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TRABAJO FIN DE GRADO

DEVELOPMENT OF AN AGENT-BASED SOCIAL SIMULATION SYSTEM FOR ANALYSING DRIVERS EMOTIONS AND THEIR IMPACT ON DRIVING BEHAVIOUR

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TRABAJO DE FIN DE GRADO

Título:	Desarrollo de un Sistema de Simulación Social Basada en Agentes para el Análisis de Emociones de Conductores y su Impacto en los Estilos de Conducción
Título (inglés):	Development of an Agent-based Social Simulation System for Analysing Drivers Emotions and Their Impact on Driving Behaviour
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Diego García Fierro

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Resumen

La conducción se considera por norma general una actividad racional. Desde el momento en el cual se fija el destino hasta el final del trayecto, la mayoría de las decisiones se toman siguiendo una explicación lógica. Sin embargo, existen múltiples factores que pueden interrupmir este comportamiento racional. Hay sucesos, o bien ligados a situaciones del tráfico o bien a otros conductores, que pueden tener una gran carga emocional para los conductores.

Se ha demostrado que las emociones tienen un efecto considerable en los estilos de conducción. Desde la felicidad o el exceso de confianza hasta el enfado o la ansiedad, se dice que las emociones pueden tener un gran impacto en ciertos rasgos de conducción como la velocidad, la aceleración o la frenada y, por lo tanto, en los comportamientos asociados a la conducción en general. En base a esto, el objetivo de este proyecto consiste en llevar a cabo un análisis de la influencia de las emociones en los estilos de conducción. Para ello, se propone un Sistema de Simulación Social basada en Agentes capaz de evaluar las interacciones que los conductores pueden tener en la carretera.

El desarrollo de este sistema es el propósito principal de este proyecto. El sistema de simulación debe ser capaz de analizar la forma de la que las emociones, la personalidad o el estrés condicionan la exhibición de ciertos estilos de conducción. Además, un modelo de estimación de riesgos de accidente se implementa como segunda parte de este proyecto. Estas dos partes del proyecto, aunque independientes la una de la otra, tienen un nexo de unión común: los estilos de conducción. La probabilidad de accidente de los conductores será estimada a través de la combinación de los rasgos de conducción predominantes que caracterizan a cada conductor y las distracciones que se puede encontrar durante el trayecto.

En resumen, este proyecto espera proporcionar un mayor entendimiento de la compljeidad asociada a la conducción así como de los numerosos factores condicionantes que pueden intervenir en el resultado de las decisiones tomadas durante la misma.

Palabras clave: Emociones, Personalidad, Estrés, Estilos de Conducción, Comportamiento durante la conducción, Riesgo de accidente, Modelado basado en Agentes, Modelo de Simulación, Distribución de Poisson

Abstract

Driving is in general considered a rational activity. From the moment a destination is set to the end of the ride, most decisions are usually made following a logical explanation. However, there are multiple factors that can interrupt this rational behaviour. There are events, produced by either traffic-related situations or by other road users, that can have intense emotional implications for drivers. The moment emotions are elicited and take over control, drivers' decisions become biased and susceptible to personal interests.

It has been proved that emotions have a considerable effect on driving styles. From happiness or overconfidence to anger or anxiety, emotions are said to have a big impact on driving features like speed, acceleration or braking and, therefore, on driving behaviour overall. Keeping this in mind, this project aims to analyse the influence of emotions in driving behaviour, characterizing the way a specific feeling can trigger different driving actions. In order to do that, an Agent-based Social Simulation System is proposed to evaluate the interactions that drivers can have while being on the road.

The development of this system is the main goal of this project. The simulation model must be capable of analysing the way emotions, personality and stress contribute to the exhibition of certain driving styles. In addition, an accident risk estimation model is implemented for the second part of this project. This two parts of the project, although independent of each other, have a common junction point: driving styles. The drivers' accident probabilities will be estimated through a combination of both the predominant driving traits that characterize each driver and the distractions that they might face during the performance of the driving task.

All in all, this project hopes to provide a deep understanding of the complexity of the driving task and the many conditioning factors that can change the outcome of driving decisions.

