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Smart Roads Data Exchange Analysis

TESI DI LAUREA MAGISTRALE IN
MOBILITY ENGINEERING

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Abstract

The increasing demand for transportation due to population growth has led to traffic congestion, increased travel time, and traffic accidents. Smart road systems that leverage advanced technologies such as IoT, AI, and big data analytics have emerged as promising solutions to optimize transportation efficiency and sustainability. This thesis focuses on the analysis of IT infrastructure requirements for a smart road communication system deployed by ANAS SpA, which uses Decentralised Environmental Notification Message (DENM) and Cooperative Awareness Message (CAM) messages to communicate with vehicles.

The study areas are the A91 and SS51 highways, where assumptions are made based on traffic flow data and message frequency to estimate the number of messages generated per day by connected vehicles. The study considers the future growth of connected vehicles to provide strategic insights for the development of a storage system to store and process the messages.

Each message has a storage space of 5kb, and the study highlights the need for large infrastructure to store, read, and extract insights from the messages. The analysis provides critical information to support strategic decision-making on the development of an IT infrastructure for the smart road communication system.

The findings of this thesis have significant implications for policymakers, transportation planners, and engineers, emphasizing the importance of investing in IT infrastructure to support the deployment of smart road systems. This study also provides a foundation for future research on IT infrastructure requirements for smart road systems, paving the way for the development of more sophisticated and effective solutions to address the challenges of transportation in the future.

Keywords: Smart Road, Cooperative Awareness Message, Decentralized Environmental Notification Message.

Abstract in italiano

La crescente domanda di trasporto a causa della crescita della popolazione ha portato a congestione del traffico, aumento del tempo di percorrenza e incidenti stradali. I sistemi stradali intelligenti che sfruttano tecnologie avanzate come IoT, AI e analytics big data sono emersi come soluzioni promettenti per ottimizzare l'efficienza e la sostenibilità dei trasporti. Questa tesi si concentra sull'analisi dei requisiti dell'infrastruttura IT per un sistema di comunicazione Smart Road implementato da ANAS SpA, che utilizza messaggi Decentralised Environmental Notification Message (DENM) e Cooperative Awareness Message (CAM) per comunicare con i veicoli.

Le aree di studio sono le autostrade A91 e SS51, dove vengono fatte delle ipotesi basate sui dati di flusso del traffico e sulla frequenza dei messaggi per stimare il numero di messaggi generati al giorno dai veicoli connessi. Lo studio considera la crescita futura dei veicoli connessi per fornire informazioni strategiche per lo sviluppo di un sistema di archiviazione per memorizzare e processare i messaggi.

Ogni messaggio ha uno spazio di archiviazione di 5kb, e lo studio evidenzia la necessità di un'ampia infrastruttura per archiviare, leggere ed estrarre informazioni dai messaggi. L'analisi fornisce informazioni critiche per supportare la presa di decisioni strategiche sullo sviluppo dell'infrastruttura IT per il sistema di comunicazione Smart Road.

I risultati di questa tesi hanno significative implicazioni per i policy maker, i pianificatori dei trasporti e gli ingegneri, sottolineando l'importanza di investire nell'infrastruttura IT per supportare l'implementazione dei sistemi stradali intelligenti. Questo studio fornisce inoltre una base per ricerche future sui requisiti dell'infrastruttura IT per i sistemi stradali intelligenti, aprendo la strada allo sviluppo di soluzioni più sofisticate ed efficaci per affrontare le sfide dei trasporti in futuro.

Parole chiave: Smart Road, Cooperative Awareness Message, Decentralized Environmental Notification Message.

Contents

Introduction

One of the most important things for a country's growth is its transportation infrastructure. The transportation infrastructure serves as the nation's economic controller and provides a crucial connection between production and consumption. The volume of traffic on the nation's highways can show how far the nation has come. In terms of distance travelled and system output, transportation has seen significant increase over time.

Productivity rises when transportation improvements make it easier for people and businesses to access employment, goods, services, and activities. This increase can be a result of improved transportation infrastructure and shorter travel distances. Companies see increases in worker productivity as the labour market temporarily moves closer to their places of employment due to reduced travel times.

Due to how convenient driving is, cars are now the primary mode of transportation. With more automobiles on the road, there is a higher likelihood of vehicular accidents and traffic congestion because roads are dumb. Cities are under pressure to address environmental problems brought on by snarled traffic and a burgeoning urban population, while also delivering more equal mobility and sustainable transit.

The development of smart infrastructure is crucial for modernisation as cities are under increased pressure to build more efficient roads and highways. Cities and transportation authorities may be able to gather and analyze data using smart roads built on Internet of Things(IoT) and information and communications technology (ICT) to enhance daily traffic management. Data can be evaluated in near-real time and used to enhance crowded roads, optimizing traffic flow, with the use of IoT sensors, cameras, radar, and 5G-equipped technology. Additionally, provide for vehicle-to-vehicle (V2V) and vehicle-to-everything (V2X) communication.

Problem Statement

Data Analytics are now not just used by large, wealthy corporations. With 59% of businesses employing analytics in some way, it is already widely used. And businesses are making use of this technology in a variety of ways.[8]. It also applies for the Smart Roads. Data plays a crucial role in the functioning and operating the smart road. Due to the presence of computing technologies, including IoT and ICT-enabled devices, edge and cloud computing, and AI large amount of data is collected every second related to various aspects from traffic calculation, cameras, environment, and V2X communication messages. Cities may lessen traffic congestion, control traffic flow, and enhance pedestrian safety by having access to smart road devices that gather and analyze data in almost real-time. In Italy ANAS "Anas Smart Road" is underpinned by a pioneering C-ITS (Cooperative-Intelligent Transport Systems) infrastructure which leverages several ground-breaking technologies letting the Company keep up with the most recent innovation achievements worldwide. More specifically, the Roadside Unit consists of a basement, aka "TEG -Technology Energy Gate", hosting any pivotal network equipment and a "TAG-Technology Access Point", featuring:

- Wi-Fi Access Point
- Dedicated Short Range Communication (DSRC) & C-V2X antennas enabling communication with vehicles.
- a Video Camera allowing surveillance and intelligent image processing for security purposes.
- Light Emitting Diode (LED)

The ANAS Smart Road Program are distributed in various locations in Italy and for the focus of the thesis I used the "SS 51 Alemagna" this road, connects the "Province of Treviso" to the town of Cortina in the "Veneto" region and with "A91" this road, connects the "City of Roma" with "Fiumicino airport". The infrastructure can collect information and process to extract insights about traffic and communication messages.

European Telecommunication Standards Institute (ETSI) has published two standards for messages exchanged between vehicles and infrastructure or between vehicle and vehicle:

- Cooperative Awareness Message (CAM): The message exchanged between vehicle and from vehicles to infrastructure communicating the position of vehicle on road.
- Decentralised Environmental Notification Message (DENM): The message sent between vehicles and infrastructure to notify events of different types. It's used for vehicle-to-infrastructure and vehicle-to-vehicle communication.
- Infrastructure to Vehicle Information Message (IVIM): The message sent by infrastructure if it needs to send messages different from events to be notifies such as speed limit indication and road signs.

When talking about V2X communication messages each message generated should be stored by the infrastructure and each message occupy certain amount of space on the hardware. It is significant to understand the number of messages that will be generated on the highway to design the system that can store and process the messages. But the information about the number of messages in future are not know as it highly depends on the number of vehicles that are capable of V2X (Vehicle to Everything) communication and number of vehicles that are making trips on smart roads. In addition, a study was carried out regarding the number of vehicles crossing SS51 and A91 and the road maximum capacity expressed by the manual. The major question that is answered through this analysis is

What should be the system capacity to be able to process the information communicated bv V2I and V2V?

Methodology

Thus, the thesis aims to analyze the smart road capacity using the test data obtained from ANAS Smart Road tests performed by test vehicles. To deep dive into the analysis, it is required to understand the functioning of the ANAS Smart Road technology and the significance of message type when they are generated. Literature study is performed to understand the functioning of the system. As the concept became clear the data analysis is performed from the data that is collected by the tests performed on smart road by ANAS test vehicles. The data is cleaned and transformed to extract information from the data to estimate the number of messages. Then data is analysed, and hypothesis were created and compared against each other to identify the best scenario by considering assumptions. As the smart road is fully useful when the vehicles are connected and at present the connected vehicles are low and we need to estimate the future growth of connected vehicles to estimate the system's capacity. The future growth of connected vehicles is estimated according to the past data. Also, as we are talking about highways it was required to analyze if the traffic on the system is according to the capacity that is system is designed for. So, the traffic flows are compared with the Highway Capacity Manual by dividing the highway into segments of 1km each and compared traffic flows with manual.

Therefore, this work is structured by academic literature that explains the basic concepts of smart road technology and their functioning followed by the ANAS Smart Road functionality. Then, the in the data analysis section the test data and the analysis will be presented, focusing on the insights and hypothesis developed and their validation. Later estimating the connected vehicles and comparing traffic flows on highway with the manual.

1 Smart Road

A nation's economic and social development is significantly influenced by its transportation system. Effective transportation infrastructure is essential to sustaining consistent economic growth, employment, and wealth since it facilitates the development of new markets and the enhancement of those that already exist. An inefficient transportation system limits the likelihood of reaching new markets, the range of trades, the production capacity, and the potential for economic and social growth at a time when any production system needs to succeed in the challenge of the "global" competitive market. Civilizations are becoming substantially more reliant on their transportation infrastructure, while at the same time, in industrialized nations, the demand for mobility has risen dramatically in recent decades.

Trading requirements have drastically evolved during the past few years. The mobility requirements and behaviours of people and products have resulted in a fundamental shift in how we view transportation networks and, consequently, in the visions and strategies that must guide policy in this area. Land transportation is making way for the multi-modal paradigm as the conventional model, in which people and commodities transportation is seen as a series of "mono-modal" motions, is replaced. This implies that a trip is made up of a collection of connected transfers. This suggests an increase in traffic jams, accidents, and delays in moving people and goods. Such occurrences jeopardize the capacity of transportation networks. The danger is that networks won't be able to support additional vehicle traffic in this fashion. In addition to increasing the number of infrastructures, it is also required to optimize and boost the effectiveness of transportation systems by utilizing available resources.

Due to how convenient driving is, cars are now the primary mode of transportation. With more automobiles on the road, there is a higher likelihood of vehicular accidents (Vas). One never knows what will happen on the next road on a trip, especially in poor weather. Driving might be challenging in this circumstance because of poor sight, which could result in an accident. Additionally, it was discovered that in poor weather, delays in getting information about an occurrence can lead to multiple vehicle collisions (MVCs).[4]. To cope with the changing situation of the transportation system and to increase safety, and maintainability the infrastructure should be upgraded. Transport needs to be redesigned as an integrated, dynamic system where data, management, and control interact to organize mobility and make the best use of infrastructures.

1.1. Technology

There has been a significant transition from analog electronic and mechanical equipment to digital technology throughout the 1980s sparked the so-called "Digital Revolution" within Humanity. The Information Era began in the 1960s [1] when the Third Industrial Revolution—also known as the Computer Age, Digital Age, or New Media Age—saw a surge in innovation.

The World Economic Forum's founder and executive chairman Klaus Schwab coined the term "fourth industrial revolution," which portrays a world in which people use connected technology to empower and govern their lives as they travel between online and offline realms. Researchers argue that industry 4.0 brings a significant change in the future of business and governments through:[3]

- Active usage of artificial intelligence
- Integration of different industries
- Improved quality of life
- Internet of Things

The Internet of Things (IoT) is a new paradigm that makes it possible for electrical gadgets and sensors to communicate with one another over the internet to make our lives easier. IoT is steadily growing in importance and is now pervasive throughout our daily lives. IoT is a technological advancement that combines a wide range of smart systems, frameworks, intelligent devices, and sensors. The interconnection of these embedded devices is anticipated to enable sophisticated applications like a smart grid, expand to areas like smart cities, smart home systems, smart health sensing systems, smart roads, and smart mobility (autonomous/connected vehicles) and bring in automation in almost all disciplines. [2].

In contrast to earlier times, the Smart Age has significantly characterized and changed many areas of today's society. Significant advancements in this direction are characterizing various facets of contemporary reality in a progressive manner, including science, the economy, education, health, and governance, altering people's lifestyles, and advocating a new emphasis on the sustainability of the planet's ecosystems. Business models, organizations, and society are drastically changing thanks to smart technologies that make collaborative resources available and accessible. Information and communications technologies (ICTs) such as end-user Internet service systems, the Internet of Things (IoT), cloud services, big data, artificial intelligence (AI), and edge computing(EC) are included in smart age technologies. [3]

With the development of information and communication technologies, Intelligent transportation systems (ITS) are designed. Intelligent Transport Systems (ITS) means systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles, and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport. [5]. The example typologies of ITS include: [5][7]

- Short- and long-range communication technologies used by Infrastructure to increase sustainability and network management, such as road user fees, variable message signs, and controlled motorways
- Telematics and in-vehicle technologies used by vehicle-based systems that can offer drivers safety-based services, such as eco-driving, blind spot monitoring, and navigation systems

The ITS must go through a digital transformation process and be integrated with technologies that can allow information interchange between the many participants in transport systems to be determined a more efficient use of infrastructures, vehicles, and logistic platforms. The European Commission is putting together strategies for the Cooperative Intelligent Transport Systems (C-ITS) that will enable road users and traffic controllers to share information and utilize it to coordinate their actions in this interaction. By assisting the driver in making the best decisions and adjusting to the traffic situation, this cooperative element—made possible by digital connectivity between vehicles and between vehicles and transportation infrastructure—is anticipated to significantly increase road safety, traffic efficiency, and driving comfort. To boost the safety of future automated vehicles and ensure their full integration into the larger transportation system, communication between vehicles, infrastructure, and other road users is also essential. Automation, connectivity, and cooperation are not just complimentary technologies; they also strengthen one another and will eventually entirely converge. [6].

Given that infrastructures supporting the transportation sector are a real chance to attract significant investments due to their ability to connect various manufacturing bodies and industries, the digital transformation of these infrastructures is a driver for the overall economy of the nation. In this regard, countries have a lot to gain from the digital revolution because it allows for the greatest possible use of all the resources already in place through technical advancements, which typically take less time and money to complete than improvements to physical infrastructure.

1.2. Smart Road: Definition

Over the years, a variety of transportation-related technologies have developed, addressing an interestingly broad spectrum of issues. Beginning with melody roads, the development of vehicle-to-vehicle communications, vehicular ad hoc networks, electrified roads, energy harvesting from roads, smart road intersections, self-weighing roads, ITS cooperative emergency rescue, techniques to capture driving behaviour, smart streetlights, and wireless digital traffic signs are just a few examples of the technological advancements that have taken place.[10] Due to various functionality of the smart roads, there is no clear definition of the smart road. According to Wikipedia-The terms "smart highway" and "smart road" refer to several ways that technology is being incorporated into roads in order to improve the operation of connected and autonomous vehicles (CAVs), traffic signals, and street lighting, as well as to monitor the state of the road, traffic volume, and vehicle speed.

Self-Monitoring Analysis and Reporting Technology was the initial shorthand for the word "smart." This has changed into its true definition, which is clever or intelligent, to characterize any type of gadget that can connect with internet networks and afterwards communicate with other devices or remote databases. Finally, the definition can be offered: A smart road is an informationalized road that aims to provide novel services such as self-awareness, self-adaptation, information interaction, and energy harvesting based on satisfying fundamental traffic operations.[9]

1.3. Smart Road Technologies

Smart roads rely on various technologies and there are no single smart road concepts. The following are some of smart road functionalities that are implemented as individual technology or can be implemented all together.

- **Smart roads that harvest energy**: Road energy is being harvested using a variety of techniques. Some create electricity using sunshine (so-called solar roads), while others do it using mechanical vibrations caused by moving automobiles. The weight of the car pushes the harvester's top plate downward as the tires of the vehicle roll over it, which causes the electromagnetic generator to rotate and produce electrical energy. About 5 cm of piezoelectric crystals are positioned below the asphalt's surface, and as cars traverse the road, these crystals gently distort. Electrical current is generated through crystal deformation. So, the mechanical energy generated by automobiles is now transformed into electrical energy. The East Japan

Railway Company (behind the subway station gates) and Innowattech Ltd. have both used piezoelectric devices (under roads in Israel). [10]
The electricity generated by the "smart" roads will be stored in roadside batteries and used to power sensors that detect the emergence of potholes as well as streetlights, road signs, and air pollution monitors. Additionally, data on vehicle speeds, the sorts of vehicles using the roads, and other information on traffic flows will be produced by smart roads. Additionally, the energy obtained can be stored or supplied to the electrical system.[11,12]

- **Solar powered roads**: Considering fact that roads are facing the sun most of the time and availability of large area allows solar roads to be a promising solution. The purpose of solar roadways is to replace asphalt with solar panels that produce electricity from the sun and can be utilized by nearby homes or businesses that are connected to the system from either the driveway of the home or the parking lot of the business. If the station is linked to the solar roadway, the panels will also enhance the number of electric vehicles charging stations. The road lines will be created using the individual LED lights on each panel. [16]. It is made up of three layers: a base plate layer, an electrical layer, and a glass layer. Providing and wiring the foundation plate, installing, and connecting solar photovoltaic cells with the previously installed layers, and situating the glass layer which acts as the outer surface that interact with the vehicle tyres. [14]. Netherlands is the first country to implement a 72meters bike path with such technology on 21st October 2014 in Krommenie, Netherlands.[13]. Though it was a failure as the wear on the road is too high.
  The laboratories from countries Belgium, Netherlands, and Germany are working on a project called "Rolling Solar" financed by European Cohesion Policy. The project focus on the use of sound barriers on highways and integrate them with solar panels to generate electricity and act as multifunctional barriers.[14]
- **Roads that measure weight of vehicle:** Roads are frequently used for both the transportation of goods and people. In many nations, road transportation is crucial to the freight industry. Overloaded trucks can be dangerous on the road because they frequently swerve at high speeds, halt suddenly, or make fast curves and corners. Trucks must therefore frequently have their weights and safety compliance assessed. While the vehicle is moving through the measuring field, sensors and loop sensors are installed in the traffic lane to measure the pressure of the axle on the road surface. High-performance strain gauges called minimally invasive in-ground strip scales are inserted into pavement grooves no deeper than 75mm and can function in a variety of environmental situations. They work by detecting the change in resistance

as they lengthen in response to the strain of the base material (the load cell).[12]. The management system receives the measurements in real time after they have been processed by algorithms.

A measurement analysis enables the selection of vehicles whose parameters are outside of allowed limits (of total load, axle load, number of axles, length of the vehicle). Through the use of weighing sensors buried in the road surface, the Weigh in Motion System enables continuous monitoring of the weight of each moving vehicle. Through the installation of automatic vehicle barriers, the control system enables remote and automatic access control and management activities to the intersections along the route.[10,17]

- **Electrified roads:** A road that provides electric power to moving cars is referred to as an electric road or electric road system (ERS). In order to achieve climate goals, it is necessary to invest on electric vehicles but one of the major constraints is the range anxiety. There are two types of charging option one is static charging and other is dynamic charging. Static charging is charging the vehicle when at rest, waiting for signal, or completely at halt whereas dynamic charging is charging of the vehicle while in motion through induction charging system or overhead electric supply (which is possible in city limits but not on highways).

  The plan is to bury wires beneath the road's surface to produce electromagnetic fields that are potent enough to be picked up by a receiver device inside a car and converted into electrical power. This idea adheres to Michael Faraday's electromagnetic induction rules.[10]. Through an electrical receiver installed underneath the car, inductive electrical infrastructure beneath the asphalt charges moving vehicles. All models of electric vehicles can use the system. Smart road Gotland is a wireless electric road that is between the city of Visby and the Visby Airport, a 4.1 km piece of road has 1.6 km of electric road installed by Smart Road Gotland. To test and showcase the technology, a heavy truck as well as a passenger shuttle bus operating between Visby Airport and the city centre are now operating on the electrified road.[18].
- **Digital Traffic Signpost:** Traffic signs have not undergone any substantial alterations or adjustments for a very long time. The analog erect-and-display signs currently in use depend on pedestrians and drivers of automobiles to perceive and follow them. Using a radio transceiver in conjunction with a digital client-server signpost architecture, analog traffic signposts will be replaced by digital ones in smart highways. The Road Side Unit (RSU) is mounted to a road sign that connects and communicate with the On-Board Unit (OBU) is installed in the vehicle. The OBU-equipped vehicle establishes a connection with the RSU using a predetermined ad hoc Wi-Fi connection

when it approaches the RSU. Once connected, OBU can receive the special Ethernet frame broadcast by RSU that contains details about the road signs. The OBU in the car will detect the wireless sign signal and alert the driver to its existence (verbally or visually)or display a warning message to the driver upon arrival.[19]. Using the new wireless traffic sign has several benefits:[10]

(i) As a result, I it is no longer necessary for the sign to be visible to the human eye,
(ii) It is no longer necessary for the driver to be aware of signs while driving,
(iii) It is no longer necessary for the driver to remember all the traffic signs,
(iv) It is not impacted by inclement weather or poor lighting conditions, and
(v) The sign is programmable, making changing a sign as simple as reprogramming it.
(vi) Complex signal processing and picture traffic sign recognition, which are now used in self-driving automobiles, are not necessary.
(vii) Automated traffic volume calculation,
(viii) Low cost

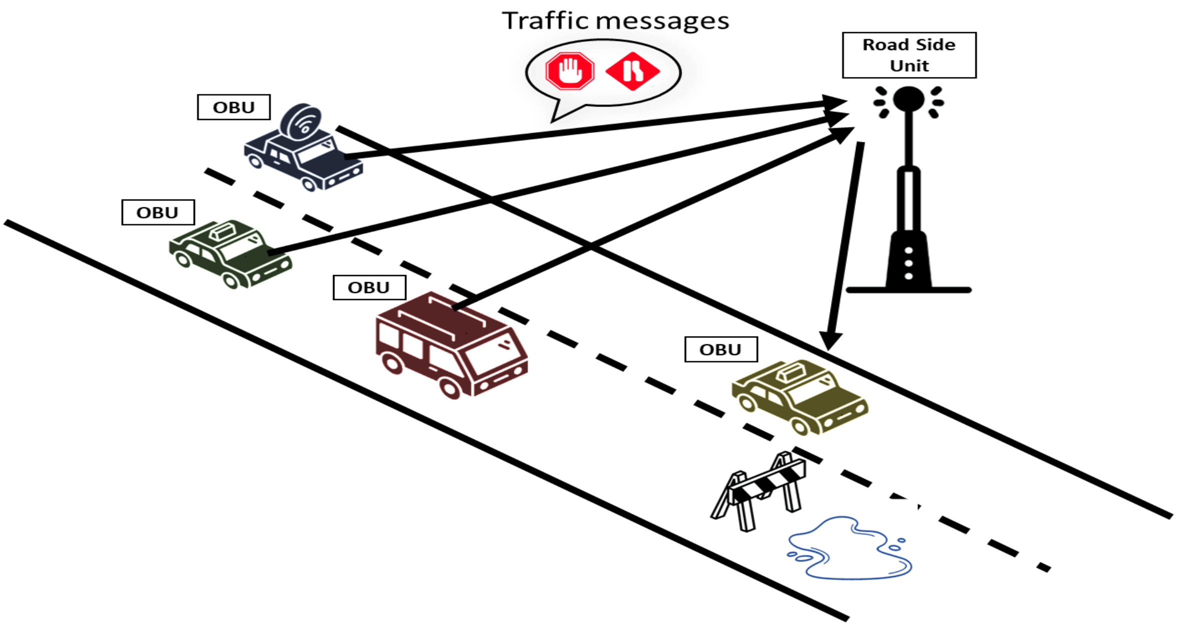

Figure 1. 1 Digital Traffic Sign

- **<u>Roads that communicate with vehicles:</u>** With the help of vehicular ad hoc networks and car-to-car communications, also known as Vehicle to Vehicle (V2V), mobile ad hoc networks have entered the automotive industry. Vehicle to Infrastructure(V2I) refers to communications from an automobile to any infrastructure along the side of the road, whereas Vehicle to Anything

(V2X) describes communications from the car to any other object. V2X is significant because it enables communication and the sharing of vital data between vehicles and objects, including information about position, identity, physical presence, and speed. With the help of this data, vehicles can be warned about potential impending traffic dangers, reducing accidents and improving road user safety.

