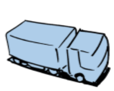
After-sales service:

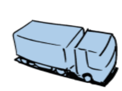
- 1-year warranty on RouteGuard hardware

Loyalty and incentive programs:

- Discounts on large volume sales for B2B segments
- Use of customer reviews and testimonials via social media to build trust and attract new customers.

4- Channels :





4- القنوات:

كيف يعلم الجمهور بوجودنا أو منتوجنا أو خدمتنا؟.

ما هي قنوات التوزيع التي يفضلها العملاء للتواصل معهم؟

ما هي القنوات الأكثر فعالية مقارنة مع تكلفتها

1/4- الآليات والطرق لإعلام بمنتوجنا أو خدمتنا:

- **Digital**:
  - Stores: Google Play, App Store.
  - Social media: Videos showing the installation of the kit and alerts, marketing campaigns via Facebook, Instagram, to expand the reach and use of influencers in the fields of driving and safety to increase confidence in the product.
- **Physical**:
  - Auto parts stores.
- **Events:**
  - Technology fairs: Algeria 2.0, SITEV, SIVEHA
  - Road Safety Days: Civil Protection events.
  - Organize educational workshops at trade fairs on the importance of technology in improving road safety. (UBBAT)

2/4- قنوات التوزيع التي يفضلها العملاء:

- Digital marketing (social media and Google)
- Outlet Operations (Auto Parts Stores)
- RouteGuard Sell Points

5- الشركات الرئيسية:

5- Key partners:

– من هم الشركاء الرئيسون الذين يمكن مساعدتنا في الانتاج أو الخدمة أو في تسويقها أو توزيعها؟ (الشركاء الذين أضع معهم عقد).

– من هم الموردين الرئيسيين؟ (الذين يقدمون لنا: المواد الأولية + الآلات للإنتاج + برنامج لتقديم خدمة +...)

Investors and Startup Incubators

- Startup Incubators and Accelerators for development and financing.

- ➢ Tech and Security Investors: Looking for investors who specialize in innovations.

Suppliers and Production Partners

- ➢ Electronics component construction companies: Collaboration with leaders for components (GPS, batteries, development board, etc.).
- ➢ Cloud and API services (Firebase, Google Maps API, Mapbox)

Technology and Science Partnerships

- ➢ Universities and Research Centers: Development of artificial intelligence to perfect intelligent functionalities.
- ➢ International Certification Laboratories: Obtaining quality and compliance with road safety standards.

Distribution and Marketing Networks

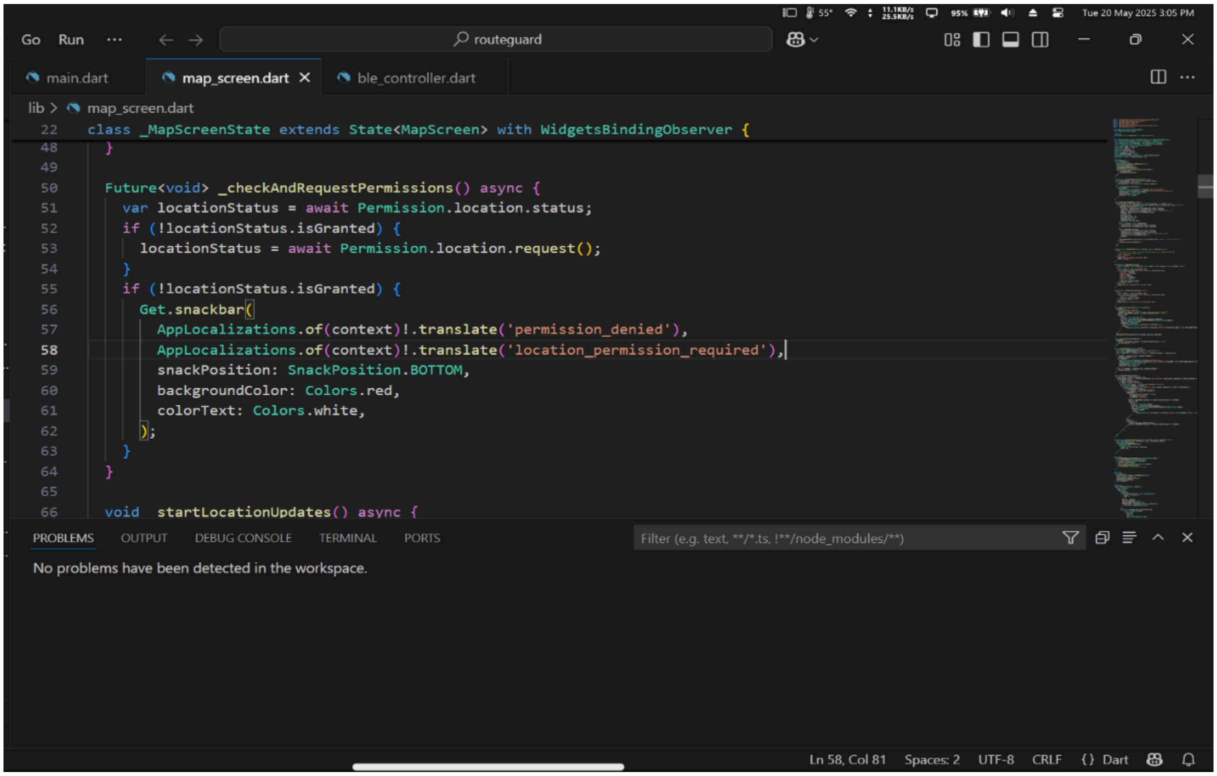
- ➢ Auto parts stores: Distribution in stores.
- ➢ E-commerce Platforms: Sale on Amazon, Alibaba, Jumia for a global deployment.