Keywords: Emotions, Personality, Stress, Driving Styles, Driving behaviour, Accident risk, Agent-based modelling, Simulation Model, Poisson distribution

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CHAPTER 1

Introduction

It is well-known that road accidents are one of the leading causes of death in the world. Approximately 1.35 million people die each year as a result of road traffic crashes and between 20 and 50 million more people suffer non-fatal injuries, with many incurring a disability as a result of their injury [5]. The analysis of driving styles and the factors that shape the way drivers behave while being behind the wheel, such as emotions, personality or stress, is a matter of great importance in road accident prevention.

Driving requires full physical, visual and cognitive focus. Nowadays, when talking about the factors or distractions that can affect driving performance, people usually picture drivers using mobile phones to talk or text. However, although the fact that emotions influence driving behaviour is often underestimated, the truth is strong positive and negative emotions can affect us physically and mentally and also dictate our behaviour, even more than mobile phone-related distractions do.

The term 'emotion' has been used to refer to mental and physical processes that include aspects of subjective experience, evaluation, motivation and body responses as arousal or facial expression [6]. Emotions play a significant role in humans' everyday lives, and they can seriously affect the mental process of decision making, shaping the performance humans display in every aspect of their lives. When it comes to drivers, reaction time is very short and decision making must be as effective and accurate as possible. While feelings and emotions like anger tend to provoke aggressive gestures, honking and even driving too fast, others such as happiness can incite an excess of confidence and relaxation [7]. Therefore, there is an evident relation between emotions and the way drivers perform on the road, which leads to think that a driver assistance model based on the analysis of both drivers' emotions and external factors is a viable scheme.

In the last years there has been a growing concern about the harsh consequences of driving and an increased level of interest in the traffic safety problem of car accidents. This line of research has mainly focused on human factors that are involved in car accidents, such as sociodemographic and general personality factors [8]. Personality represents the characteristic patterns of thoughts, feelings and behaviours that define a person and, consequently, it is trivial to acknowledge that it has a direct impact in daily tasks like driving. The same kind of reasoning applies to stress, although stress can come from a much wider variety of sources: work, family, health, economical situation, etc.

The human factor in driving consists of two elements: driving skills and driving style. While driving skills are characterized by a person's innate abilities to drive, driving style refers to the way a person chooses to drive or to their customary driving mode, including features such as speed, headway and habitual levels of attentiveness and assertiveness [9]. Keeping this in mind, the goal of this project is to propose a way of understanding why driving is such a complex exercise, since so many factors can contribute to the performance that drivers display on the road.

Nevertheless, not only does road safety depend on elements that have an internal effect on the driver's mind, but it also relies on the intrinsic capacity of the driver to keep attention. Distractions are one of the main causes of road accidents in the world [5], and it is imperative to bring awareness about how some of them, even answering a simple phone call, can have terrible consequences for drivers.

Modelling human behaviour is an extremely complex task. Over the last few years, social simulation technologies have become increasingly popular, but there are not many simulation models that are able to provide a proper representation of the human mind effect on driving. This project aims to address these challenges by proposing an Agent-based Social Simulation System to analyse the impact of drivers emotions and some other factors on driving behaviour. This kind of computational models provide a simulation tool to evaluate the interactions of different autonomous agents with one another and with the environment that surrounds them, which suits perfectly with the driving problem being addressed in this project. Drivers in the system are characterized by emotions, personality traits and stress, factors that have a direct effect on driving features such as speed or response time. Besides, a model for accident risk estimation is presented taking both driving styles and distractions as contributing elements.

Taking this into consideration, the following model has been designed in a hopeful attempt to create a system that provides useful information related to driving styles and the accident probability that comes along with them.

1.1 Project goals

This project aims to create an Agent-based Social Simulation System that allows researchers to make a thorough analysis of the impact that several factors can have on driving styles. Among these factors, emotions are the main focus, but personality traits and stress are also taken into account when evaluating the way driving traits are influenced. The designed model takes the emotions, personality and stress values that characterize drivers in order to assign driving profiles that include the expected speed, acceleration, braking, steering wheel movement and response time for a specific driver.

Besides, this project aims to take this analysis even further so that driving styles, conditioned by all the factors that have already been mentioned, help to estimate the accident risk that drivers might suffer. Other external factors such as distractions or alcohol/drug consumption are considered as well in the accident probability appraisal.

In order to achieve these objectives, the following procedure has been undertaken:

- Study of the State of Art about the relation of emotions, personality traits and stress with driving styles.

- Compilation of articles and datasets that provide enough evidence for the algorithm design in a later stage.