V2X architecture will be very beneficial in life-saving emergencies. When a car crashes, current call systems like e-Call, OnStar, and other emergency call systems automatically send a crash notification notice to the nearby emergency call centre over various wireless communication channels. Then, call centres will dispatch assistance and emergency personnel to the accident scene. Although efficient, there are delays and a lack of knowledge regarding the severity of the event and the situations of those affected in advance.

The warning sent out by a crashed car can be utilized by vehicular ad hoc networks (VANETs) to warn other adjacent vehicles to slow down or halt, and some people can provide aid whenever it is possible (for example, one of the drivers or passengers could be a doctor, medic or fireman). Additionally, V2I will make it possible for the control centre to receive the crash alert and to call for emergency assistance. The simultaneous warning and notification transmissions using V2V and V2I can increase the efficiency with which aid is delivered to the crash site's victims.[10,12]

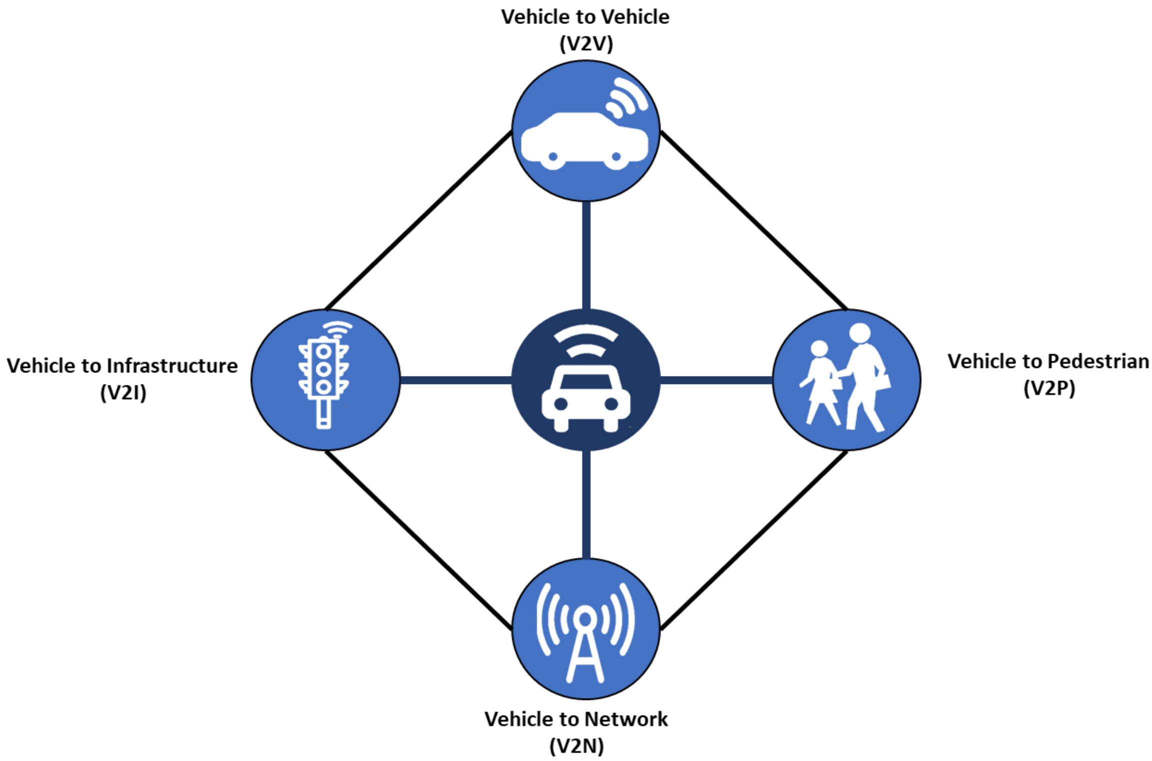

Figure 1. 2 Vehicle to Everything (V2X) Architecture

1.4. Communication technology

The field of ITS (Intelligent Transportation Systems) research is focused on developing cooperative applications in vehicular scenarios, which are more important for the connected automobile of the future. They are intended to reduce traffic deaths, increase road capacity, reduce the carbon impact of road travel, and improve the user experience while traveling. Despite the numerous vehicular applications that are anticipated for the short, medium, and long terms, these can be divided into the following classes.[21,22,23]

- Safety: Applications of this kind are designed to lessen collisions and protect the lives of pedestrians and car occupants. Examples include avoiding collisions, warning of accidents, or approaching emergency vehicles.
- Traffic efficiency: These applications increase the capacity of the road network and shorten travel distances. Examples include variable speed limits, dynamic intersection management, or the identification and alleviation of traffic congestion.
- Infotainment: primarily focused on providing Internet access, multimedia, and comfort apps with additional value. Examples include video on demand, context-aware tourist assistance, and video conferences.

Future connected vehicles under the ITS (Intelligent Transportation Systems) will require cooperative services in vehicular scenarios to achieve the above classes. Two types of messaging services are standardised by the European Telecommunications Standards Institute (ETSI) these are the Cooperative Awareness Basic Service, defining the Cooperative Awareness Message (CAM), and the Decentralized Environmental Notification Basic Service, which specifies the Decentralized Environmental Notification Message (DENM). While DENM occurs periodically (in an event-driven manner) when traffic hazards or unusual conditions are noticed, CAM is a message that occurs periodically and contains location or trajectory information.

1.4.1. CAM message

The CAM messages are periodically transferred between two ITS Systems that is two vehicles communicating and sending out messages including presence and location data. The messages are shared to ITS systems located within a single hop distance that is in close vicinity of the sender. The ITS station is aware of other stations in its neighbourhood and their positions, movements, and pertinent characteristics thanks to CAM communications it receives. ETSI standard also specifies the message format, A header and a body integrate together to create the CAM message format. The message’s version, message identity, and generating time are all collected in the header. The message’s body includes the following details about the ITS station that sent it:

- A unique identification of the sender ITS station
- ITS station type (mobile, public authority, private, etc.).
- A set of associated CAM parameters that can be optionally included in accordance with the standard’s requirements based on the ITS station type.
- Reference location given as latitude, longitude, elevation, and heading.

The ETSI standard specifies the message handling procedures in addition to the CAM message format specification. On one hand, the document offers instructions for the scheduling needs for the repeated generation of CAM messages. The frequency can be changed to improve operation depending on the type of ITS application using CAM messaging facilities. On the other hand, the standard specification also outlines generation principles that assist in determining the proper time to send a CAM message. [22,23]

1.4.2. DENM message

DENM message shares information about the road traffic conditions, road works, and in case of an event on the road over an area of the road. The message is shared by the DENM emitter to all the ITS stations within certain range from the location moving towards the event location. The standard specification states that an event is identified by an event type, which is an identifier associated with the type of event detected (such as a car accident, a traffic jam, etc.), an event position describing either a concrete position or geographical area, an event detection time, which is an expiration time representing when the event is expected to end, and a destination area indicating the geographic area over which the DENM message needs to be sent. The ITS application notifies the DENM facility to update the information in the DENM message when the event's state changes. The DENM facility stops sending DENM messages once the expiration time has passed. As an alternative, DENM messages informing of this scenario can expressly cancel events. [22,23]

2 Company Description

Since its founding in 1928, "Azienda Nazionale Autonoma delle Strade" (Anas) S.p.A., the Italian joint stock company responsible for managing national roadways, has dedicated itself to tying Italian locales together with cutting-edge infrastructure. It has been a member of the Ferrovie dello Stato Italiane corporate group since January 2018 and has been a subsidiary of RFI SpA since June 2022. ANAS is the main national operator of the road network, it builds and manages the roads that connect each location in Italy, designs civil works with high engineering specialization and takes care of their maintenance.

ANAS employs about 6,800 people, many of whom work as road operators, engineers, or architects, and operates almost 32,000 km of Italy's national highway system. ANAS works on initiatives to build and expand the country's road system. provides a variety of services as well, assisting public organizations and promoting road design, construction, and maintenance both domestically and internationally. Through investments in research and innovation and the use of cutting-edge materials and technologies, the primary objective is to secure the geographical continuity of the road network and an ever safer and more efficient viability, in accordance with expected time and costs. ANAS coordinates the operations of operating personnel while monitoring the roadway infrastructure to ensure safety and viability. This is done through a network of 21 Regional Monitoring Centres, a National Monitoring Centre, and a fleet of over 1,000 vehicles outfitted with cameras and GPS satellite systems.

Figure 2. 1 ANAS SpA Operations

2.1. ANAS Smart Road

The way that roads develop is closely tied to how the world of mobility does, which is why ANAS is very sensitive to technological advancement and its uses. In this light, the Anas Smart Road project was started as an enabling technology for the growth of smart mobility and as a precursor to scenarios including autonomous vehicle operation in the future.

The project, which aims to increase traffic efficiency and road safety, is built on a sophisticated infrastructure and digital platform supported by V2X and IoT (Internet of Things) Systems, AI (Artificial Intelligence), Big Data, and advanced sensors through the development of the national ultra-broadband network. Anas Smart Road offer new opportunities to enhance user security by allowing an increasingly complete, responsive and connected view of the entire infrastructure.

ANAS has started to develop Smart Roads in Europe well in advance in accordance with the directives received from the Ministry of Sustainable Infrastructure and Mobility. The objective is to give the nation a reliable road system that keeps getting better and is ready for any new difficulties that arise in the future, including the use of electric power, aided driving, and even self-driving cars.

The ANAS Smart Road is made to offer the user a variety of functionalities and to improve network administration:

- A safe trip, without difficulties, with driving assistance
- Safe roads, with adequate levels of maintenance.
- Prompt emergency response and mobile device alerts, and real-time information on mobility.
- An improvement in efficiency by applying current technology to increase the operational efficiency of existing roads.
- Intelligent monitoring of road infrastructures, traffic, and goods transit, as well as the environment and climate, designing and implementing Cooperative-Intelligent Transport Systems (C-ITSs) so as to improve road safety and traffic control and enable advanced driving experience.
- Fully integrating existing databases and technology into a single digital platform.

The company wants to lead the digital transformation of Italy's road infrastructure with the Smart Road program, to provide the country with a functional road network, it is important to expand and strengthen the services that promote mobility and oversee roadways.

In actuality, the connectedness between people, cars, and things forms the basis of Anas concept. To achieve this, it is necessary to transform the physical road infrastructure into a more effective one that enables technology-enabled information sharing among all road users.

The usage of bidirectional communication (V2V and V2I) will enable users and infrastructure operators to communicate real-time information to promote road safety, optimize traffic management, and improve driving comfort for a better travel experience. Such interactions constitute the cornerstone of C-ITS.

Through Digital Transformation (DT) of the road infrastructure, services, and solutions that address contemporary user needs, the Smart Road initiative aims to increase road safety and use through these services:

Figure 2. 2: Services Enhanced by Smart Roads

- **Monitoring:** V2X and Internet of Things (IoT) Systems enable the intelligent monitoring of road infrastructures, traffic, cargo transport, weather conditions, and other factors. They offer new opportunities to enhance user security by allowing an increasingly complete, responsive and connected view of the entire infrastructure.
- **Mobility Management:** It is done through predictive and real-time systems for demand management, infrastructures, and special events.
- **Security:** Real-time info mobility systems, the prevention of improper behaviour, preventive cooperative security, assisted and/or connected vehicles are used to provide security.
- **Usability:** By developing services that enhance the travel experience for infrastructure users for greater user comfort.
- **Sustainability:** Sustainability is achieved by using methods for producing electricity from renewable sources, primarily solar systems (Green Island).
- **Data protection:** using contemporary security processes to assess, identify, and manage any external threats.

2.2. ANAS Smart Road Concept

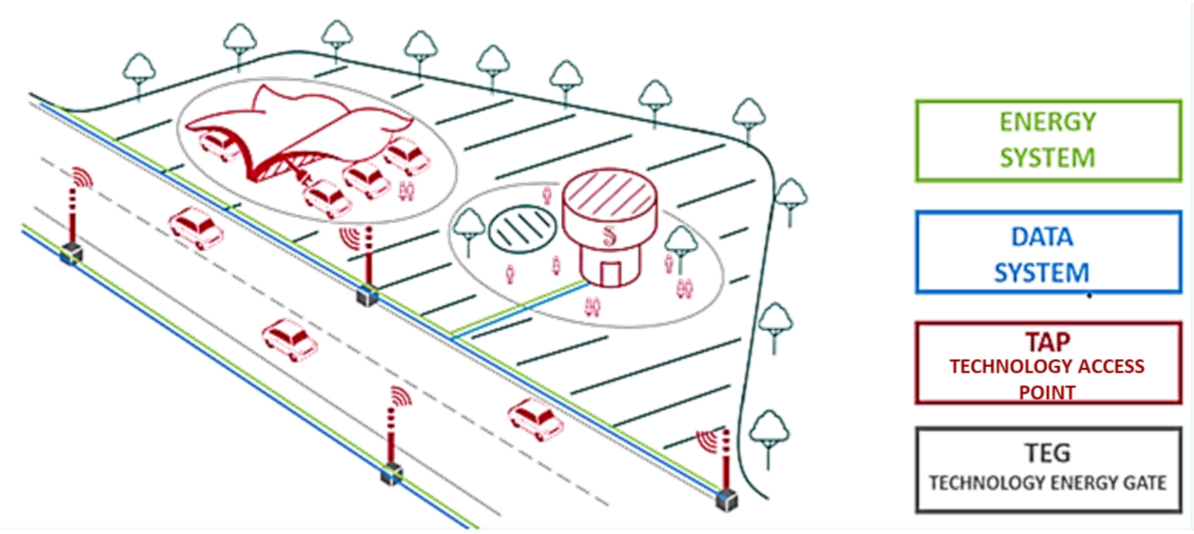

Figure 2. 3: ANAS Smart Road Concept

The ANAS Smart Road represents how the idea of a road has evolved from a purely public undertaking to a piece of technical infrastructure. Technology expands the functional and spatial capabilities of roads to boost their operational capacity. In order to assure safety, connectivity, innovation, and pave the way for autonomous driving, Anas S.p.A. created the "Smart Road Program" in 2016.

The Smart Road Project is based on key elements and implementing enabling technologies for each element:

- Open data and Big data
- Internet of Things (IoT)
- Communication system
- Energy system

2.2.1. Open data and Big data

The Smart Road is a digital route that is expected to generate lots of useful information for those in charge of managing infrastructure, as well as for users, regulators, and planning agencies for the digital world in general. This information could help new business ventures grow.

Data is utilized using open and accessible data, to improve transportation efficiency and foster development. The first criterion will be developed in accordance with current (national and European) rules, and the second condition will be met by developing an acceptable platform for data storage, retrieval, and processing that is based on cutting-edge technologies and that makes it easy and efficient to transmit data for both internal use (services for Anas S.p.A.) and for use by third parties with authorization.

ANAS is of the opinion that privacy-by-design implementation is essential to ensuring a balance between big data and privacy. This transparent approach will allow consumers to fully understand why their data is being gathered, how it will be used, and how much control they have over it. Regarding the administration of personal data, ANAS shall gather, handle, and utilize data in accordance with the privacy laws currently in effect, without having the option of disclosing them to third parties, so guaranteeing their secrecy.

2.2.2. Internet of Things (IoT)

The Smart Road is equipped with a variety of sensors that operate well over time and have a long range. Consider, for instance, all the many kinds of traffic sensors that are currently in use to monitor the stress on equipment, the ground, the local climate, the environment, bridges, viaducts, tunnels, traffic barriers, and hydrogeological conditions: IoT technology now provides low-cost solutions for needs, and it will do so even more in the future. Soon, it's anticipated that both the market for sensors and the uses for them would soar. Roads are undoubtedly seen as one of the hottest sectors, both for applications that directly connect cities to the outside world and as enabling structures for applications that serve the areas covered.

One example of Anas Smart Road IoT System The “AREA”(Automatic Road works Extension Alert) system leverages IoT technologies to effectively monitor both dynamic and static road works status. It consists of a Low-Power network made up of one Primary gateway and a number of Secondary sensors to detect and measure essential parameters such as temperature, air pressure, road work position and some alert about security road works status.

Ultimately, a centralized software platform processes the collected data allowing Operating Rooms to perform real time construction site status monitoring and reporting as well as detection and management of work progress information and dangerous events.

2.2.3. Communication system

Effective connectivity for mobile devices and automobiles is a requirement for digital roadways.

In this regard, the communication system is essential for ensuring:

- Connectivity between people and digital devices
- Connectivity of vehicles
- Connectivity of infrastructures.

The Smart Road offers operators and consumers a collection of services designed to utilize road infrastructures effectively and steadily raise service levels for safety and efficiency.

The objective of this initiative is to build a cutting-edge technology foundation that can accommodate contemporary, cutting-edge Smart Road services and handle the levels of growth that new services and new applications will need.

ANAS to ensure the guaranteed level of performance and future growth potential it relies on technologies that adapt the solution to current market norms and those that are anticipated to gain traction in the future.

The network is designed with two types of communication systems.

- To connect infrastructures and personal devices, Wi-Fi in Motion uses the IEEE 802.11 a/b/g/n standard at unlicensed frequencies of 2.4 and 5 GHz (i.e.: mobiles, tablets, etc.).
- DSRC (i.e. ITS ETSI G5 DSRC)/C-V2X (i.e. LTE-V) antennas acting as a Road Side Unit for V2I communication.

The communication is enabled by the Smart Infrastructure developed by ANAS the **Road Side Unit(RSU).** Wi-Fi Access Points, DSRC hotspots and LTE-Vehicle Base Stations, can communicates with On-Board Units (OBUs), which vehicles are equipped with, to provide drivers with Day 1 and Day 1.5 Services and make road maintenance and traffic management more efficient and effective by means of Big Data Analytics and Artificial Intelligence techniques

2.2.4. Energy System

The sustainable "Green Island," which serves as the beating heart of "Anas Smart Road," is totally powered by green energy sources. The site, which features unusual architectural forms inspired by nature, is intended to produce, and transmit electricity using a system of solar cells that maximizes energy efficiency and promotes sustainability. In addition, similarly, fed charging stations are intended for use by electric vehicles driven by road users.

Figure 2. 4: ANAS Green Island

The "Green Island" also houses a cutting-edge Control Room that offers the road operator monitoring technologies that are increasingly important for strategic road management and safety. Green Islands are also equipped with Electric Vehicle charging infrastructure.

Figure 2. 5: Solar Panel for energy generation in Green Island

Figure 2. 6: Control room in Green Island

The partitioning of the route into modules that are each about 30 km long is the foundation of the Smart Road. The Green Island, which sits in the middle of the module, can produce all the energy needed to run the section's systems using renewable resources.

To this energy area, named Green Island, it will be possible to recharge electric cars and from here will be distributed clean energy feeding fiber optic network and electricity network provided on the Smart Road section.

These Islands are designed also to host a center of data processing and a control room equipped with video walls to manage and control traffic on routes. The realization of Green Islands will permit to maximize energy efficiency, guarantee lower operating costs as well as to create a technological heart for collecting data and finally to manage them by the most functional way for the wellbeing of users and infrastructures.

2.3. Communication Technology

V2I (Vehicle to Infrastructure) technologies' primary goal is to reduce traffic accidents brought on by driver negligence and distraction since they can identify potential dangers and collision situations before the driver does. The V2I is based on the interchange of data between vehicles and infrastructure; communication makes use of DSRC (Dedicated Short Range Communications) and C-V2X technology for the exchange of data including each vehicle's location, speed, direction, and potential deceleration. Devices that enable contact with other road users can be included directly into the design of new vehicles, added as "aftermarket" components to pre-existing vehicles, or, once more, utilized as personal communication devices (for example: mobile devices, tablets, etc.).

The Anas RSU is equipped with dual mode communication and enables centralized road network management and C-ITS services provided to the users whose vehicles are equipped with DSRC or C-V2X On-Board Units (OBUs).

Two standards were released by the European Telecommunications Standards Institute (ETSI) for messages transferred between vehicles and infrastructure or between vehicles:

- **CAM (Cooperative Awareness Message)** : Messages that are generated by the vehicle to communicate their position in real time using C-V2X technology.
- **DENM (Decentralized Environmental Notification Message):** Messages that are generated by the smart road infrastructure that communicates

dangerous situations ahead, traffic, environmental condition, construction works, vehicle breakdown, etc. to the vehicles travelling in that direction.