6- Key activities:    6- الأنشطة الرئيسية:

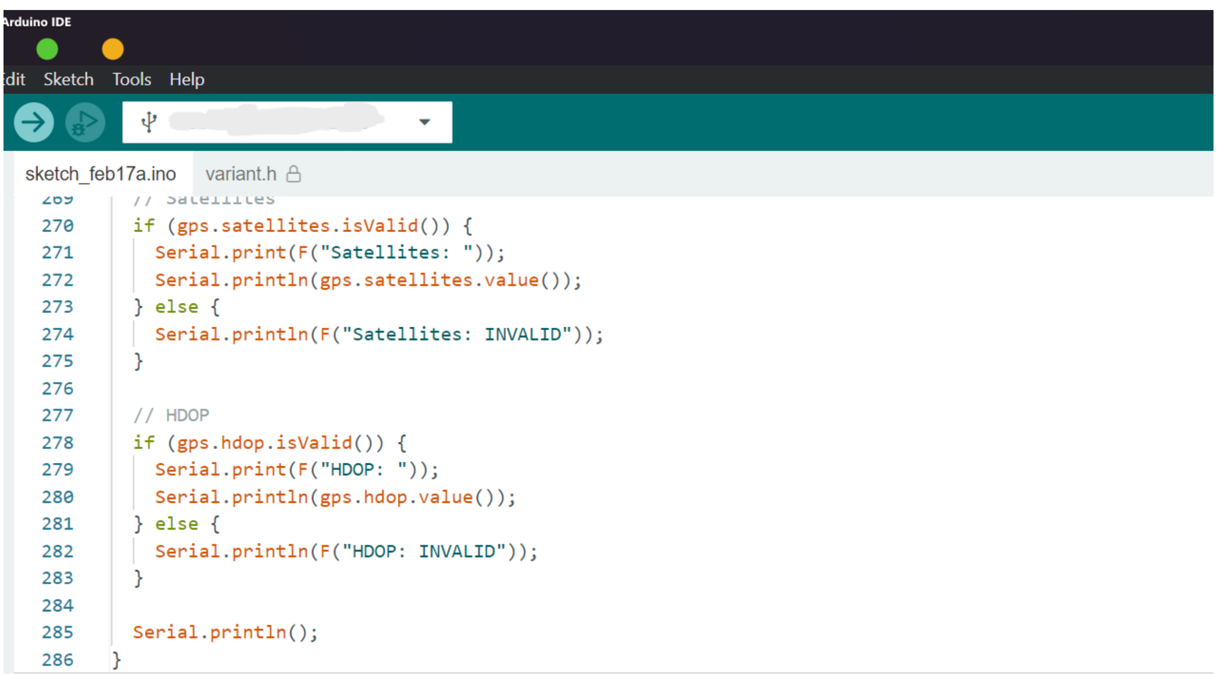
ما هي أهم المراحل الرئيسية للإنتاج أو الخدمة؟. (نذكر المراحل من إقتناء المواد الأولية إلى المنتوج النهائي)

هل هناك أنشطة ثانوية؟ (نذكر الأنشطة الثانوية التي تدخل في منتوجنا أو خدمتنا)

a) **Research and Development**: Research and find the ideal codes for software development (the application and software of the device)



Application development

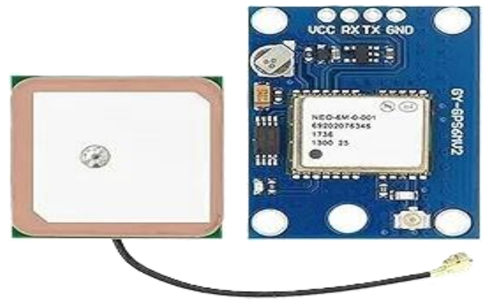


Device development

b) **Design and Prototyping**: Simple device design and application interface for ease of use

c) **Assembly (Hardware):** the assembly of electronic components to obtain the final product.