- Development of the Agent-based Social Simulation System. The system includes the accident probability module that estimates the crash risk drivers have at a specific moment during the simulation.

- Analysis of the results obtained from the Simulation Model by means of graphic tools.

1.2 Structure of this document

In this section, a brief overview of the chapters included in this document is provided. The structure is as follows:

Chapter 1. Introduction. This chapter provides a general introduction of the project by analyzing the impact of several factors in driving behaviour. Moreover, the project goals and the structure of the present document are included in this chapter as well.

Chapter 2. State of the Art. This chapter provides an overview of the current State of the Art, focusing on the main characteristics of the proposed model an the enabling technologies of the project.

Chapter 3. Simulation Model. This chapter describes the way the Simulation Model has been designed to achieve the proposed objectives.

Chapter 4. Architecture. This chapter covers the implementation of the Simulation Model.

Chapter 5. Results. This chapter provides a thorough analysis of the results collected after the simulations and explains the main reasons why these results might have been obtained.

Chapter 6. Conclusions and future work. This chapter goes through the main conclusions reached after the completion of the project and the future steps that might be followed later on.

Appendix A. Impact of the project. This appendix describes the social, economic, environmental and ethical implications of the project.

Appendix B. Economic budget. This appendix goes into detail about the economic budget required to implement the project.

CHAPTER 2

State of the Art

2.1 Introduction

In order to accomplish the goals of this project successfully, it is vital to analyze and study the State of Art. There are multiple approaches and theories regarding the way emotions, personality and stress have an impact on driving behaviour. With regards to the accident risk estimation, this chapter digs deep into the main causes of traffic accidents as well as how distractions can actively lead to dangerous situations on the road. Furthermore, the most popular technologies for agent-based modelling are also covered in this chapter.

2.2 Emotions

Drivers can experience a wide variety of emotions that have a direct impact on their driving performance: joy, distress, happiness, pity, gloating, resentment, hope, satisfaction, relief, disappointment, etc., are some of them. Multiple emotion classification theories have emerged over the years in an attempt of getting a deeper understanding of the human mind and its role in activities like driving. The OCC model describes a hierarchy that classifies 22 emotion types. The hierarchy contains three branches: emotions concerning consequences of events (e.g., joy and pity), actions of agents (e.g., pride and reproach) and aspects of objects (e.g., love and hate) [10]. The model was created by Ortony, Clore and Collins, and in [1] they describe the structure of the model, the eliciting conditions of emotions and the variables that affect their intensities.