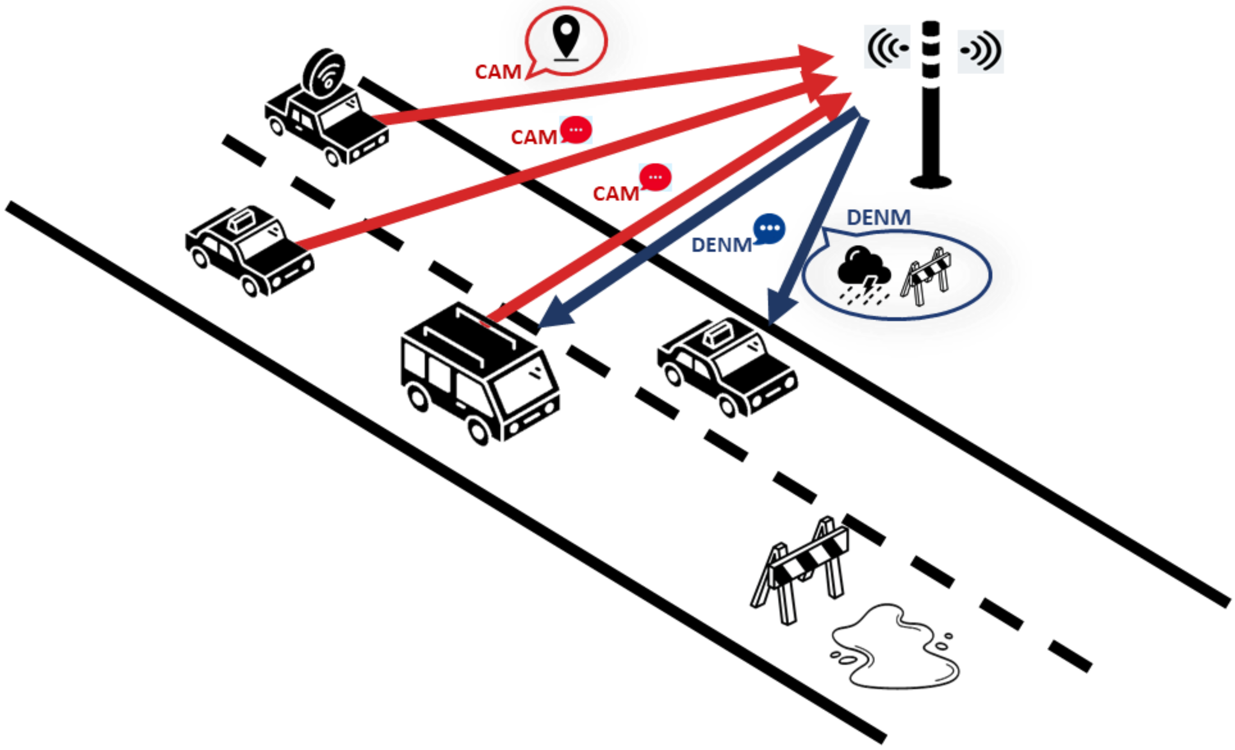

Figure 2. 7: Communication on Smart Road

To enable V2I communication:

- **On Board Unit (OBU):** Device with an antenna designed for use in moving vehicles. These devices can be the vehicles that are equipped with in-built communication technology or use of personal electronic devices such as mobile devices, tablets, etc.
- **Road Side Unit (RSU):** Device with a built-in antenna for usage with road and highway infrastructure

Figure 2. 8: Roadside Unit (RSU)

ANAS Smart Road leverages on ground breaking technologies and one such technology is **Road Side Unit (RSU)**. Multipurpose stations serve the goal of housing the necessary tools for the delivery of the services needed by the Smart Road (environment, security, connectivity, information, etc.). will make it possible to provide optional services in addition to the user and vehicle connectivity and enhanced video monitoring that are required.

Each RSU acts as both receiver (to hear V2V communication messages) and transmitter (communicate DENM messages). According to ETSI ITS-G5 specifications, the RSU transmits local and selective information to the road users in real time using DSRC.

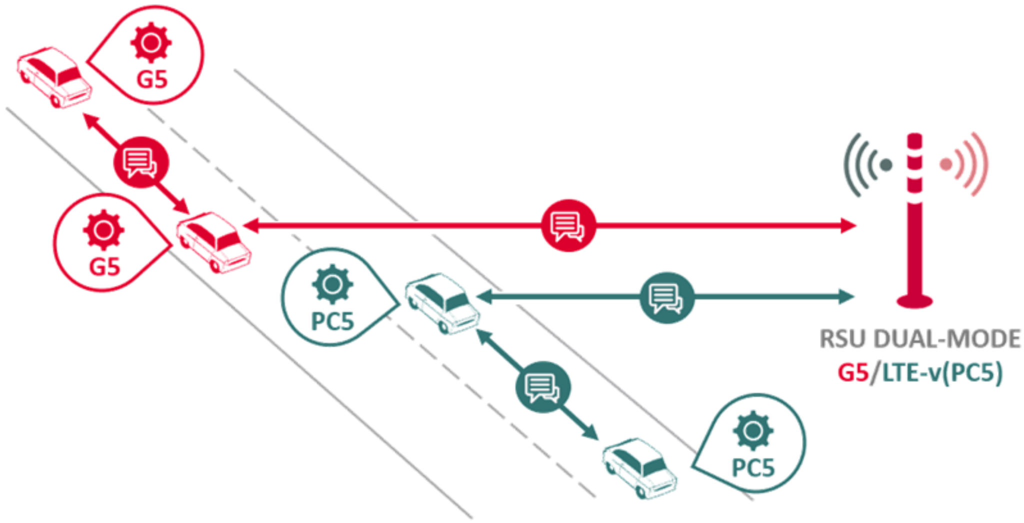

Figure 2. 9: Roadside Unit Communication Technology

Roadside Unit consists of a basement, aka "TEG -Technology Energy Gate", hosting any pivotal network equipment and a "TAP-Technology Access Point", featuring:

- To connect infrastructures and personal devices, Wi-Fi in Motion uses the IEEE 802.11 a/b/g/n standard at unlicensed frequencies of 2.4 and 5 GHz (i.e.: mobiles, tablets, etc.).
- DSRC (i.e. ITS ETSI G5 DSRC)/C-V2X (i.e. LTE-V) antennas acting as a Road Side Unit for V2I communication.
- LED lighting

Figure 2. 10: Technology Energy Gate of Roadside Unit

The Technology Energy Gate (TEG) is the lower part of RSU which consists of PoE Switch Transformer and DC/DC Converter, Battery container, IoT Narrowband Gateway, UTP Cable Terminal BOX, and Optical Fibres Terminal BOX.

The Technology Access Point (TAP) is the part of RSU which contains the technologies that enable it to communicate with the vehicles, smart cameras that monitors the traffic for safety and security, and IoT sensors.

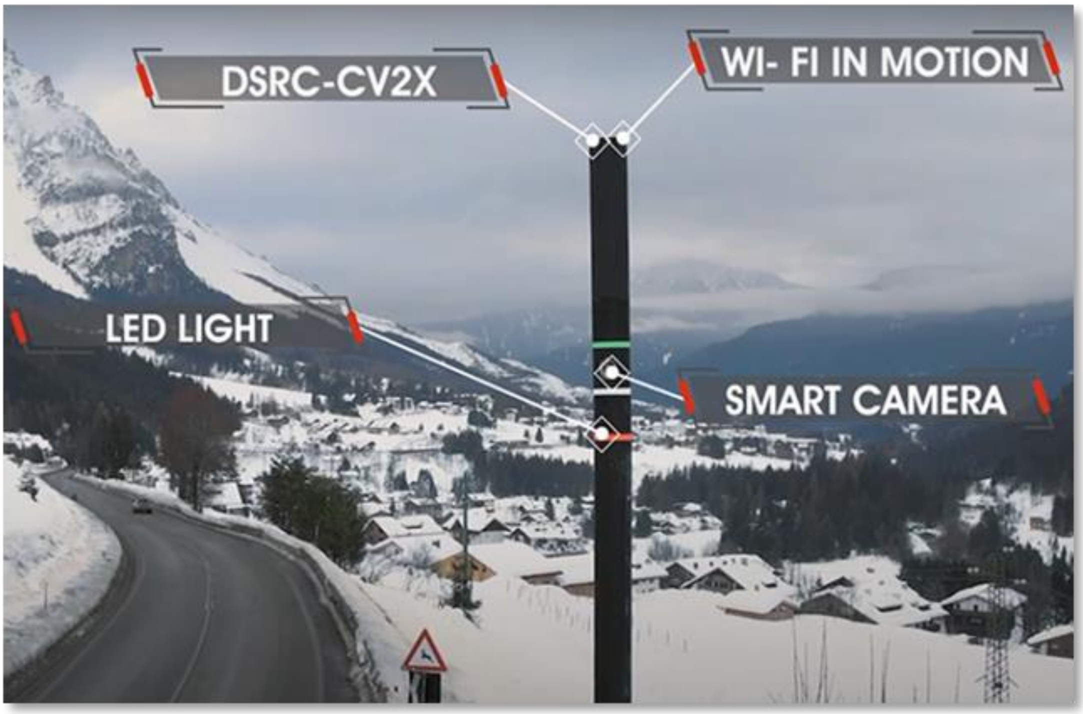

Figure 2. 11: Technology Access Point

The technology of ANAS is able to provide services to the road users according to the list of services that intelligent transport systems must offer to users throughout European road networks is identified in the European policy on C-ITS systems, which was issued in Brussels on November 30, 2016. Day 1 and Day 1.5 Services are designed to increase traffic safety, improve traffic flow, and reduce outside influences. Due to the dynamic nature of the elements that affect these aspects, service definitions may change to reflect new information and operational requirements. However, there are three primary operational responsibilities that C-ITS services are meant to fulfil:

- Informing drivers about ways to increase comfort and safety on the road journey
- Indicate legal restrictions using signs that alert drivers to certain obligations, constraints, or limits
- Warn drivers of impending events and their types.

Paragraph. Use Cases

Figure 2. 12: C-ITS services (Day 1 services, Day 1.5 services)

These are two-way communication services for aided and autonomous driving that connect infrastructures and users as well as users on various vehicles.

Road safety, congestion, and the economic and environmental performance of road transportation can all be improved through intelligent transport systems. The European Commission seeks to have an impact on infrastructure development in order to take use of the potential provided by smart digital solutions to improve the sustainability, efficiency, and safety of transportation.

The European Union's support system is its transportation infrastructure. It helps to realize the founding fathers' vision for the European Union, which was based on the four freedoms that unite nations and people within the single market and increase its prosperity. Deploying C-ITS in accordance with the European framework Day 1 and Day 1.5 Services is therefore a long-term investment in the transportation infrastructure of the future, and as we get closer to automated driving, C-ITS will enable communication between vehicles and between vehicles and infrastructures. To enhance the driving experience and user security, C-ITS provides drivers with the appropriate information at the appropriate moment, based on their location and the circumstances they face.

1st day and 1.5th day Services are designed to reduce outside influences and increase traffic safety and flow efficiency. Due to the dynamic nature of the elements that affect these aspects, service definitions may change to reflect new information and operational requirements. However, the three primary operational purposes that C-ITS services are meant to fulfil are as follows:

- Informing drivers on ways to increase their comfort and safety on the road.
- Road users should be warned about impending incidents and their nature.
- Regulation limits should be displayed via signs that alert drivers of specific requirements, restrictions, or prohibitions.

These are assisted and automated driving services that utilize two-way communication not just between infrastructures and users, but also between users operating various vehicles. With the goal of preparing Italian roads for present and future challenges, "SS 51 Alemagna" and the other routes targeted by the "Smart Road Program" have been planned to adapt existing infrastructure to Day 1 and Day 1.5 Services.

One of the most important innovations in travel that "SS 51 Alemagna" offered to the Italian infrastructure was the European framework Day 1 and Day 1.5 Services. These services are being tested and will be made available for "SS 51 Alemagna" in two phases, first using a Smart Road app on users' cell phones and then by extending connectivity to vehicles with OBU.

Smart Road provides warnings and information to the driver regarding:

- Repetition of road signs: The goal of the next use case is to continuously notify the driver about road signs to raise the level of safety while driving on the Smart Road.
- The goal of reporting traffic conditions is to lower the danger of potential accidents caused by abrupt situations of traffic congestion (sudden development of queues) by allowing approaching vehicles to modify their driving style to the situation.
- Reports of inclement weather: The purpose of this use case is to promptly alert Smart Road users to inclement weather (such as hail, wind, and so forth) or potentially hazardous conditions on the road surface (such as the presence of snow or ice). This information is helpful for planning the best driving practices to ensure greater safety while traveling.
- Notification of Speed Limit
- Emergency vehicle presence signalling: The purpose of the service is to notify other drivers when a rescue vehicle is approaching or has already arrived in order to facilitate any necessary interventions and reduce the risk of accidents for those using the Smart Road.
- Signalling the existence of a road work site: The goal is to quickly alert drivers on Smart Road to the presence of a road work site or of any work in progress on the road or by the side of the road that may impede their movement and help prevent accidents.

- Emergency Braking Warning: This use case aims to manage emergency braking occurrences effectively and safely over the Smart Road network in order to rapidly warn approaching vehicles and improve the safety of passengers.
- Accident or breakdown-related stationary vehicle warning: The goal of this feature is to alert Smart Road users to the presence of a stationary vehicle to promote safety for oncoming traffic and prevent hazardous circumstances.
- To reduce the risk of accidents for users traveling on the Smart Road, the service's objective is to indicate the presence of a slow vehicle or mobile construction site on the road (the signal originates from the slow vehicle itself).

All the smart road infrastructure is powered by the green islands. Each green island has a remote-control centre present in it and all the green islands are connected to a Intelligent Central System. The information is passed from the RSU to the Green Islands and all the green islands share information with the central system.

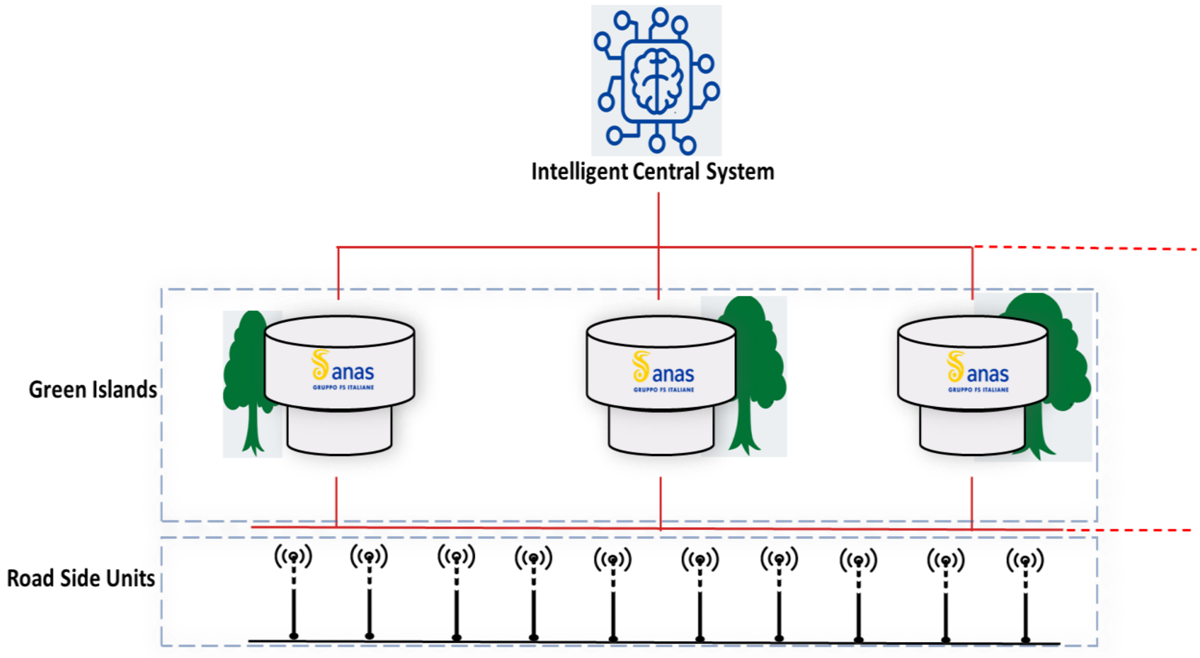

Figure 2. 13: Smart Road Functional Hierarchy

ANAS served the first Smart Road experience in Europe during the 2021 Alpine Skiing World Championships in Cortina d'Ampezzo. The project allows participants to take advantage of an integrated platform for the management of mobility that will ensure the highest level of travel quality in the Valley. State highway 51 "Alemagna" was outfitted with a Smart Road technological infrastructure by the company.

The 80 km long Smart Road Cortina 2021 uses V2X and IoT technologies to continuously regulate and monitor the road and infrastructure in real time to enhance traffic flow and boost standards of road safety.

Other two example of Anas Smart Road in Italy, are the A90/A91 which encircles Rome and connects it to the Fiumicino Airport - and the A2, which is the longest road in Southern Italy.

The study presented in the following section majorly focuses on SS51 and A91 highways.

3 Smart Road Data Analysis

Data analysis of ANAS test vehicles, traffic flow data, and ANAS Smart Road test data will be carried out in this section of the report. The correct coding process involves analysing each feature, spanning from data transformation, numerical, and descriptive features. This analysis is done in a Python environment, Tableau, or Excel. The correlation of traits was also considered. The data analysis process's most noteworthy outcomes will be displayed in the pages that follow.

The tests are performed by the ANAS test vehicles on the roads "SS 51 Alemagna" this road, connects the "Province of Treviso" to the town of Cortina in the "Veneto" region and with "A91" this road, connects the "City of Roma" with "Fiumicino airport". The tests are performed by two vehicles on each highway that are equipped with the communication technology to communicate with the infrastructure and other vehicles. All the results that will be presented will be focussing on SS51 and A91 separately.

3.1. DENM message analysis

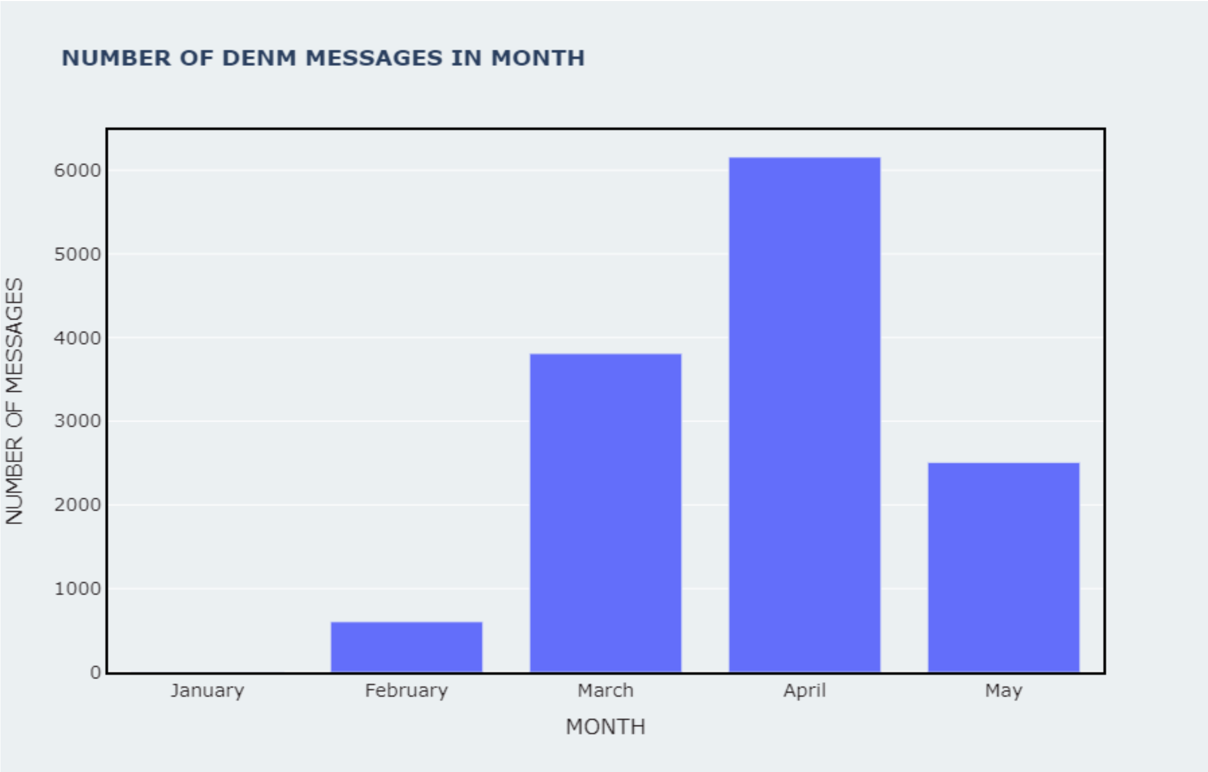

Figure 3. 1: Number of DENM messages per month

The dataset on DENM messages is the basis for all the analyses that follow. Interesting trends throughout time will be plotted in this portion of the investigation.

All the data that is presented in the analysis is collected from the first 6 months of 2022.

The DENM data is the raw data which contains information about the cause code, sub-cause-code, location, active time as per the ETSI message Standard. The data is extracted from the message, and it plotted in the following graphs.

Firstly, looking at the overall DENM data set and grouping the data by month to see the dynamics of messages over month. As can be seen in figure 3.1; the number of messages is low in January and high in April. The is because the more tests were performed by ANAS Test vehicles in April and low in January. The variation in number of messages over month is not seasonal but due to experimentation.

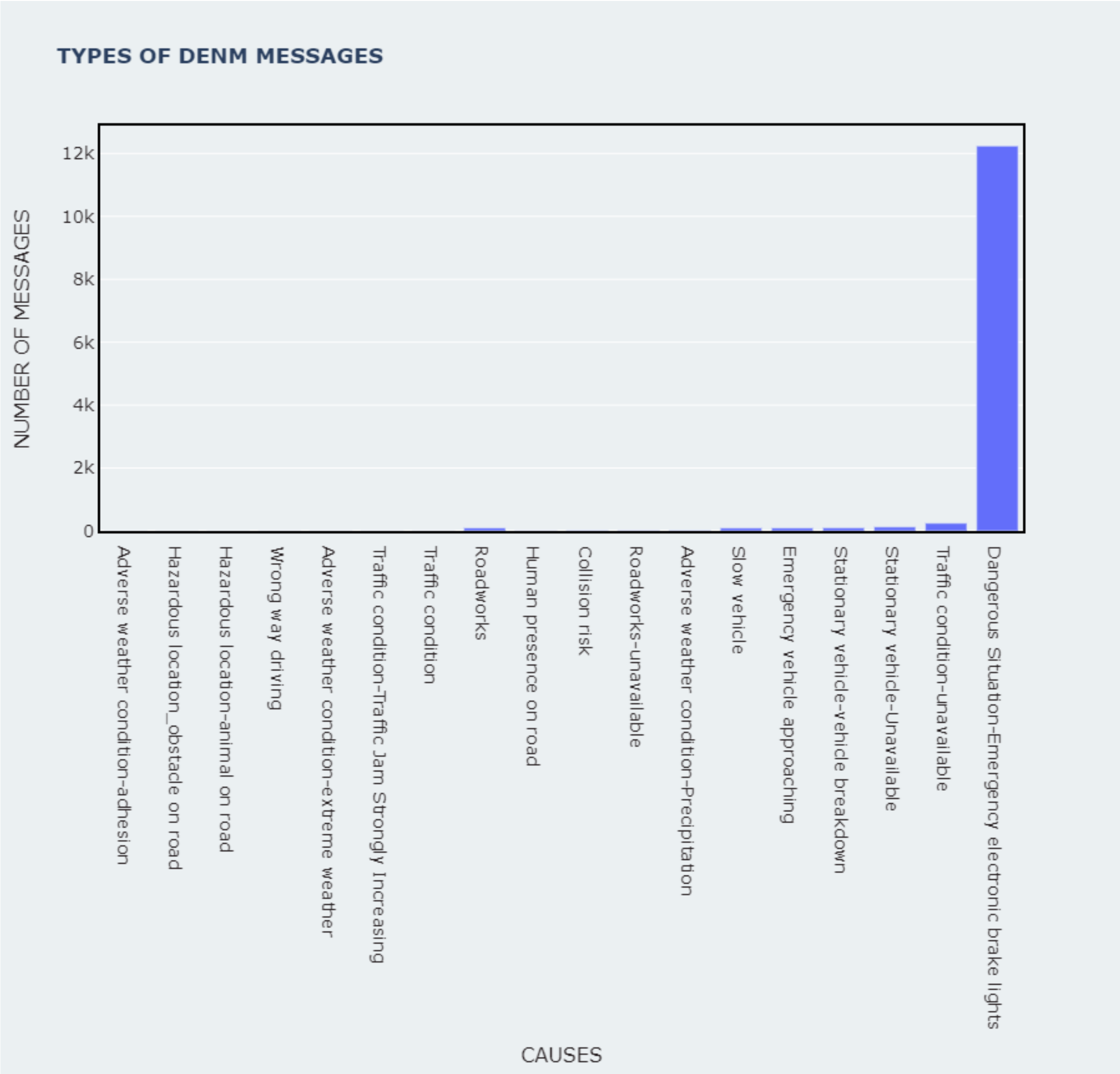

Figure 3. 2: Types of DENM message

The figure 3.2 represents the type of DENM messages that are tested by the ANAS test vehicles. Majority of the messages that are generated are of “Dangerous Situation- Emergency electronic brake lights” that are around 12.239k with least messages of 1 message of kind “Adverse weather condition-adhesion”, “Hazardous location-obstacle on road”, “Hazardous location-animal on road”.