Development board

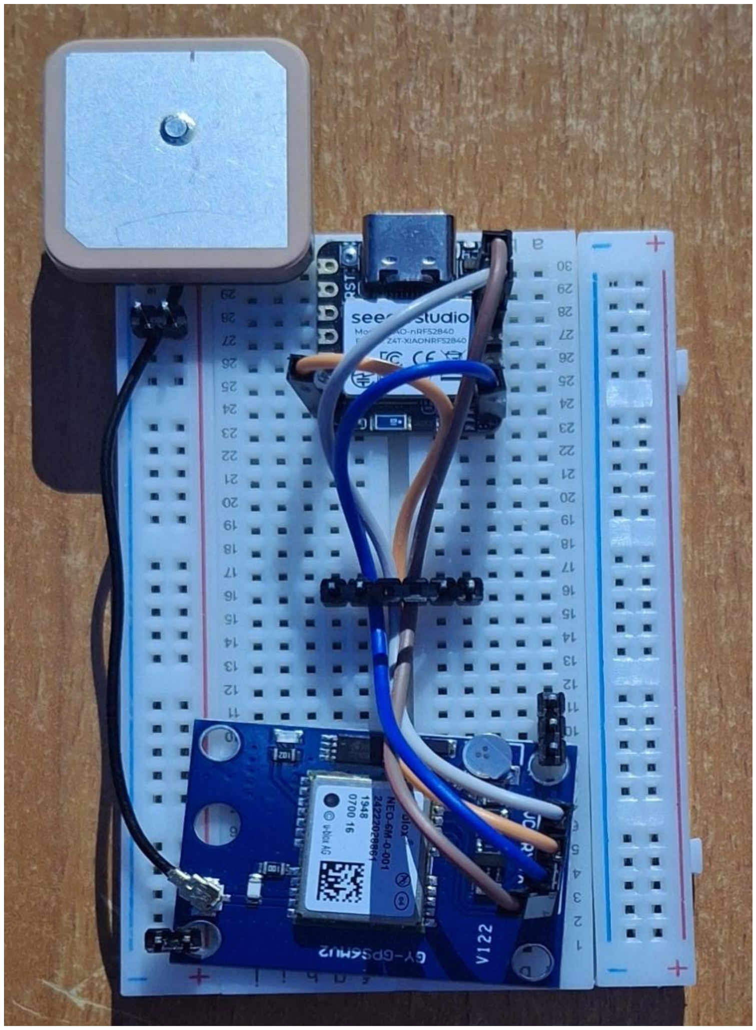


GPS Module

d) **Testing and Validation**: Experimentation in real conditions and take notes if there are problems to correct and then the final validation.

e) **Marketing and Deployment:** Sales and distribution through the appropriate channels.

f) **Support and Maintenance**: Availability of technical and after-sales services and continuous improvements based on user feedback.



RouteGuard Prototype

7- Key Resources

7- الموارد الرئيسية:

Material Resources

1/7- الموارد المادية

Resources	Source (local/foreign)	Provider
Electronic equipment (GPS, Battery, BLE)	Foreign	AliExpress
Protective case	Local	DZ 3D Print

Human Resources

2/7- الموارد البشرية:

Type of Human Resources	The number
Co-founder	1
Assistant	1

Financial Resources (RouteGuard Prototype)

3/7- الموارد المالية:

Financial Resource	The need
GPS	1 piece
Battery	1 piece
Development Board	1 piece

8- Cost Structure

8 - هيكل التكاليف:

For the first year, we plan to produce 2000 units of RouteGuard The operational team will consist of 2 employees. This framework allows us to accurately estimate the fixed and variable costs of delivering the project. The table below presents the detailed cost structure associated with this activity

Cost Type	Category	Element	Estimated Price (DA)	Total cost	
Annual fixed costs	Administrative Fees	Commercial register	8,000	**809,000DA**	**5,681,000DA**
		Lawyer	2,000		
	Wages	Employee (1)	25,000/month		
	Marketing & Communication	Social networks, website...	50,000 /year		
	Other expenses	Electricity	5,000/quarter		
		Employee Insurance (1)	26,250/ quarter		
		Internet	2,000 /month		

Annual variable costs	Production Cost	Components (GPS, BLE chip, etc.)	2,300 / piece	**4,872,000DA**	
	Logistics	Packaging	100 / piece		
		Transport and Delivery	6,000/month		

9- Revenue Streams    9- مصادر الايرادات

9-1 Total Revenues

- **Data:**
  - **Number of units**: 2000
  - **Total cost (fixed + variable):** 5,681,000DA
  - **Desired profit margin**: 40%
- **Calculation of the profit margin (40%):**

  Profit margin = 40% × 5,681,000 = 2,272,400 DA

- **Total Selling Price = Total Cost + Profit Margin:**

  5,681,000 + 2,272,400 = 7,953,400

- **Sale price per unit = Total price ÷ Number of units:**

  7,953,400 ÷ 2000 = **3, 976.7DA / unit**

- **Net Profit (Profit Margin) = Total Sales Price (with Profit) - Total Cost**

  7,953,400 – 5,681,000= 2,272,400 DA

Final Result: Calculation Table of the Sale Price with Profit Margin

Element	Value
Number of units produced	2000 units
Total Cost of Production	5,681,000 DA
Desired profit margin (40%)	**2,272,000 DA**
Total sales price (with profit)	7,953,400 DA
Selling price per unit	**3,976.70DA / unit**
Net profit (profit margin)	2,272,400 DA

9-2 Sources of income

- Direct sale of the RouteGuard device

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