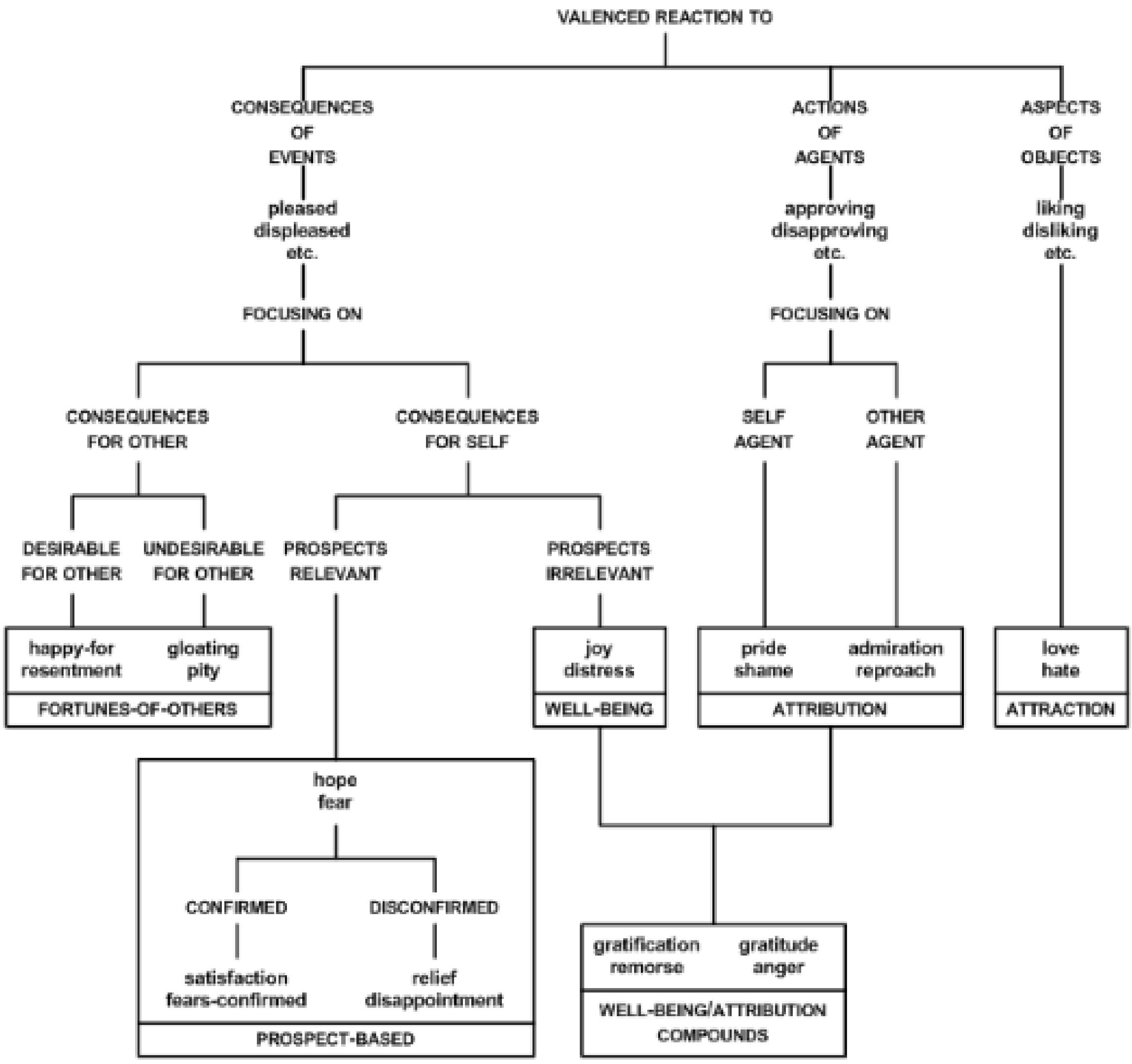

Figure 2.1: Structure of emotions of the OCC model [1]

However, the OCC model is one of the many classification theories of emotions. Another remarkable theory is Robert Plutchik's, which proposes the existence of eight basic emotions: joy, trust, fear, surprise, sadness, disgust, anger, and interest, that are the main emotions from which the rest derive depending on their intensity [11].

With regards to emotion detection, facial expressions usually give away the emotions that a person is feeling at a specific moment. Moreover, multiple emotions can be identified through the analysis of head poses, eye movements, nose positions or even mouth and eyebrow grimaces. For that purpose, some works [12, 13] are dedicated to the image acquisition of facial expressions in order to detect emotions that can cause driving stress or certain behaviours while performing driving tasks. Other works such as [14] combine the facial detection with data from the steering wheel movement or the vehicle's acceleration to determine emotions that drivers might be feeling.

There are numerous research that take a different approach and deepen the influence of emotions on driving styles. Although most studies [7, 15, 16, 17, 18] are based on driving simulators that record driving patterns after the elicitation of specific emotions, some other works [19] take it further and carry out real driving experiments or even compare the participants' performance in both real and virtual driving experiments [20].

Roidl, Frehse and Högernger proved in [7] that anger, contempt, anxiety and fright are some of the most important emotions influencing driving performance in various ways during traffic situations, with immediate effects including changes in acceleration and velocity directly after the emotion eliciting sequence. In [19] the frequency, determinants and consequences of three relevant emotions in traffic (anger, anxiety and happiness) were investigated, with results showing that anger was mostly associated with progress-related events, for which another driver was usually responsible, and anxiety was mostly linked to safety-related events, for which a traffic situation was responsible. Recent research has also covered how emotions (anger, calmness or happiness) can impact on other driving traits such as steering variability or reaction time [15].

Finally, there are works that propose more complex models to analyze the relation between emotions and driving behaviour. In [18] a representation of the human mind with four mental subsystems is suggested: personality, rational cognitive, affective and decision making. According to the article, decision making is influenced by the innate action tendency of the individual, with the personality system contributing to the transfer into action of the decision dictated by rational and emotional reasoning.

2.3 Personality

Personality has a direct association with the way humans behave and perform daily tasks such as driving. There is an evident correlation between personality and driving styles, and research on driving behavior and personality traits is a key factor in the development of driver-oriented safety interventions [21].