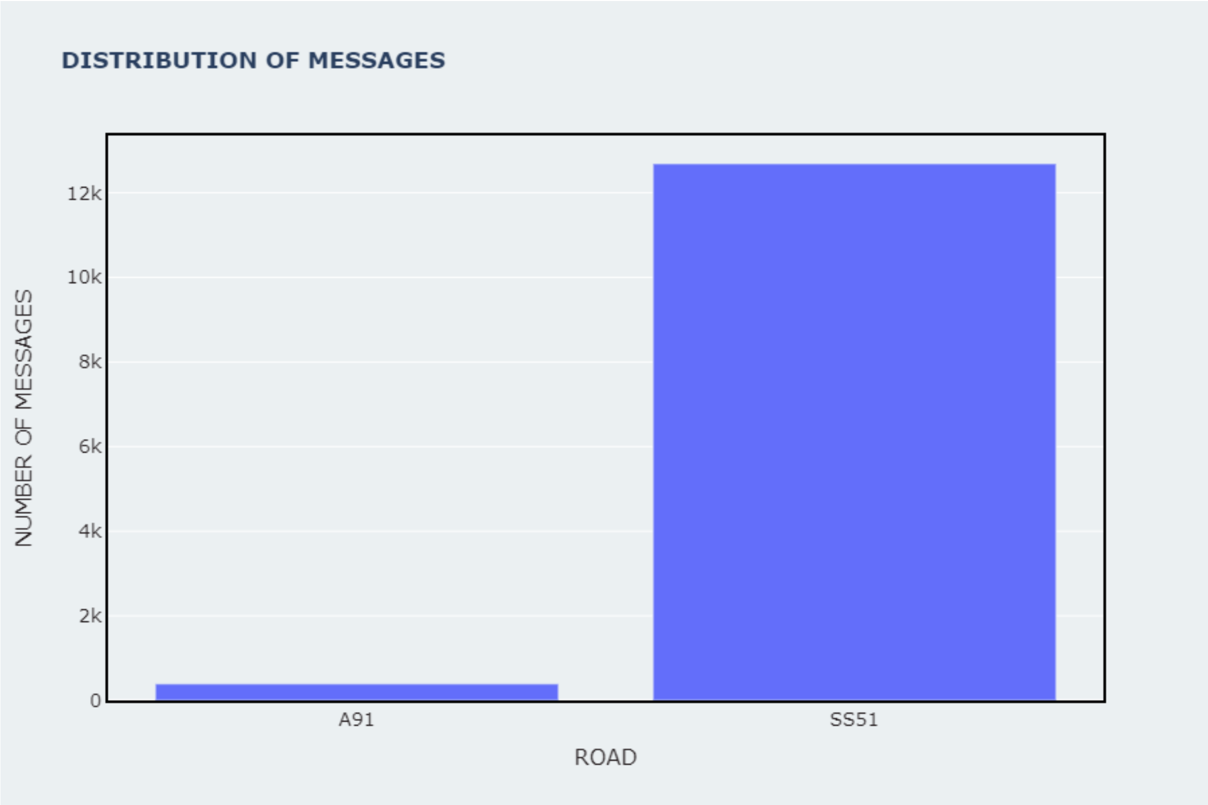

Figure 3. 3: Distribution of DENM messages by road

From the figure 3.3 the number of tests performed by DENM messages are high on SS51 than on A91. The number of messages on SS51 are 12.687k and on A91 it is 389 messages. It shows that more tests are performed on the SS51 than on A91.

Now by separating the data into two different data sets with SS51 and A91 to see the message dynamics over month and considering the direction of flow of traffic on the highway. The figure 3.4 shows the messages on SS51 by direction and majority of tests are performed on Increasing direction with very few in Decreasing direction. Whereas in the figure 3.5 represents the messages on A91 generated over month and the experiments are performed only in the Increasing direction.

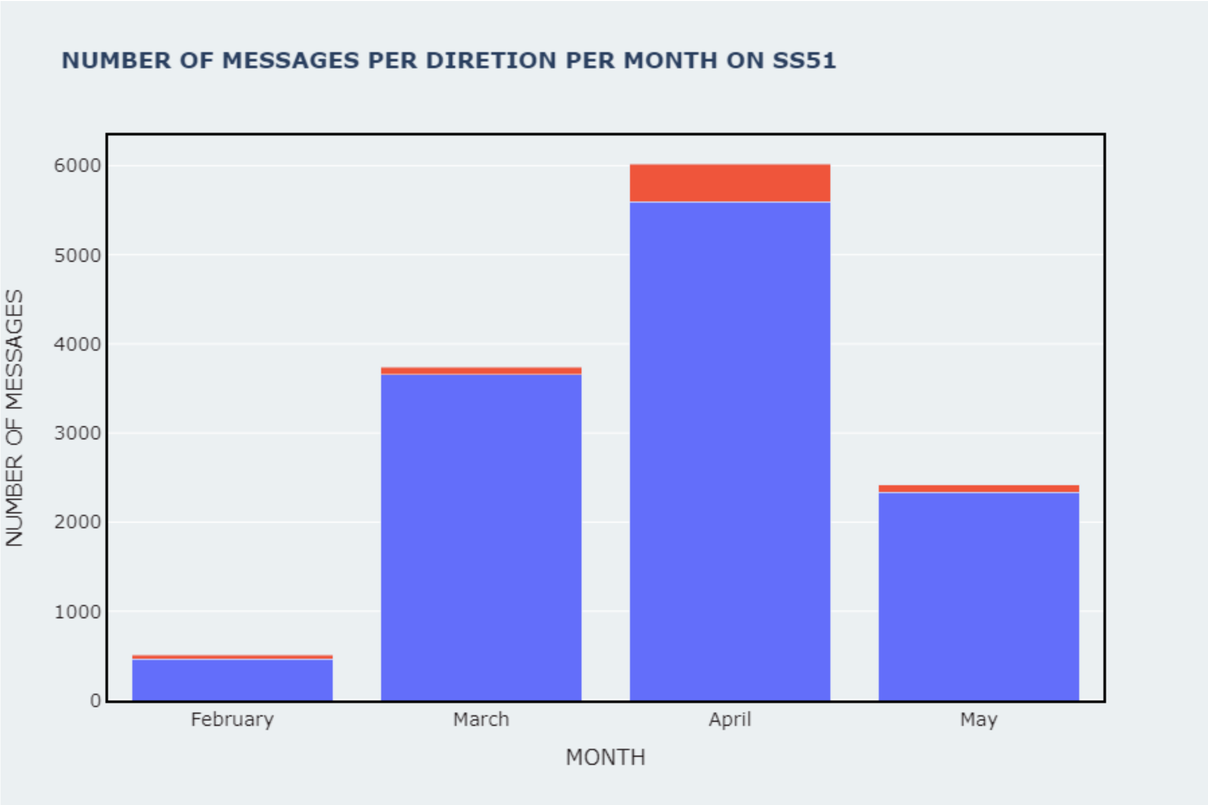

Figure 3. 4: Number of messages generated on SS51 by direction of flow

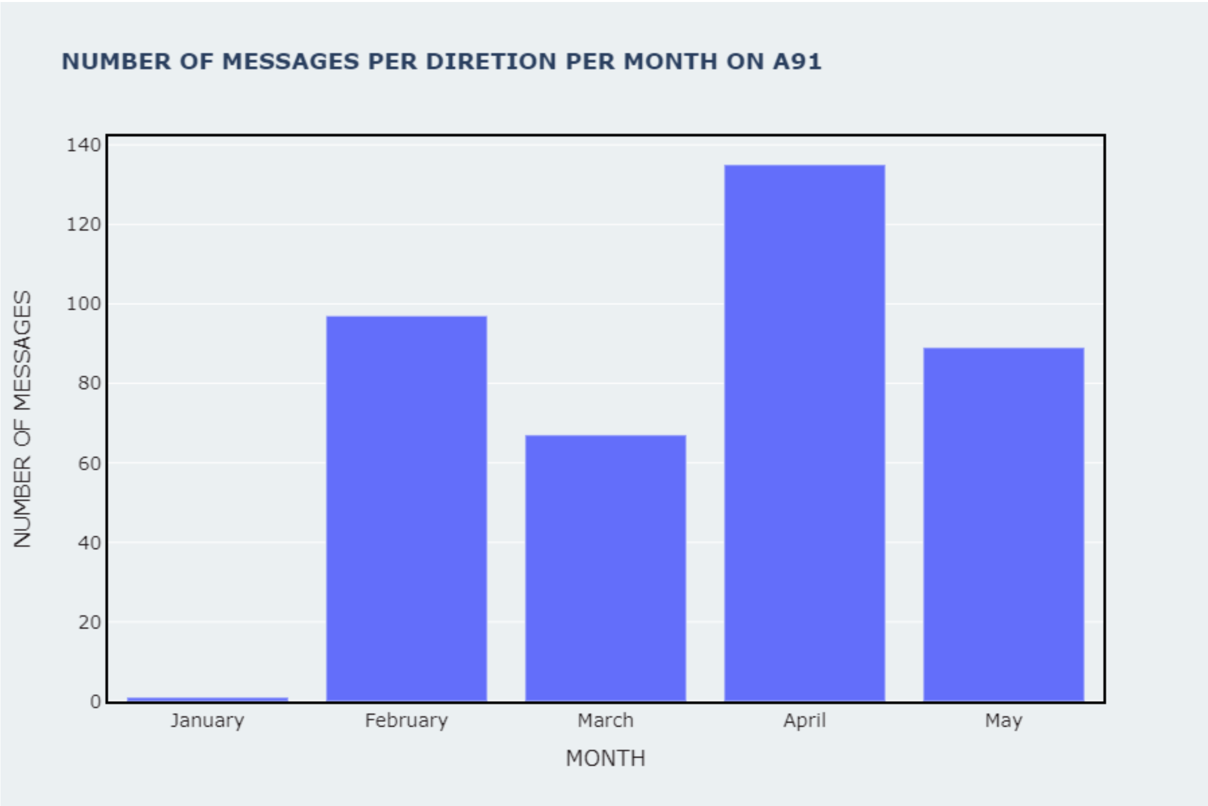

Figure 3. 5: Number of messages generated on A91 by Direction of flow

Decreasing Increasing

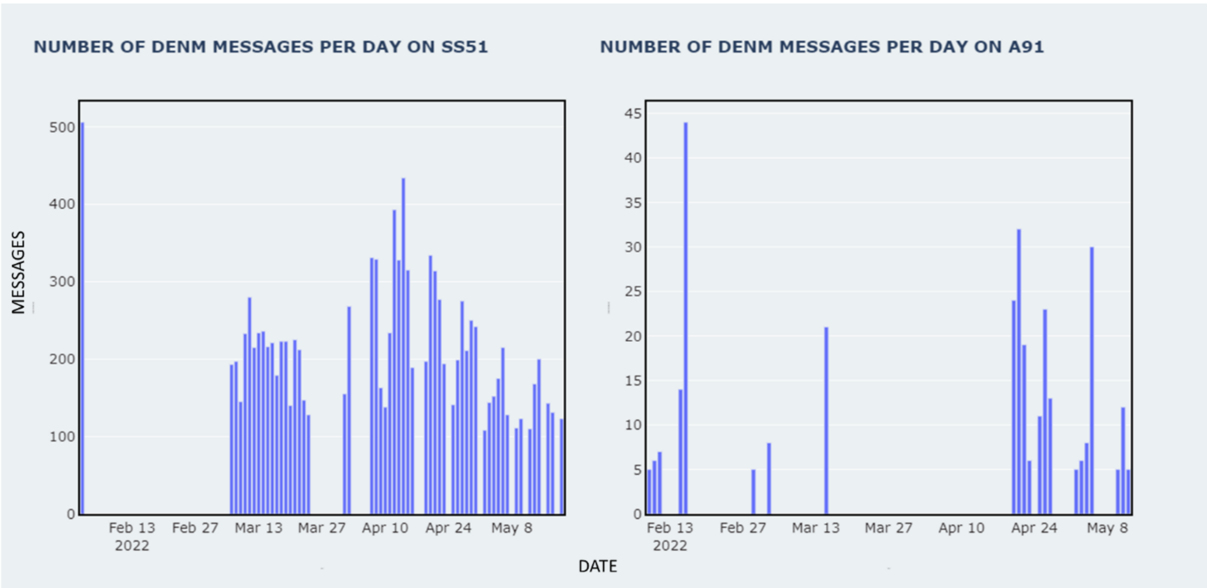

Figure 3. 6: Number of DENM messages on different dates on SS51 and A91

From the figure 3.8 we can see that the tests are not performed on all the days during the test period but are focused on specific days and the number of times test performed are very low and highly vary. Also there is high variability in the test performed on SS51 and A91.

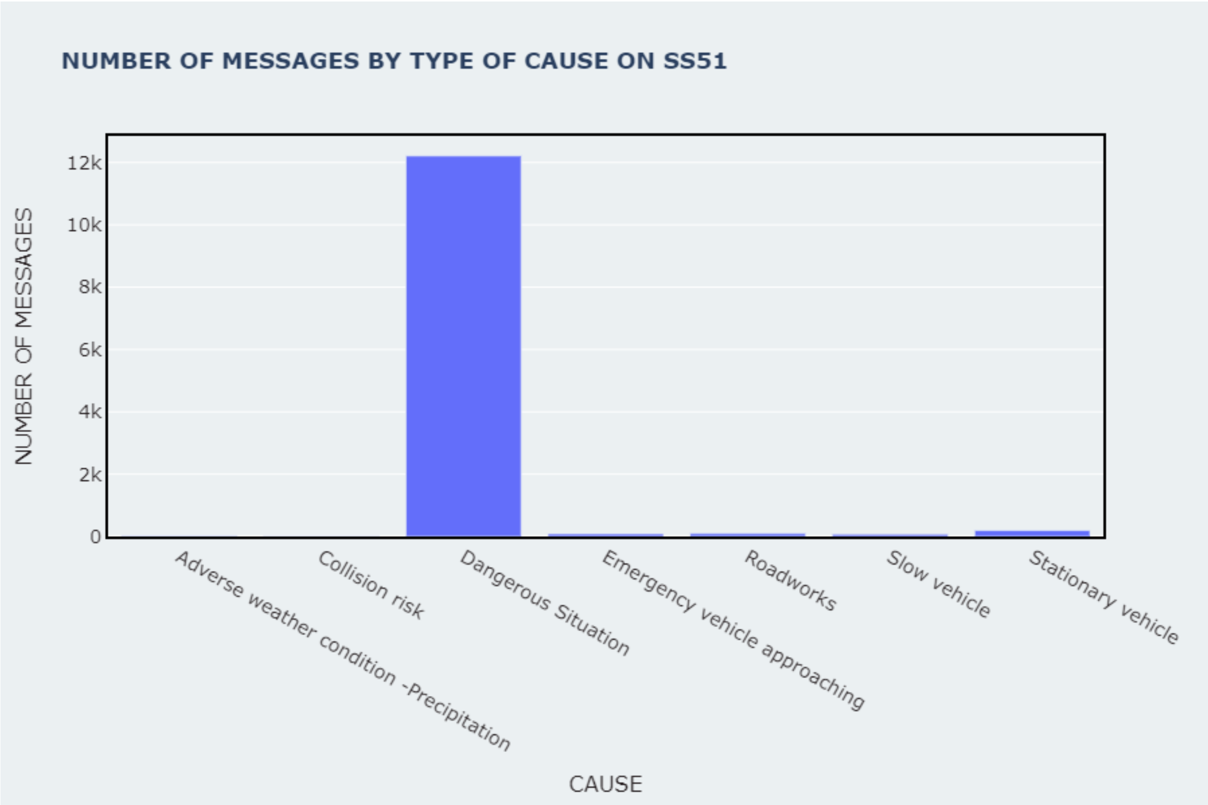

Figure 3. 7: Number of DENM message of type on SS51

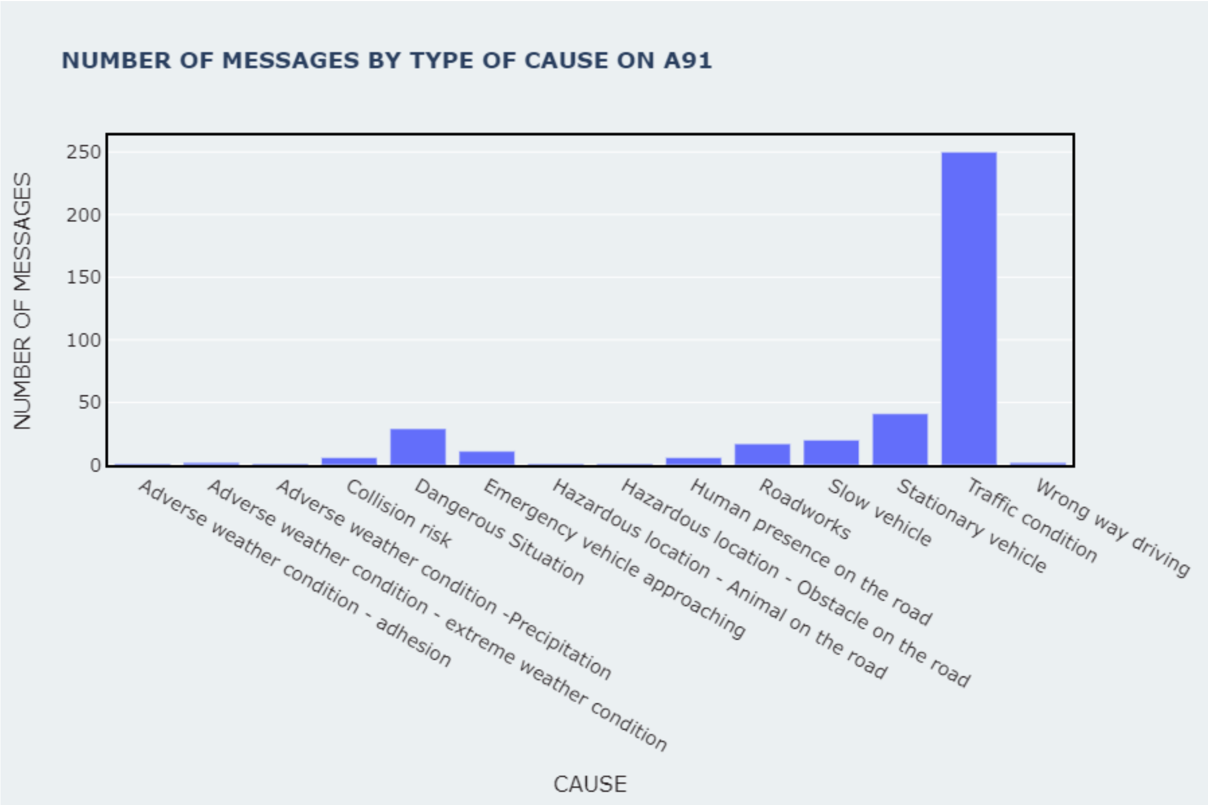

Figure 3. 8: Number of DENM message of type on A91

Now from the figure 3.6 the number of messages that are generated on SS51 are communicating about the dangerous situation with total messages of 12.21k generated in 6 months. Whereas on A91 highway the number of DENM messages generated are communicating about the traffic condition on the road

3.2. CAM message analysis

Now we look at the CAM message data set. By grouping the messages on both the SS51 and A91 by the month over a period of 6 months in 2022 obtained the following graph. From the graph it is evident that the number of messages is generated in the month of May and very low number of messages in the month of January.

As the cam messages only communicate the location there are no different types of CAM messages.

Now to look at the distribution of messages on the two roads the data set is divided into SS51 and A91. The messages are grouped by the location to see number of messages on each highway.

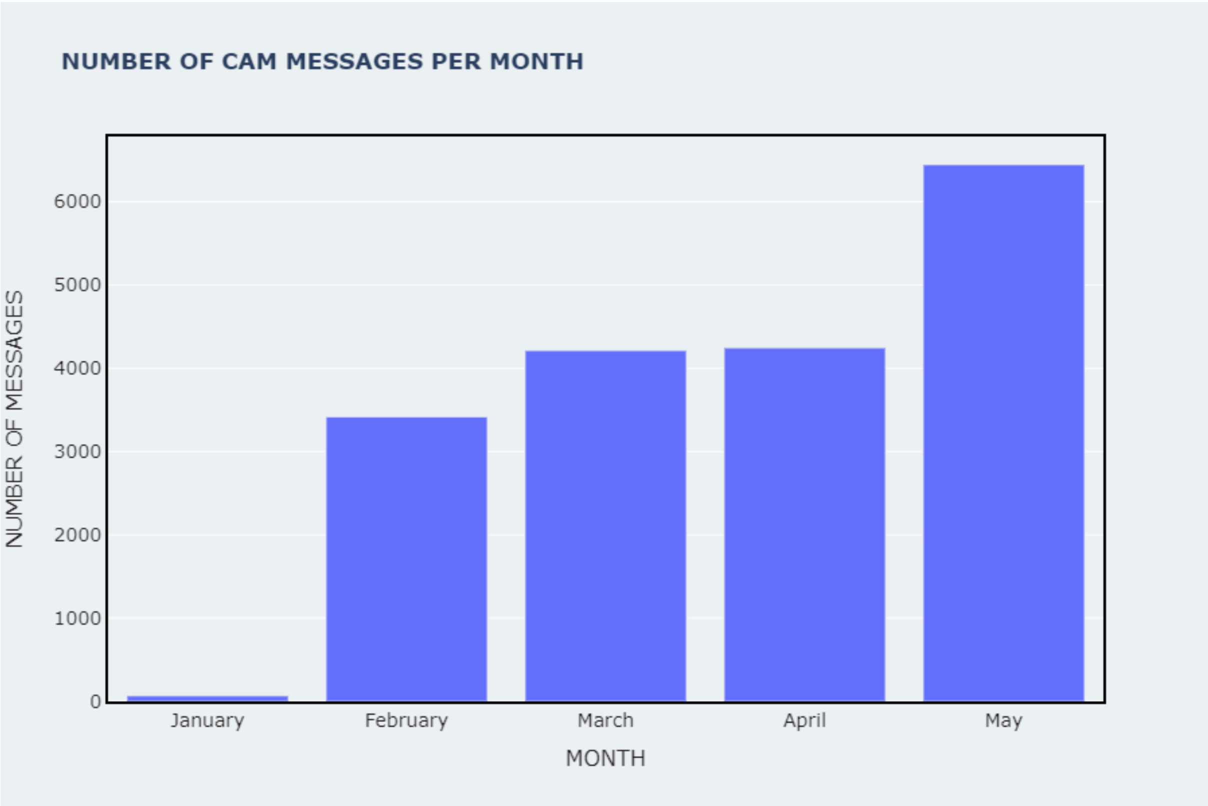

Figure 3. 9: Number of CAM message per month on A91

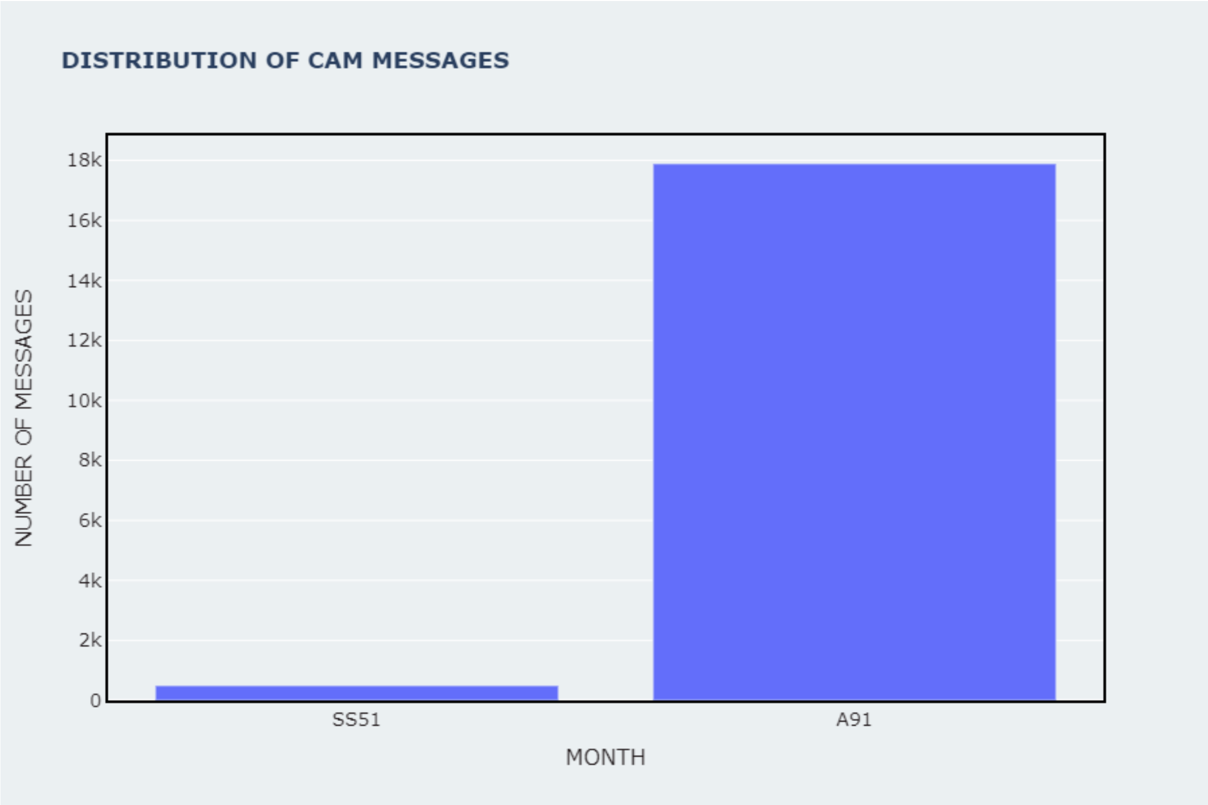

Figure 3. 10: Distribution of CAM messages on SS51 and A91

From the figure 3.9 it is seen that most of the CAM messages tested were on A91 highway with number of messages generated around 18k messages and 492 messages on SS51. CAM messages contrast with that of DENM messages where majority of DENM are tested on SS51 and majority of CAM are tested on A91.

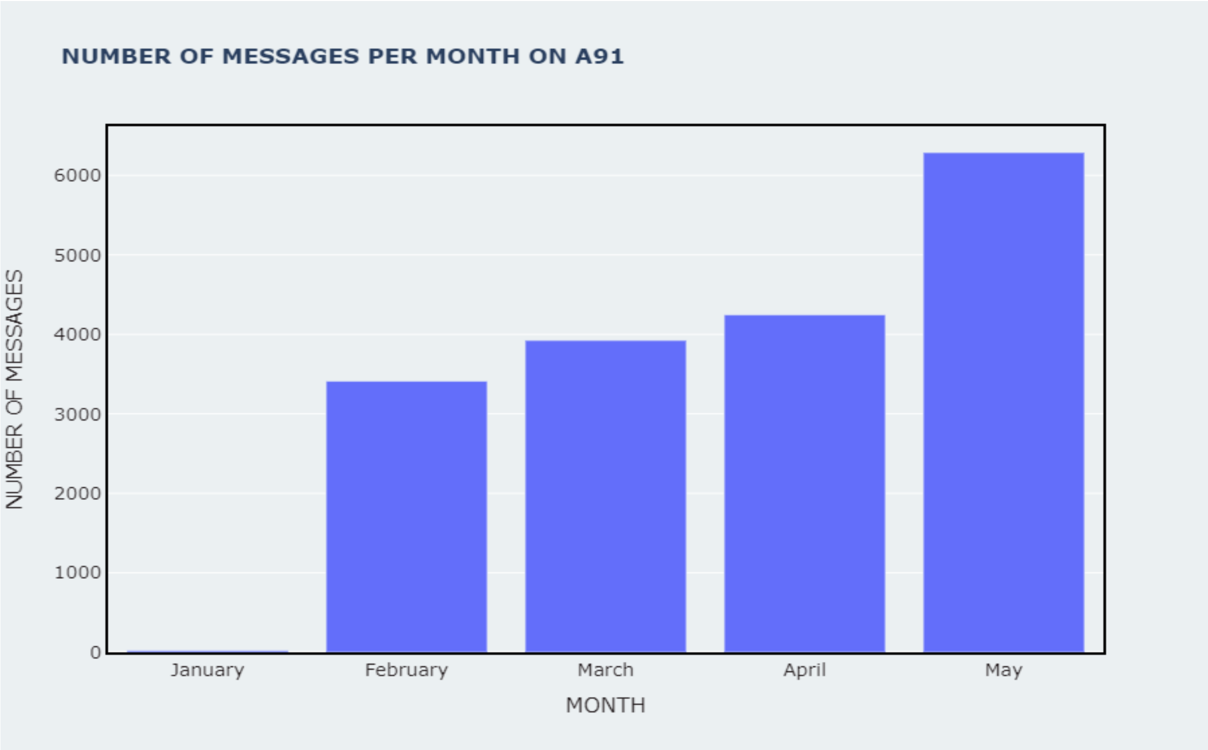

Figure 3. 11: Number of messages by month on A91

The Figure shows that the number of tests performed are high in the month of May with 6287 messages and low in January with only 22 messages.

On SS51 the number of messages generated are high in the month of March with 280 messages and with least number of messages in the month of February with 4 messages. These images show that the number of tests performed are random and are not equally performed on both the highways.

In order to deepen the understanding of the messages on different dates I plotted the number of messages tested on each highway on different dates starting from January to May 2022. The results show that the tests are not equally performed on each day but are performed on different days performing multiple tests. From figure 3.12 it can be seen that the tests on SS51 are performed on 4 months with two days of tests in each month.

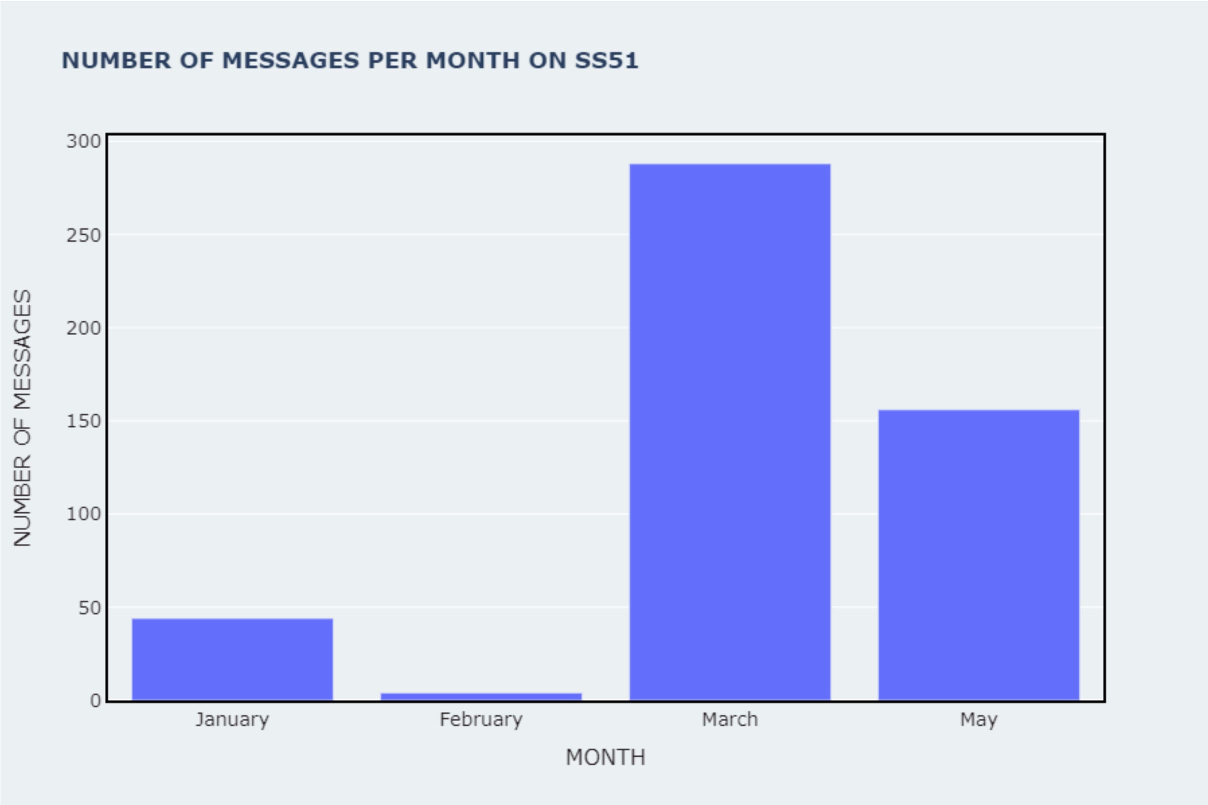

Figure 3. 12: Number of messages by month on SS51

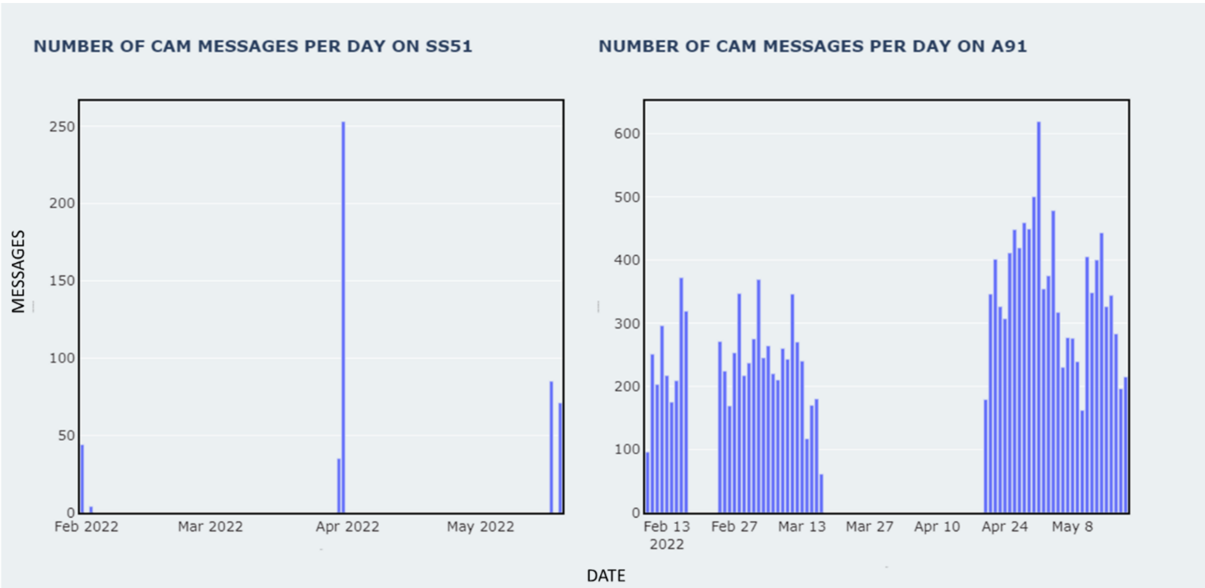

Figure 3. 13: Number of CAM messages on different dates on SS51 and A91

Here looking from the above image it is seen that majority of the CAM messages were tested in one direction and not in the other direction.

3.3. Traffic Flow Data Analysis

The traffic flow data set consists of the traffic flow from SS51 and A91 highways collected by the traffic counting machines that are present on the highway. The traffic counting machines are placed at different locations on SS51 and A91 highways. The position of the traffic counting machines on highway are shown in figure 3.14.

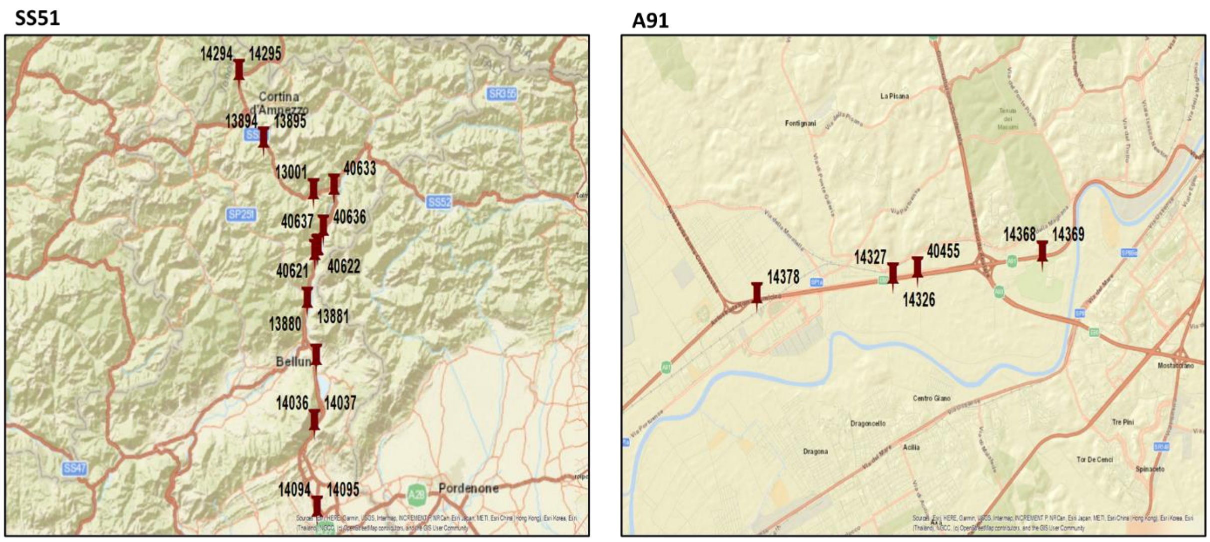

Figure 3. 14: Traffic Counting Positions on SS51 and A91

Now looking at the traffic flow on both the SS51 and A91 that is recorded by the traffic counting machines.

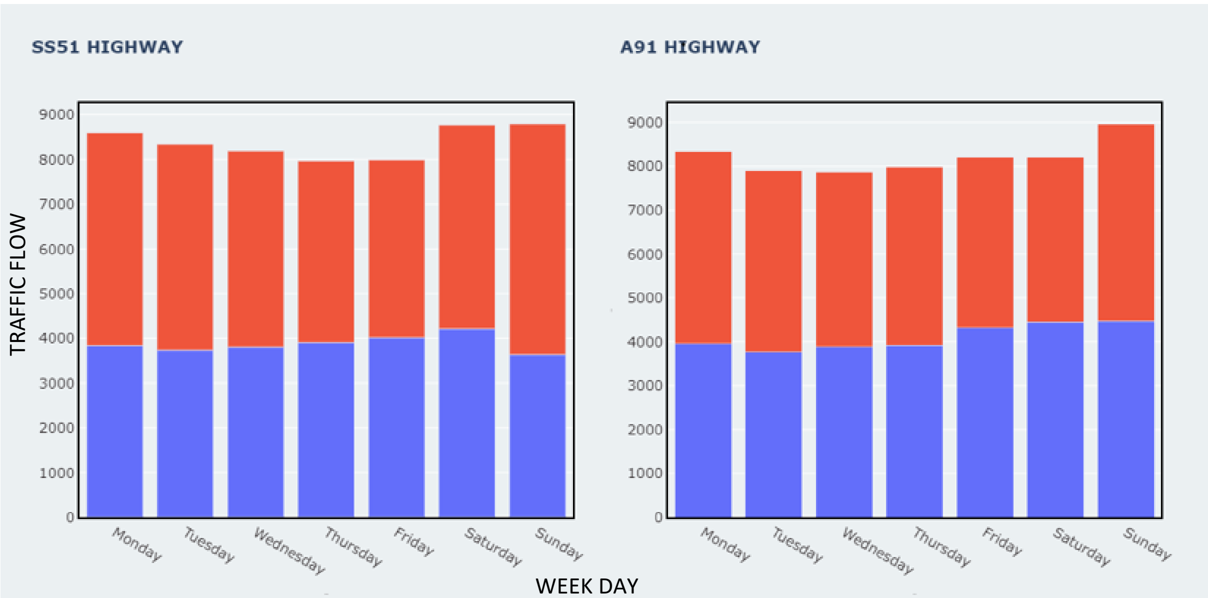

Figure 3. 15: Traffic flow recorded on SS51 and A91 by day of the week

Decreasing Increasing

The figure 3.15, represents the traffic flow on SS51 and A91 based on day of the week and the direction of flow. From the figure on SS51 highway we have highest traffic flow on the weekend which is same also in the case of A91 Highway. Also, the number of flows in the increasing direction is same as that of the decreasing direction in both A91 and SS51 highway. The traffic flow represented in the maximum flow in an hour in a direction by the day. That is obtained by grouping the data by date, time, day of the week, direction of flow, and summing the traffic flows then from the new data of sum of traffic flows taking the maximum value in a day from the 24-hour time is plotted in the graphs above. This is considered to understand what the worst traffic condition on the highway by can be considering the maximum flows.

Figure 3. 16: Overall Traffic Flow recorded on SS51 and A91 by day of the week.

The figure 3.16 represents the maximum traffic flow on each day of the week in a period of 6months. That is obtained by grouping the data by date, day, direction and taking the sum of flows for the whole day. Then from the data set grouping the data again by day, direction, and taking the maximum of the traffic flows. From the figure A91 has almost 100k of traffic flows from both the directions where as in SS51 the maximum traffic flow is on Saturday that reaches 100k.

4 Test Cases and Validation

This chapter talks about the hypothesis made, and validation of the hypothesis using the data collected and analysed to estimate the smart road system capacity. This chapter also explains the procedure followed to estimate the growth of connected vehicles.

4.1. Test Case 1: Estimation of messages by using test data.

Hypothesis 1: Estimating the messages that will be generated on SS51 and A91 highway using the test vehicles data.

To estimate the messages, the individual data sets that is Traffic Flow data set, CAM messages data set, DENM message data set should be combined to see the traffic flow position and the messages generated position. This joining is done by considering the position of the of messages generated and considering a fixed standard position on each road and measured the distance between the fixed point to the position of message generated. The same distance is measured with the traffic counting machines position and the fixed point on the SS51 and A91. The join function is used if the difference between the distance of message and distance of traffic counting machine is smaller the message is assigned to that traffic counting machine location. On combining the data, we obtain a dataset with each message assigned to a fixed location point which can be easily compared with the traffic flows at that position.

The results obtained from this new data set are as follows:

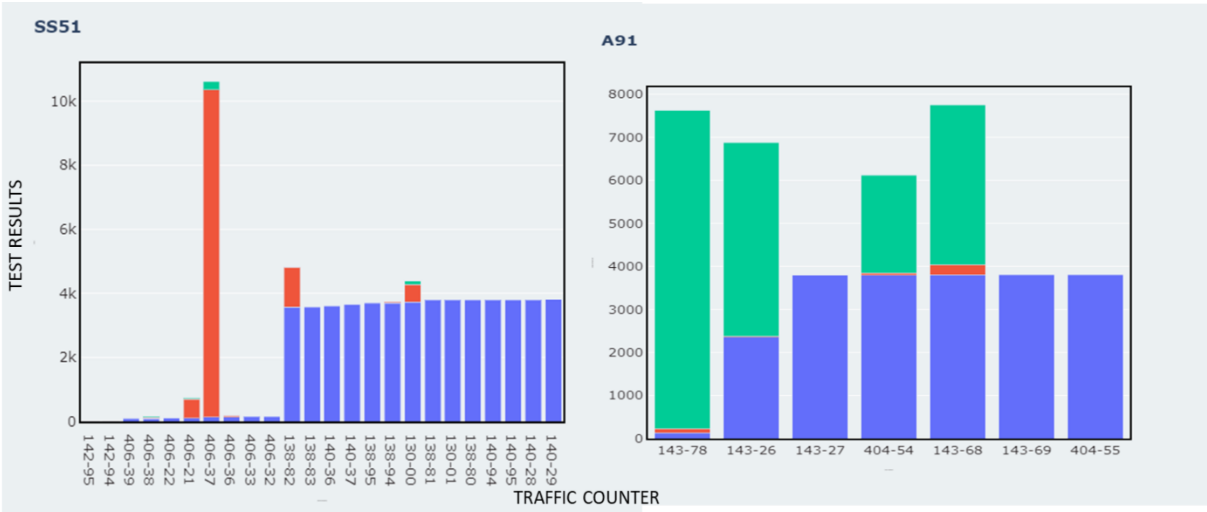

Figure 4. 1: Traffic flows, CAM, DENM messages at traffic counters

CAM MESSAGE DENM MESSAGE TRAFFIC FLOW

On joining the different data sets obtained new data set according to the traffic counting machines positions. The figure 4.1 shows the traffic count records, CAM messages, and DENM messages at each position on Highway. From figure it can be seen that the on SS51 the traffic flow is recorded in almost all traffic counters, but the messages tested are on specific positions and not on the overall length of the highway. The messages tested are primarily DENM messages and the test messages are tested in 5 different positions of the highway. With traffic counter "40637" position is tested with 10k DENM messages, but it has very low traffic flow recorded. Also from A91 the CAM messages were tested at traffic counter "14378" with high number of CAM and very low traffic and DENM messages.

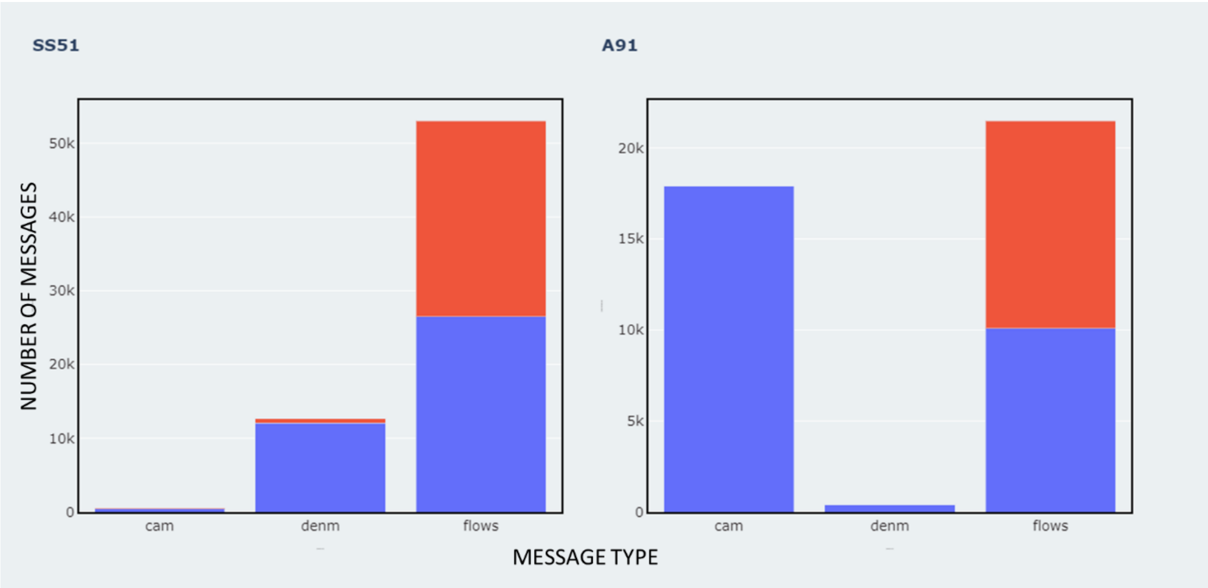

Figure 4. 2: Distribution of messages per direction

Decreasing Increasing

To estimate the number of messages by using the test data would not give realistic results as on SS51 we have a greater number of DENM messages tested and that DENM messages are focused on specific locations on the SS51. On SS51 the tests are performed in Increasing direction and not on Decreasing direction but the traffic flow that we have is in both the directions. On contrary in A91 we have a greater number of CAM messages tested with messages tested on specific locations of the highway. On A91 most of the messages are tested in increasing direction with no tests in decreasing direction. As A91 is a typical route with high amount of traffic in both the directions by using the tests data does not represent the actual situation on the highway.

To have more realistic results the hypothesis of estimating number of messages by using test data is not considered. So, the test data is not used for the estimation of messages.

4.2. Test Case 2: Weekly Dynamics of message estimation using test data

As the consolidated test data doesn't show depict real situation to see if any weekly dynamics have some correlation that depict the real scenario this hypothesis is tested. Also, as the traffic is not uniform throughout the week as on weekends the traffic might reduce and in week days the traffic will be almost linear so to see any relation this hypothesis is tested.

The data is grouped by the traffic counter position, date, day of the week, and considering the maximum traffic, minimum traffic, mean, and median traffic flows on each day of the week on SS51 and A91.

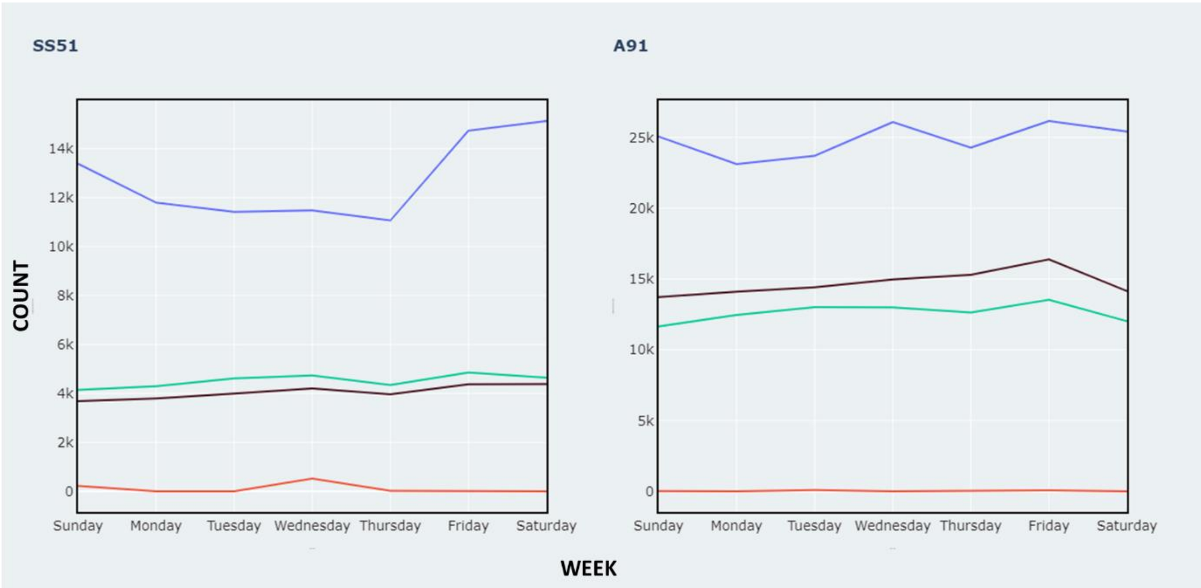

Figure 4. 3: Weekly dynamics of traffic flow on SS51 and A91

Maximum Minimum Mean Median

From the image the traffic flow SS51 is almost linear during the week days that is from Monday to Thursday where are there is a peak on weekends. Where as in A91 which is not a typical highway but road that connects City of Rome to the Fiumicino Airport. So, the traffic doesn't have any weekly dynamics but peak on Wednesday and Friday.

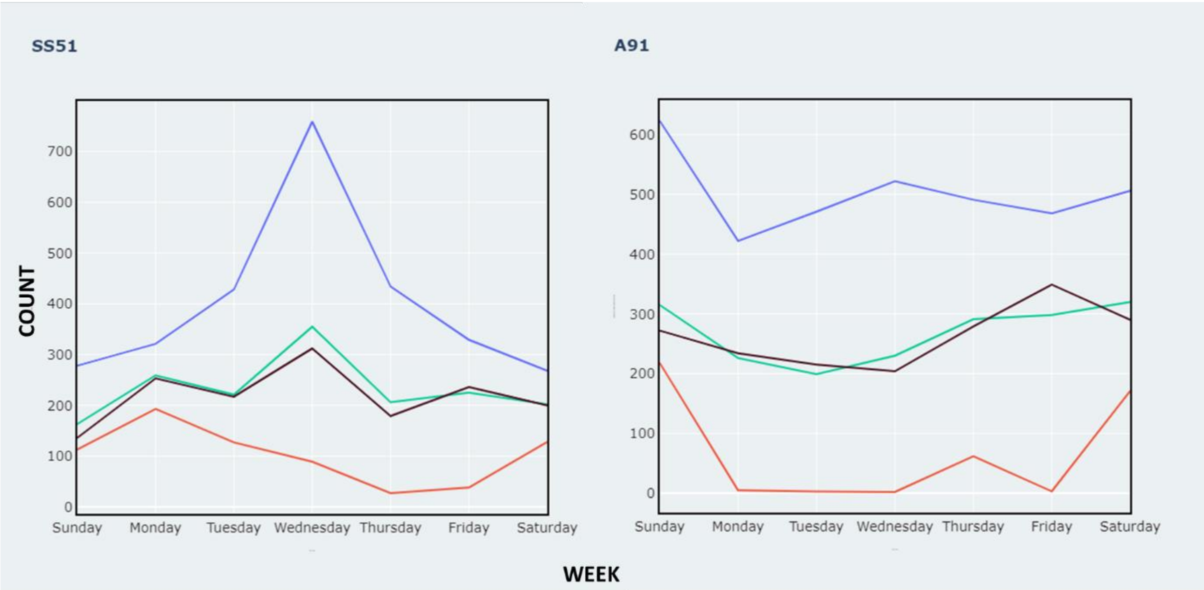

Figure 4. 4: Weekly dynamics of test messages on SS51 and A91

Maximum Minimum Mean Median

When we look at the messages that were tested on SS51 and A91 the messages don't resemble the traffic situation and dynamics over week. We can see that in SS51 we have higher number of messages tested on Wednesday and in A91 we have higher number of messages on Sunday. Also, from Figure 4.2 we know that the messages that were tested on SS51 and A91 are completely different, and this data cannot be used to estimate the overall number of messages.

Hypothesis 2 is not considered

4.3. Test Case 3: Estimation of Number of Messages in an Hour in a Day

As we have seen that the traffic flows and test messages are not consistent with each other we needed to figure a way to estimate the overall number of messages. To test this scenario, we use the traffic flow data which is recorded from the traffic counters on the highway of SS51 and A91. To know the number of messages each vehicle generates we makes certain assumptions:

Assumption 1: Considering that each vehicle generates a CAM message every one second. As we know that the frequency of the CAM message can be set with which the messages are generated and sent by the vehicular infrastructure. So, number of CAM messages communicated by a vehicle in an hour are 3600 messages per hour by a vehicle.

<u>Assumption 2:</u> DENM messages are generated by the road side infrastructure, and they are generated only if there is any obstacle or information that must be communicated. So, we don't have fixed number of messages that will be generated. For simplification we consider 1% of the CAM messages that are generated in an hour as DENM messages generated in an hour. Considering this assumption, the number of DENM messages that are communicated in an hour are 1% of 3600 that is 36 DENM messages.

<u>Assumption 3:</u> When talking of smart road infrastructure and messages are only useful when the vehicles have the technology to communicate. As of now the vehicles are not equipped with the connected technology. To estimate the number of messages we consider that all the vehicles that are running on the road to be connected vehicles that are equipped with the technology. This assumption is not true at present but in future we will have the connected vehicles on road. So according to this all the vehicles that are obtained through traffic counting machines are used as the connected traffic flow.

Based on these assumptions the number of messages including both CAM and DENM a vehicle can generate in a hour are 3636 with 3600 CAM and 36 DENM messages.

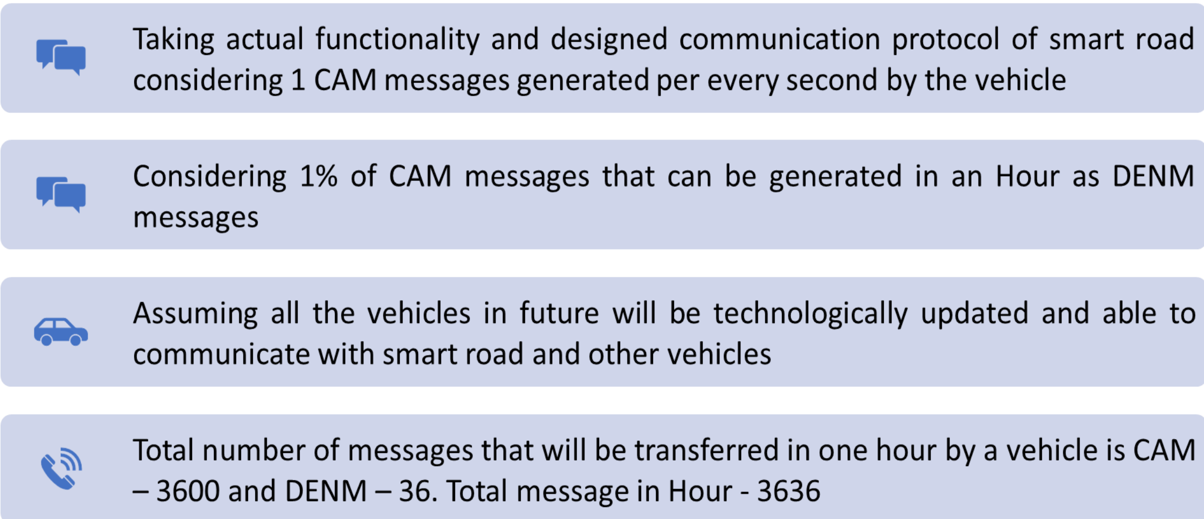

Figure 4. 5: Assumptions considered to estimate number of messages.

Based on these assumptions considering the traffic flow data to be of the connected vehicles and visualizing the traffic flow in hour of a day. To visualize the traffic flow in hour of the day the data is aggregated by hour, day, and taking the maximum of traffic and creating a new data set. This data set is the aggregated by hour and maximum traffic in each hour. This gave the maximum traffic at each hour of the day on SS51 and A91. Along with maximum traffic, minimum and mean traffic is also considered.

From the figure 4.6, the traffic during the office/school hours we have higher traffic with less in the night. On SS51 we have higher traffic from 5:00 and 16:00 when the schools, and offices end and people returning home. On A91 we have peak in traffic flow during the 5:00 to 16:00 also in A91 we can see that the traffic even at night we have people traveling as said earlier A91 is not a typical highway but an highway that connects the Fiumicino airport to the Rome city.

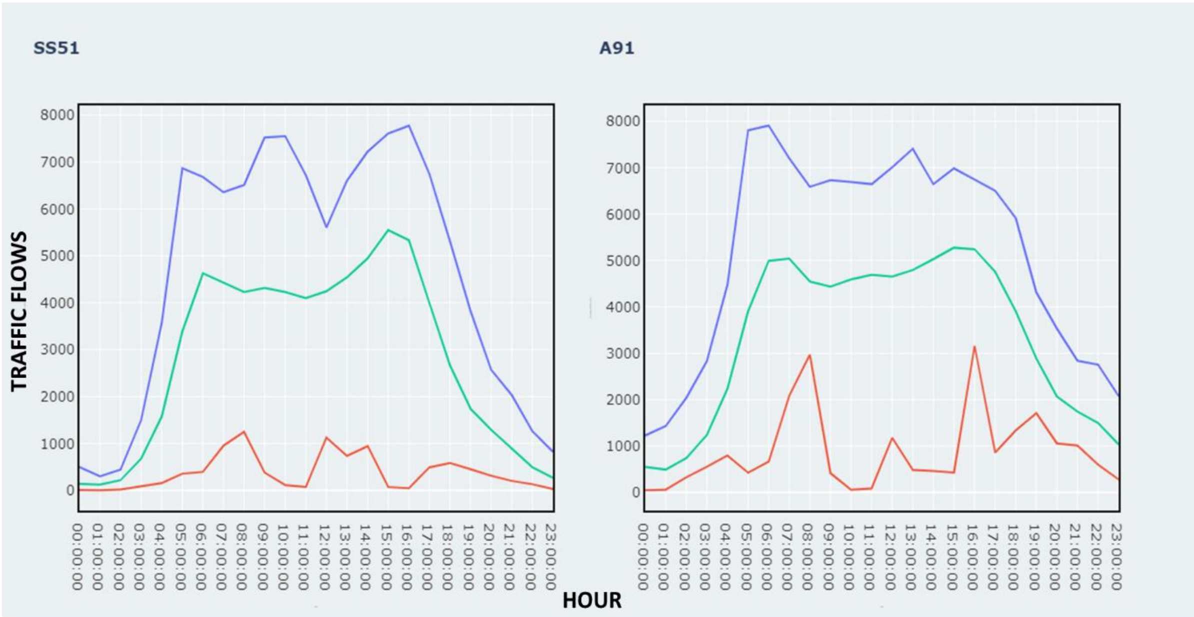

Figure 4. 6: Traffic flow representation in hour on SS51 and A91

Maximum Minimum Mean

Now to estimate the number of messages by using the traffic flow in hour and multiplying it with the messages that were assumed to be 3636 in one hour by one vehicle.

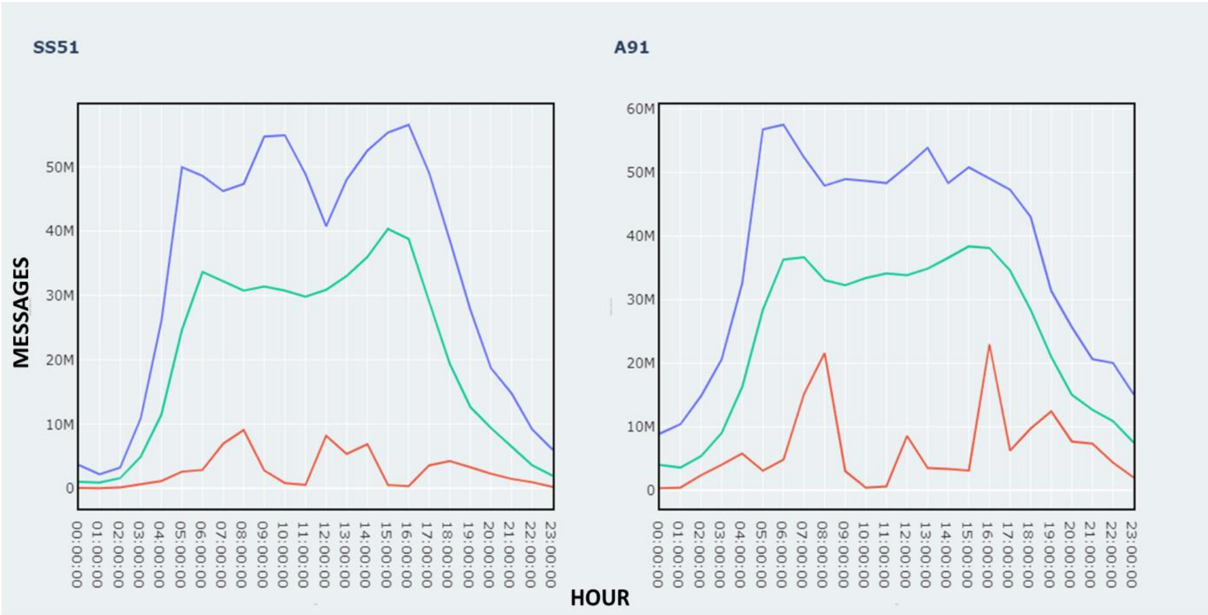

Figure 4. 7: Number of messages generated in an hour

Figure 4.7 represents the number of messages that are generated on SS51 and A91 highway according to the assumptions made. On SS51 the maximum number of messages that are generated in an hour are 56.54 million with maximum traffic as 7776 in an hour. Whereas for A91 highway the maximum number of messages that are generated in an hour is 57.5 million with maximum traffic of 7908 in an hour. This represents the real scenario if and only if all the vehicles are equipped with the technology.

To deep dive into this analysis and further estimation of messages is performed by considering the weekly dynamics. The assumptions made earlier are also considered for the weekly message's estimation.

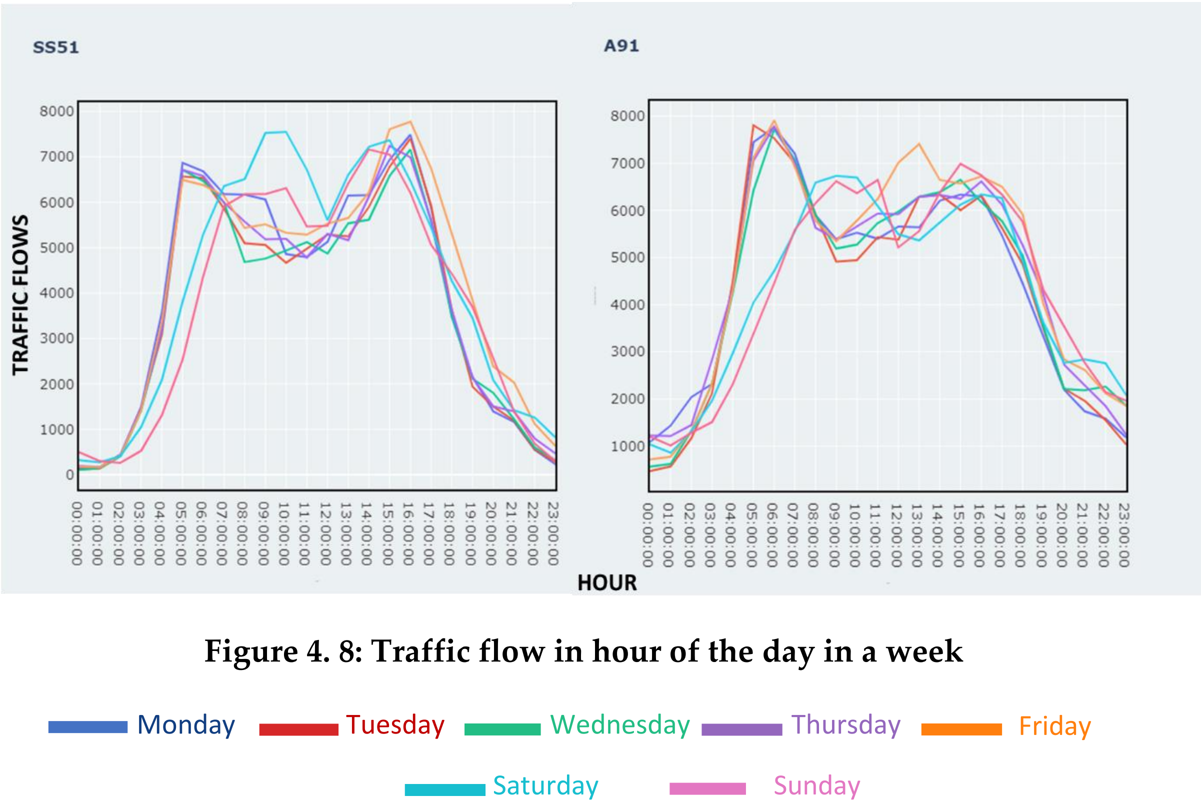

Figure 4. 8: Traffic flow in hour of the day in a week

From the figure 4.8 shows the maximum traffic flow on SS51 and A91 in an hour in a week. On SS51 the traffic flow in the week days is that is Monday to Friday follows a similar dynamic whereas on Sunday and Saturday the dynamics change in terms of the peak traffic in an hour. On weekday we have a peak of traffic at 5:00 where as on weekends the peak is at 9:00. On A91 we have different traffic dynamics on weekdays and weekends on weekdays we have peak traffic in an hour at 6:00 whereas in the weekends the peak is at 9:00. This is obtained by grouping the data by date, time, day and considering the maximum of traffic flows. The using the new data set creating a sub-data set by grouping the data by day, time, and considering the maximum of traffic flows on SS51 and A91. The maximum traffic in an hour on SS51 is 7776 and on A91 is 7908.

To estimate the number of messages we now multiply the messages that a vehicle can generate in hour with the traffic flow.

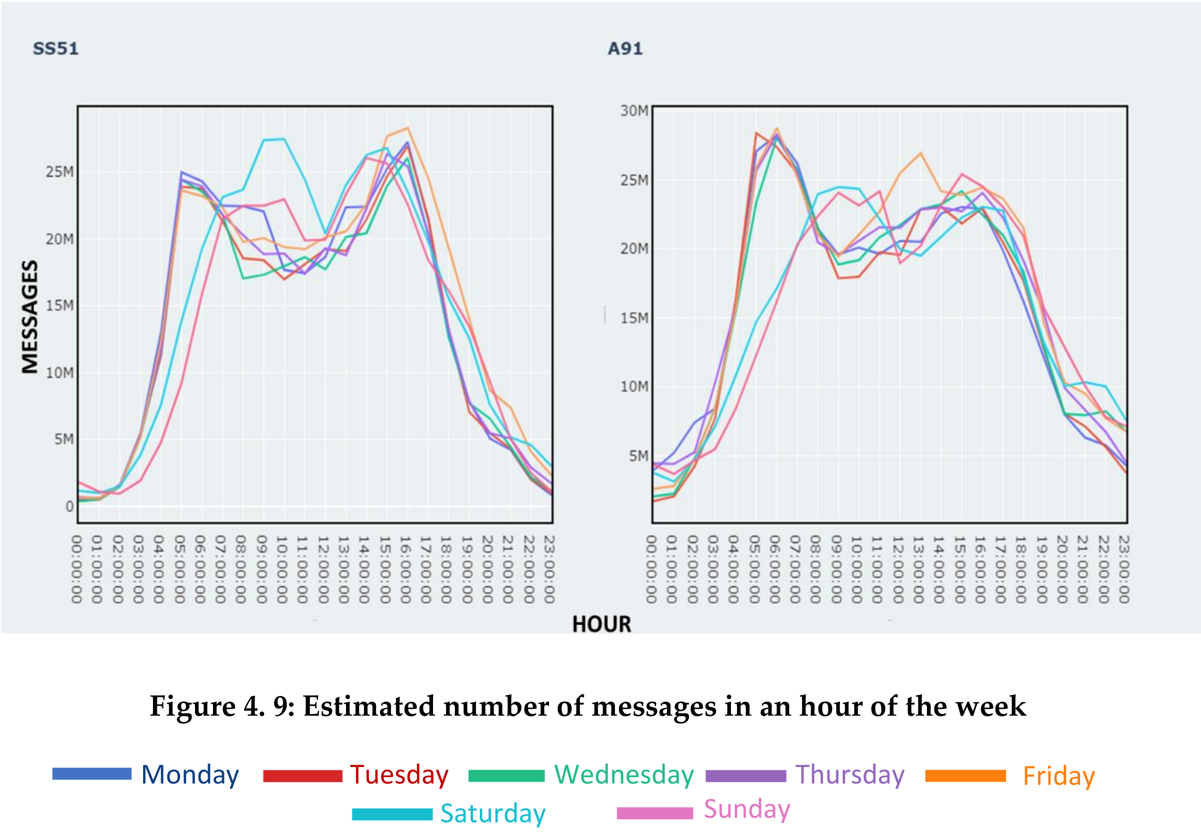

Figure 4. 9: Estimated number of messages in an hour of the week

The figure 4.9 show the number of messages that can be generated in an hour on different days of the week according to the traffic flow data and considering maximum traffic in each hour. The maximum number of messages that can be generated in a n hour in SS51 is 28.27 million and on A91 is 28.75 million.

Now as we estimated the number of messages on SS51 and A91 in an hour, but we also seen that we have two directions of flow but in the analysis presented until now is by considering as overall traffic in both directions. To see if there is a change in the number of messages by considering the individual directions of flow and not as a combined traffic flow. To perform this that data is grouped by date, time, direction, day, and the maximum of traffic flow is considered. Then separating the direction of traffic flow in Increasing and Decreasing direction. As we have both increasing and decreasing direction and the maximum traffic in an hour from both directions is summed together to have overall traffic flow in an hour from both the directions. Using this data of traffic flow is multiplied with the number of messages each vehicle can generate in an hour to get overall messages that can be generated in an hour.

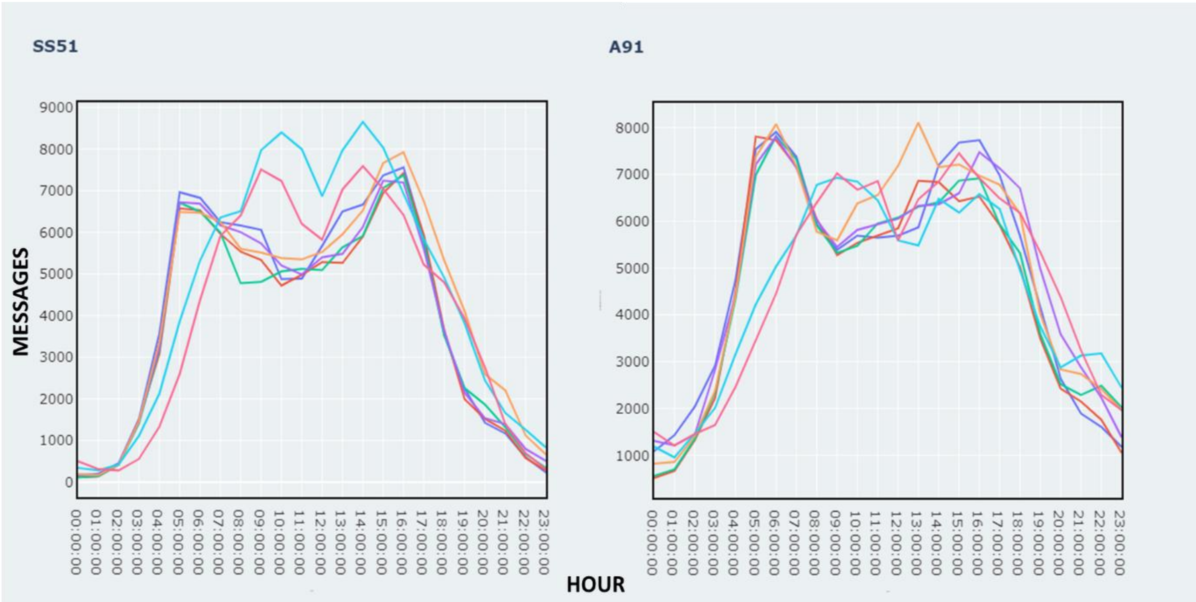

Figure 4. 10: Sum of traffic flow from both directions in an hour of the week

Monday Tuesday Wednesday Thursday Friday
Saturday Sunday

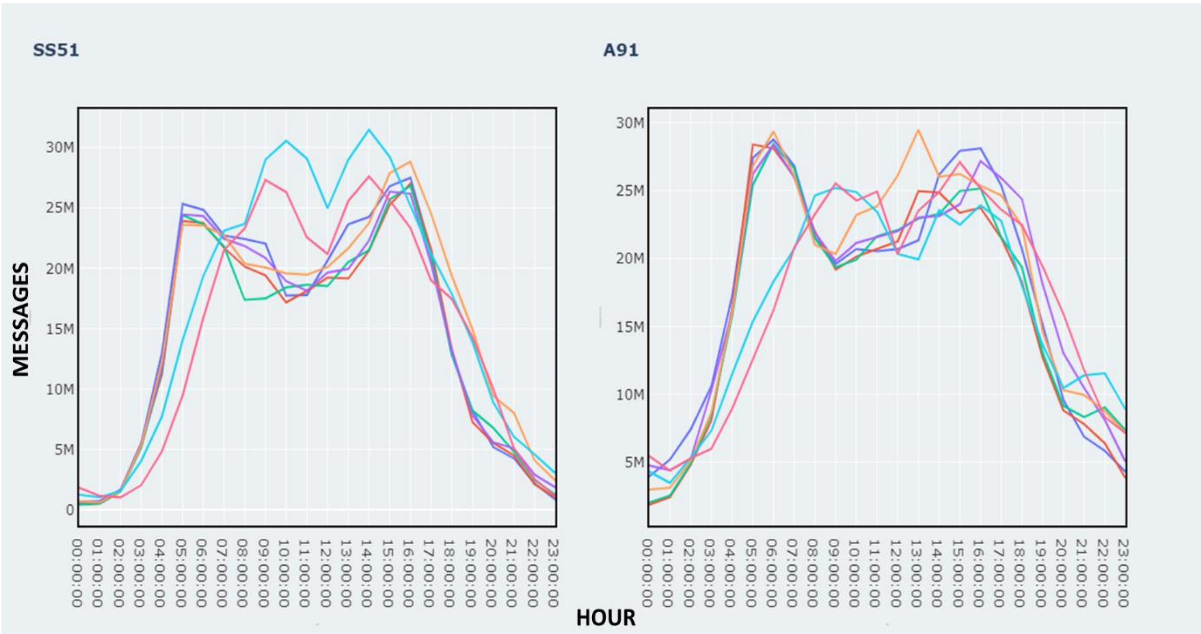

Figure 4. 11: Estimated number of messages in an hour of the week

Monday Tuesday Wednesday Thursday Friday
Saturday Sunday

The dynamics of traffic flow in hour of day is not much different from the overall traffic flow and the number of messages that can be generated follow similar dynamics of overall traffic flows.

4.4. Estimation of Number of Messages based on the growth of connected vehicle growth.

As the smart roads are effective and can be used to their full potential if the vehicle is capable of communicating with the infrastructure. But the vehicles at present are not equipped with the technology and cannot communicate with the infrastructure. With the growth of Internet of things and technology connected vehicles, and autonomous vehicles will take over the roads in future. Considering the data from Statista regarding the growth of connected cars in Italy which is expected to reach 12.66 millions of connected cars by 2023.

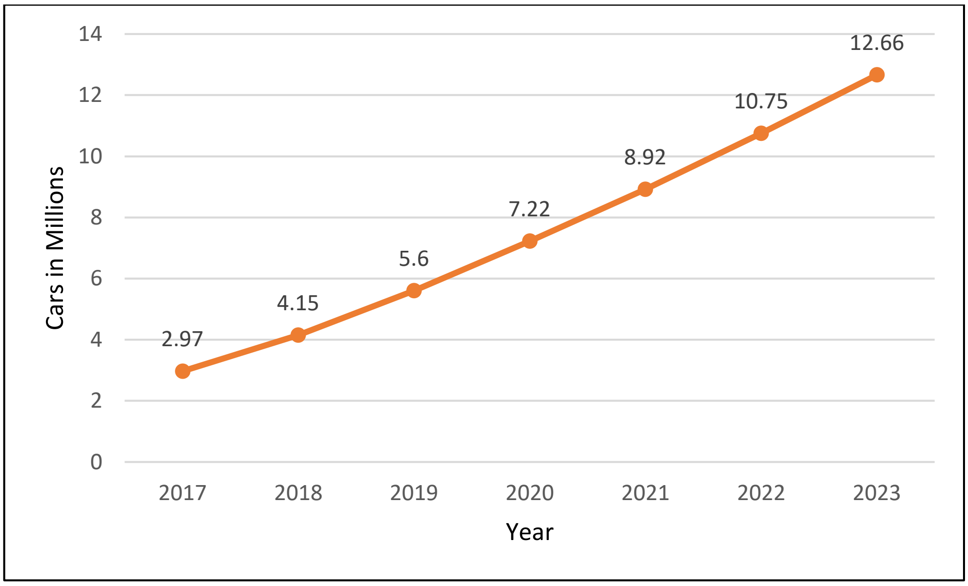

Figure 4. 12: Estimated stock of connected cars in Italy from 2017 to 2023 in millions [Source: Statista]

Using this data as a foundation estimated the connected vehicles growth in Italy. By considering the growth rate of vehicle and taking the average growth rate for each year and adding it to the overall connected vehicles in 2023 and till 2032. The overall vehicle data and its estimation of vehicle till the year 2032 is taken by considering a 1% growth every year based on the data obtained from the Associazione Nazionale Filiera Industria Automobilistica (ANFIA).

By the considerations made the number of total vehicles that can be seen on roads of Italy by 2032 are 49 million. The number of connected vehicles that can be expected by 2032 are 37 million. These estimations are based on the growth rate of pervious and the real data might vary based on various concepts such as the price, evolution of technology, incentives, and strict policies to scrape old vehicles, and many others might vary the real vehicles growth.

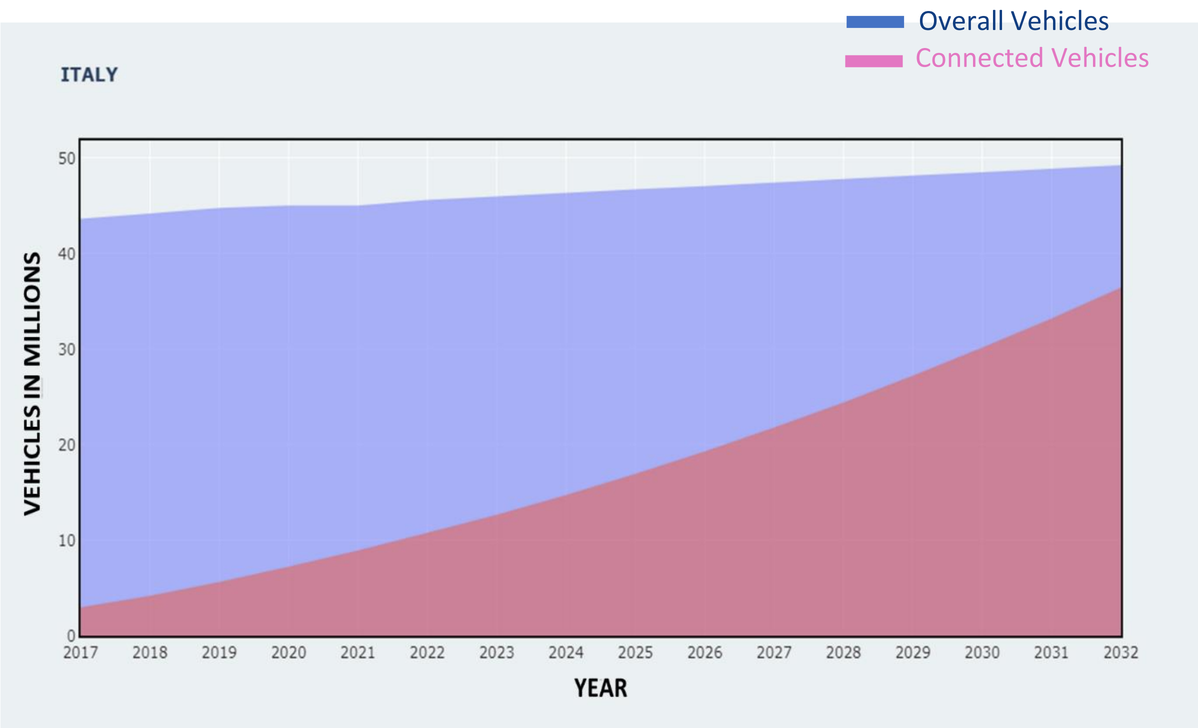

Figure 4. 13: Estimation of connected vehicle stock from 2017 to 2032

Now as our study is focused on two highways that are A91 and SS51 we will focus the growth study on these highways and use the data to estimate the number of messages that the connected vehicles will produce.

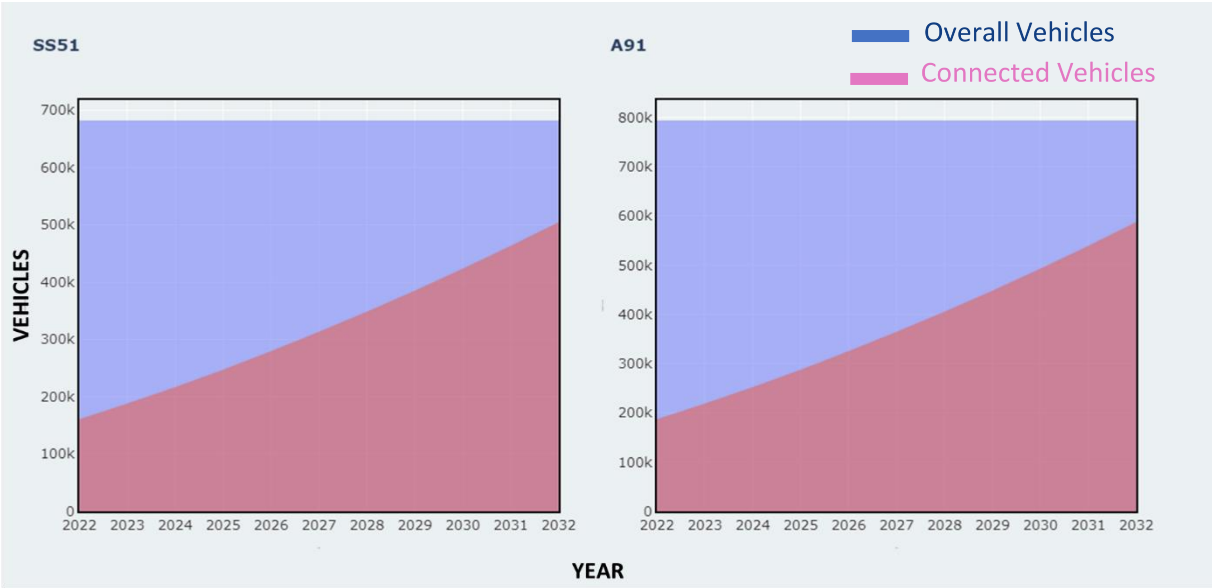

Figure 4. 14: Estimation of connected vehicles on SS51 and A91

By considering the overall number of vehicles travelled per year on SS51 and A91 highway and dividing the total number of vehicles we obtained the percentage of number of vehicles on SS51 and A91 respectively. Using this percentage value and taking the similar percentage of the connected vehicles travelling on SS51 and A91.

From the data of total vehicles, we estimated the messages that will be generated on SS51 and A91 highway per day and per year.

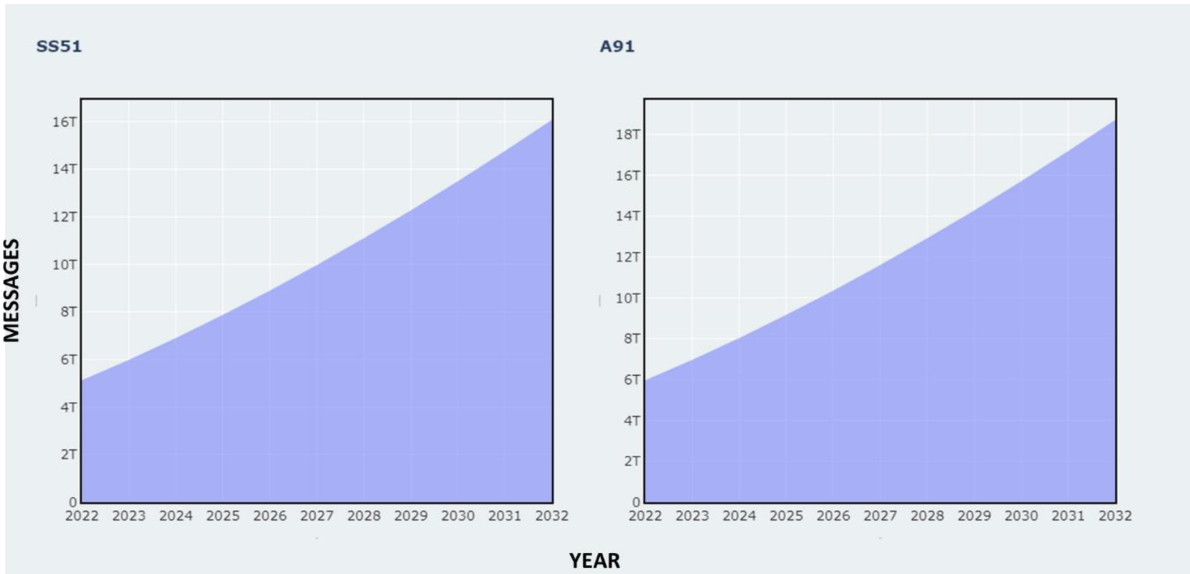

Figure 4. 15: Estimation of connected vehicles on SS51 and A91 per year

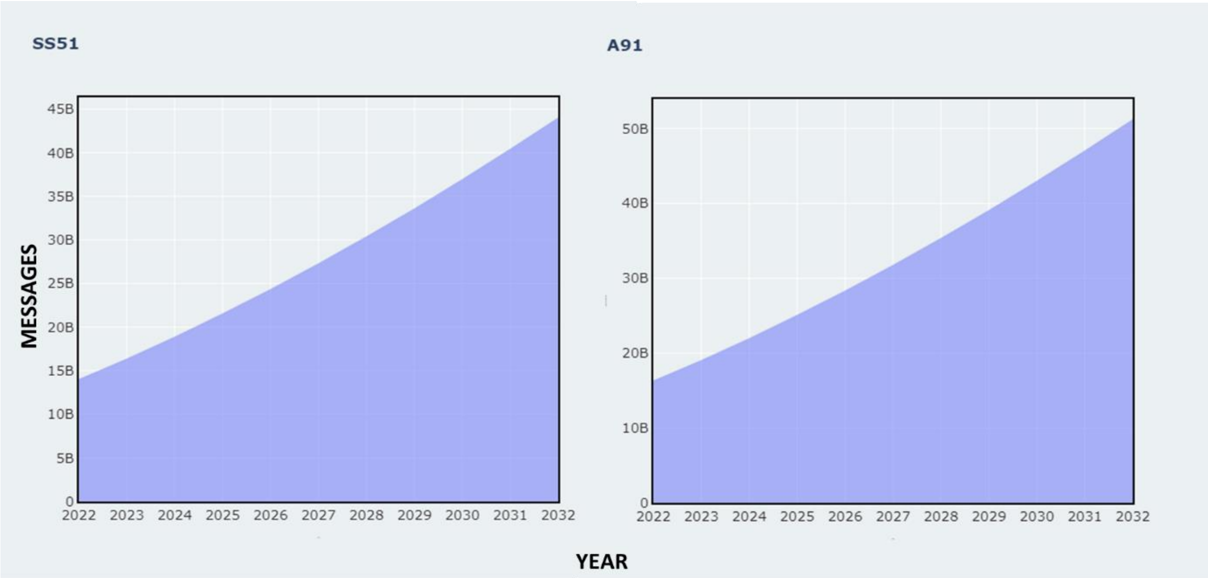

Figure 4. 16: Estimation of connected vehicles on SS51 and A91 per day

- The maximum number of messages on a day that will generate on A91 Highway is 0.94 billion
- The maximum number of messages on a day that will generate on SS51 Highway is 0.81 billion
- Estimated connected vehicles by 2032 is 36.42 million and the messages that can be generated per year are 1.16 * 10^15
- Estimated number of messages in the year by connected vehicles on SS51 and A91 is 16T and 18.7T
- Estimated number of messages in a day by connected vehicles on SS51 and A91 is 44B and 51.2B

5 Estimation of Data Driven Road Occupancy level

As we have analysed the traffic flow data that has been obtained from the traffic counter machines that are installed on the highway at a distance apart. To look at the road occupancy level of the highway we will try to consider the traffic flows between two traffic counter machines to be constant. Also, we make assumption that there is no ramp-on and ramp-off between two traffic counter machines. This allows the simplification of road occupancy level measurement.

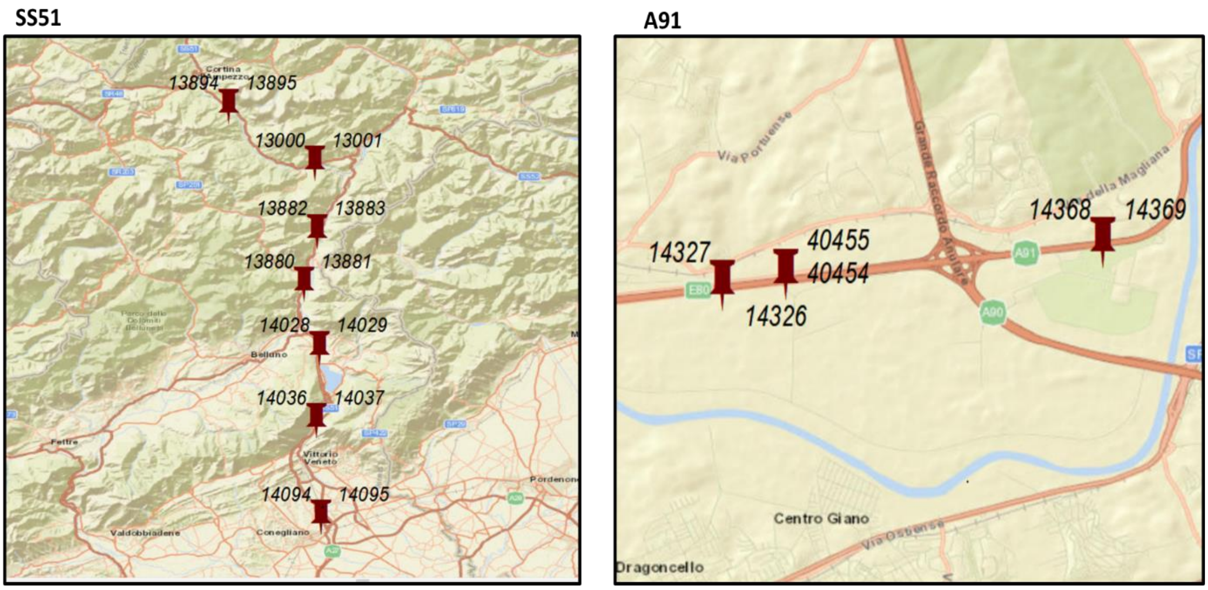

Figure 5. 1: Traffic counter positions on the highway

The traffic counters machines along the highway few are not functional and few of them are smart poles which were tested for few days to count the traffic flow on the Highway. So, the data on all the positions of the highway is not consistent so the data obtained by those traffic counters is not considered for the road capacity analysis and only the ones displayed traffic positions are considered for the analysis.

Then the traffic flow is extrapolated to the overall length of the highway that is 120km for SS51 and 17km for A91 highway. The traffic flow is plotted as a heatmap to visualize the maximum traffic flow over the period of 6 months from January to June. Also, the direction of traffic flow is considered and displayed in figure 5.2.

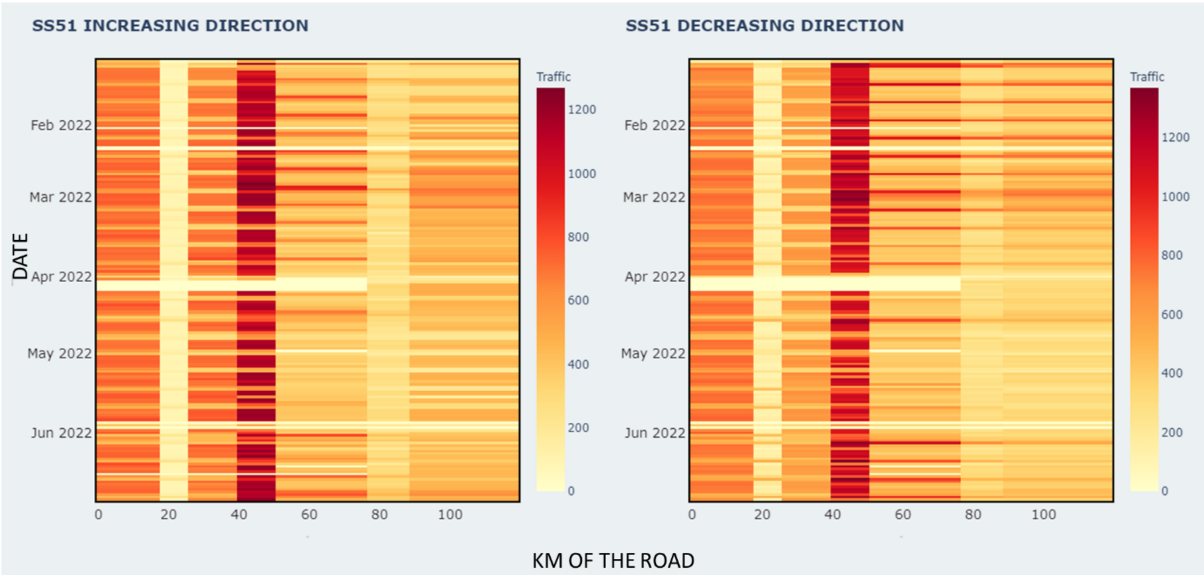

Figure 5. 2: Extrapolated traffic flow over the length of the SS51 Highway

From the image 5.2 the maximum traffic flow is seen at a distance for 40-50 km this is because of the road works that were in place on the highway in this region. The maximum traffic flow at an instance on the highway of SS51 in increasing direction is 1268 which is close to the capacity of the highway, which is 1300, and in decreasing direction the maximum traffic flow recorded is 1366 which is greater than the capacity of the highway.

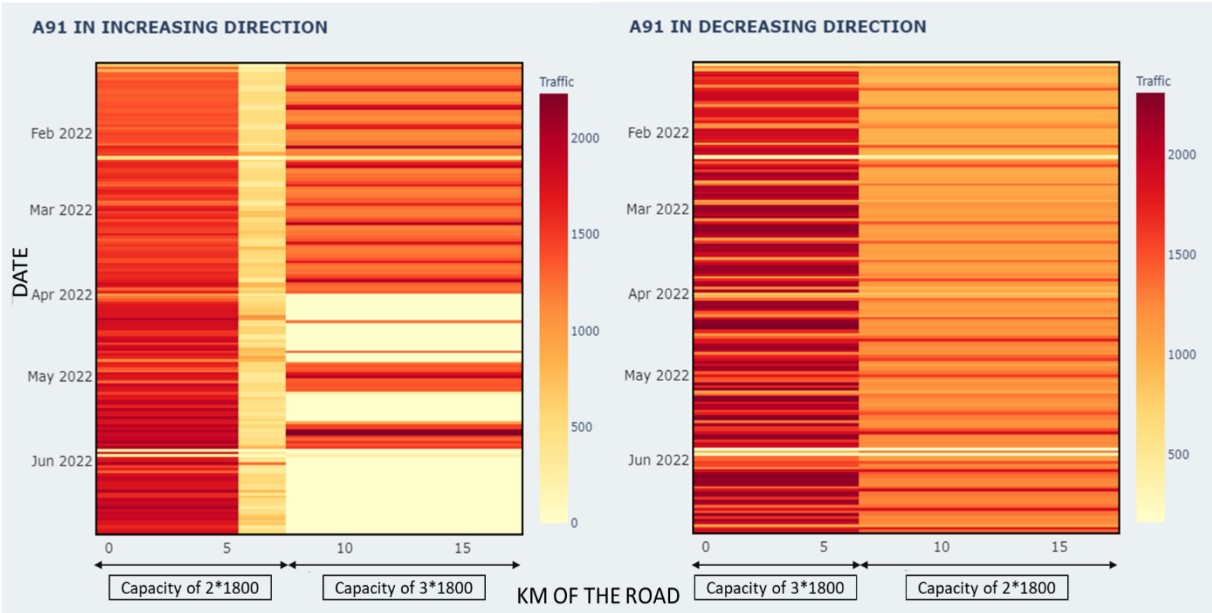

Figure 5. 3: Extrapolated traffic flow over the length of A91 Highway

The maximum traffic flows in an hour that has been recorded on A91 highway is 2229 in increasing direction but in the 3-lane road where each lane has a maximum capacity of 1800. In decreasing direction, the maximum traffic flow is 2311 which is also in the 3-lane with a maximum capacity of each lane as 1800 making it to an overall capacity as 5400.

5.1. Road occupancy level representation

Now to look at the road occupancy level of the highway we divide the traffic flow recorded by the capacity, and this gives the percentage of traffic flow whether it is free, slightly congested, or near to saturation.

$$\text{Traffic saturation} = \frac{Traffic\ flow}{Road\ capacity} \quad \text{(equation 1)}$$

If the traffic saturation is < 55% then it is displayed as Green,

traffic saturation is > 55% and < 95% then it is displayed as Orange,

traffic saturation is > 95% then it is displayed as Red.

The colour red represents the highway is highly saturated and amount of time spent on the road will be high, as if the saturation increases the speed decreases.
Using equation 1 the road occupancy levels are calculated and represented in the form of heatmap.

Figure 5. 4: Road Occupancy level representation of SS51 highway

From Figure 5.4 the traffic saturation on the highway is represented by red, orange, and green where green represents the free flow of the traffic, orange represents the saturation of greater than 55% and red represents the complete saturation of the traffic on the highway.

Now looking at the saturation levels on the highway of A91

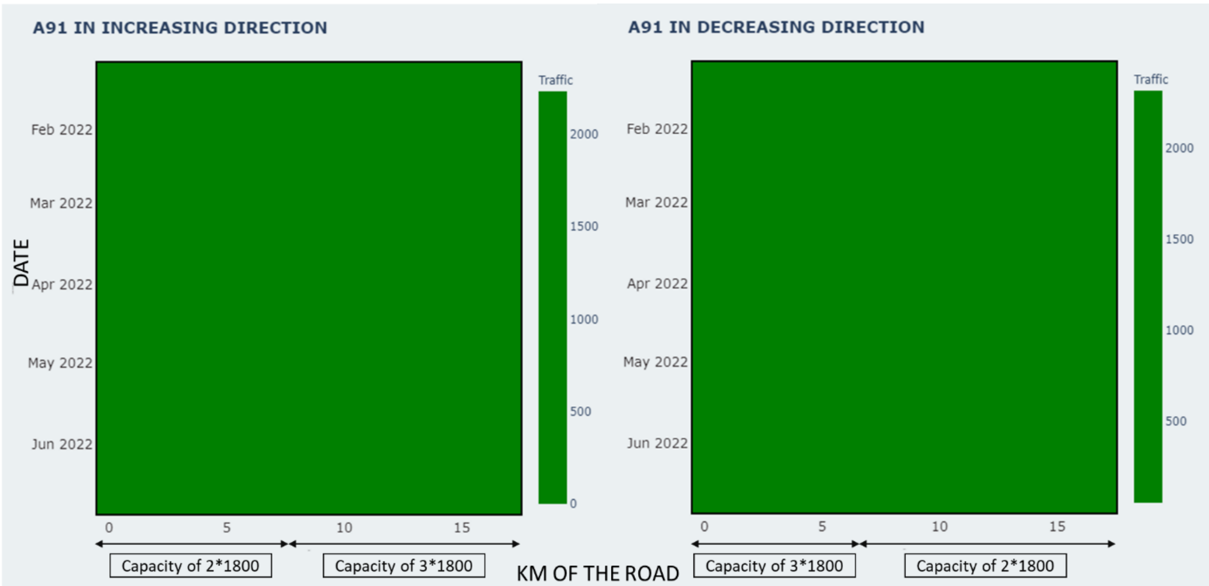

Figure 5. 5: Road Occupancy level representation of A91 Highway

From the figure 5.5 it can be seen that all the flows of traffic is below the 55% of the highway capacity this is because of the larger capacity of the highway and low occupancy. The A91 highway is not a typical highway but it connects the Rome city with the Roma Fiumicino airport. So, all the traffic on the highway is to access the airport and return from airport to the city of Rome. This is the reason for not having saturation on the A91 highway with wider multi-lane roads with capacity of 1800 per each lane.

6 Conclusion and future developments

Finally, this last chapter of the project presents the conclusions reached as a result of the research carried out on the Smart Road. Specifically, this section aims to determine both the conclusions obtained from the analysis carried out, broadly speaking, as well as the limitations detected in the research carried out and the future directions of the research that would seek to obtain more precise results and extend the level of knowledge in the paradigm of Smart Road that, progressively, is gaining greater relevance.

6.1. Analysis Conclusion

The idea of a smart road, or the "highway of the Smart Age," expands the capabilities of existing road infrastructures to better meet the demands of contemporary road users. The advancement of contemporary technologies based on information and communications technologies, including end-user Internet service systems, the Internet of Things, connection and cooperation services, big data, augmented reality, artificial intelligence, and edge computing has enabled the development of Smart Roads.

We have discussed the development of Smart roads, various definitions of smart roads based on the functionality and the technologies used. The main feature that enables safe travel to road users is the ability to communicate with the vehicles through messaging technology such as CAM and DENM. We have seen the functionality of CAM and DENM.

The major aim was to estimate the number of messages that will be generated on two different types of Italian roads, the A91 highway and the SS51 mountain road, managed by ANAS SPA.

The smart road infrastructure developed by ANAS and tests performed on the highway to test the functionality of smart infrastructure and the traffic flow data is used for estimation of the messages.

Through preliminary data analysis that is performed in chapter.3 we found that the data collected is not consistent as the tests were performed randomly on the highways and most of the data is focused on certain sections of the highway rather than distributed throughout the highway. So, we had to make certain assumptions such as all the vehicles to be connected, and 1 CAM message generated every second by a vehicle and 1% of CAM messages in an hour to be the DENM message. Using this we were able to compute the number of messages that will be generated on A91 and SS51 highway.

Highway	CAM + DENM messages/day
A91	0.94 billion
SS51	0.81 billion

Table 6. 1: Number of messages on A91 and SS51 per day.

The number of messages is estimated by the assumptions made. Later we looked at the messages generated by considering the connected vehicles growth. By using the data of connected vehicles we obtained the number of messages that will be generated on SS51 and A91 highway by the end of 2032. This data gives an insight for ANAS to make informed decisions about the infrastructure establishment to enable the storage and processing of the messages on highway year on year. The connected vehicle growth

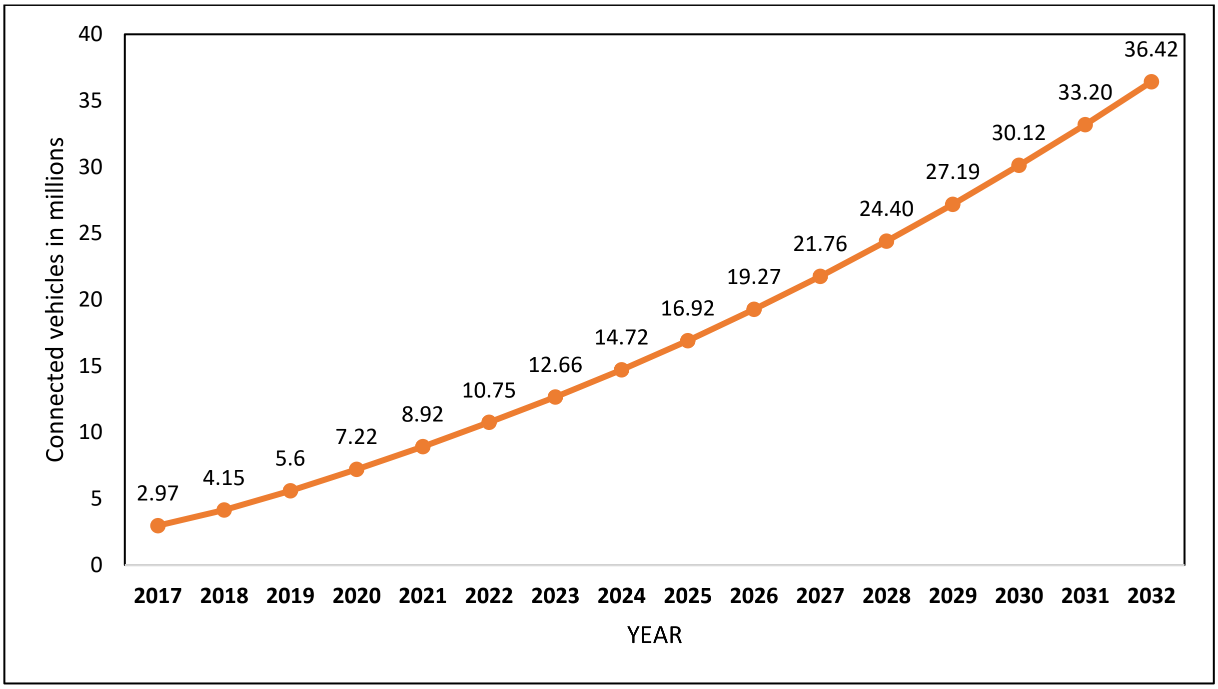

Figure 6. 1: Estimated connected vehicles growth by 2032 in millions.

By using the data from connected vehicles, the number of messages that these connected vehicles will generate on A91 and SS51 highway is considered by taking the percentage of vehicles on each highway.

Highway	CAM + DENM messages/year
A91	18.7 trillion
SS51	16 trillion

Table 6. 2: Number of messages on A91 and SS51 per year by connected vehicles.

With this we have obtained the results for the estimation of number of messages, but what does these values mean to ANAS SPA. As this information helps ANAS to decide upon the infrastructure required to be able to store the messages, process, and be able to communicate. This allows ANAS to decide the storage area that is required for storing the message data in the data storage area.

Figure 6. 2: IT infrastructure for cloud-based storage

Also, the computing power of the systems to be able to receive the messages, process the information in the message, communicate information with the neighbouring vehicles and the necessary authorities in case of accidents.

This estimation of infrastructure is based on the ANAS current infrastructure available, availability of the investment, technology access such as telecommunication network that provides Wi-Fi throughout the highway to be connected throughout the journey, and the goals and vision of the company.

Figure 6. 3: IT Infrastructure for cloud-based storage.

Using the data and by considering basic storage space of a message type and multiplying the number of messages generated by day the following results have been obtained.

Highway	Message storage space	Storage per day	Storage per year
A91	5 kb	4.7 Terabyte	1716 Terabyte

SS51	5 kb	4.05 Terabyte	1479 Terabyte

Table 6. 3: Estimated Storage space for CAM and DENM messages required.

The storage space for a single message of CAM and DENM is 5kb. This results are not a final output as it is a strategic decision to decide which kind of messages to be stored and the number of days the messages have to be stored. As CAM messages are just the position data which are shared by the vehicles and they don't have much importance to be stored for a longer time so these can be eliminated but in some cases these position data can be relevant in cases of any incidents. But, DENM messages are crucial as they share lot of information related to the highway maintainability so these have to be stored for a longer time. So, this evaluations of exact infrastructure and the time to store the messages will be developed in future.

6.2. Limitations

The analysis performed to estimate the number of messages is based on lot of assumptions. The results might just give an oversight of the situation, but the actual values might be a lot different. The primary assumption of overall vehicles to be connected gives a result that is over estimation of the actual scenario as it depends on various other factors such as policy, technology, cost of the vehicles, and people's choice of transportation. So, the results may not resemble the actual scenario.

The assumption of the growth of connected vehicles to follow the same growth rate as the previous years is also not an exact estimation. As the connected vehicles growth might increase over time with the EU policies, and the tech deployment by the vehicle manufacturers might increase the future growth.

The collection of CAM and DENM test data was also not useful, if the data had been more reliable with proper tests performed over all the positions of highway would give us a better estimation with the traffic flow data. Also the lack of speed data has limited to predict the number of vehicles at an instance on the highway and amount of time the vehicles on average spend on the highway that allows to estimate the number of messages that vehicle generates on the highway based on the time.

6.3. Future Developments

In order to correctly assess the infrastructure of the smart road network, more data is to be collected by testing with real time vehicles that are capable of communicating. With the real-time test data more informed and better results can be estimated. Also using the speed data to access the number of messages that a vehicle generates while travelling on the highway. By computing the average time, a vehicle spent on the highway we can obtain the message estimation.

Estimating the connected vehicles growth by considering multiple factors and making it by itself a whole thesis project. Later with the better estimates of the connected vehicles and the number of messages by considering the data and investment available much strategic business decisions about the infrastructure can be made.

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List of Abbreviation

IoT	Internet of Things
ICT	Information and Communication Technology
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
AI	Artificial Intelligence
C-ITS	Cooperative Intelligent Transportation System
TEG	Technology Energy Gate
TAP	Technology Access Point
DSRC	Dedicated Short Range Communication
LED	Light Emitting Diode
ETSI	European Telecommunication Standards Institute
CAM	Cooperative Awareness Message
DENM	Decentralised Environmental Notification Message
IVIM	Infrastructure to Vehicle Information Message
ANAS	Azienda Nazionale Autonoma delle Strade
Vas	Vehicular Accidents
MVC	Multiple Vehicle Collisions
EC	Edge Computing

CAV	Connected and Autonomous Vehicles
ERS	Electric Road Systems
mm	Milli Meter
km	Kilometer
RSU	Road Side Unit
OBU	On-Board Unit
V2I	Vehicle to Infrastructure
VANETs	Vehicular ad hoc Networks
V2N	Vehicle to Network
V2P	Vehicle to Pedestrian
GPS	Global Positioning System
DT	Digital Transformation
DC	Direct Current

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- **Manjith kumar reddy Sirigireddy**