Multiple approaches can be taken when evaluating the human personality. The Big Five Personality Traits [2] is a model which states that personality can be configured based on five core factors: extraversion, agreeableness, openness, conscientiousness and neuroticism. Extraversion reflects the tendency and intensity to which someone seeks interaction with their environment, particularly socially. Agreeableness refers to how people tend to treat relationships with others. Openness refers to one's willingness to try new things as well as engage in imaginative and intellectual activities. Conscientiousness describes a person's ability to regulate their impulse control in order to engage in goal-directed behaviours, and neuroticism describes the overall emotional stability of an individual through how they perceive the world.

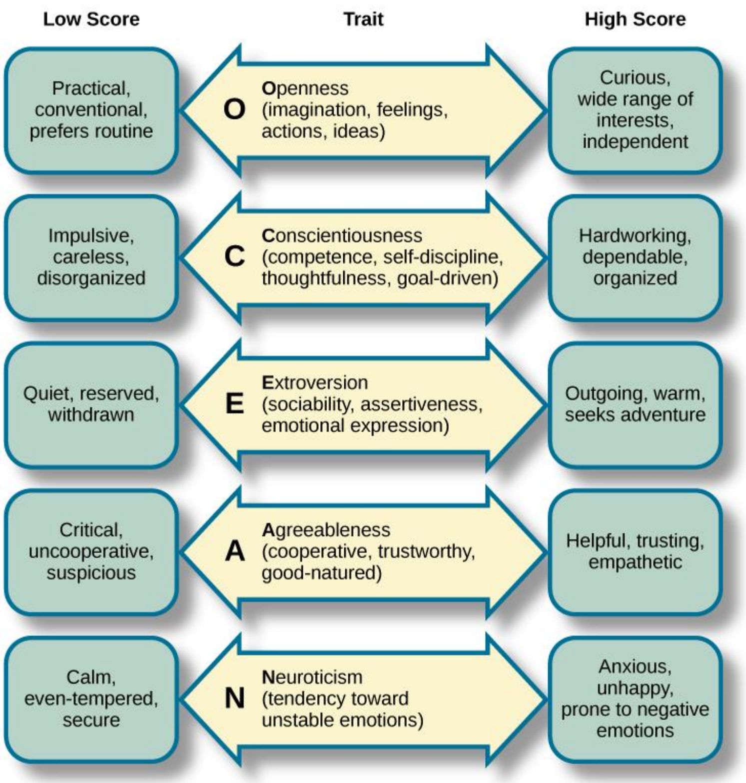

Figure 2.2: The Big Five Personality Traits [2]

However, there are many other famous approaches such as the Dark Triad of Personality [22] or some attributes like sensation seeking, aggression or impulsivity that define the human personality. The Dark Triad is formed by the personality traits of narcissism, machiavellianism and psychopathy.

When it comes to personality and driving styles, most studies [23, 24, 25] are dedicated to the analysis of theories that relate certain types of personalities with aggressive and dangerous driving behaviours. Other works [8, 26, 27] pay more attention to the Big Five Personality Traits and how they can be associated with several driving styles. In [8] the Big Five factors are correlated to speeding, drink driving and distracted driving. Orit Taubman-Ben-Ari and Dalia Yehiel suggest in [26] that the combination of the Big Five personality dimensions can result in different driving styles: reckless, angry, anxious and careful, with different driving traits being described for each style. The research carried out in [27] proposes exactly the opposite, predicting a driver's personality from daily driving behaviour.

2.4 Stress

Previous research has shown the association between stress and driving. Most works focus on the multidimensional nature of driving stress, trying to understand the main causes that produce stress and how it affects driving performance [28, 29]. Another work [30] studies the effects of divorce procedures on emotional stress and driving, suggesting that the accident rate was significantly higher after filing the divorce petition than the average accident and violation rates.

Nevertheless, there are articles that conclude that stress usually manifests as anger or anxiety on the road. Work stress has the potential to influence the frequency and intensity of anger experienced whilst driving, with perceived incidents of driving anger, aggression and 'road rage' on the rise [31]. The results of [32] highlight the need to integrate stress management and anger management when considering driving safety and any associated interventions, and the work carried out in [33] demonstrates that stress history is one of the main factors contributing to anxious driving.

2.5 Accident risk estimation

Numerous research on driving accidents has been conducted over the past few decades. While analysing the causes of driving accidents may seem like the most obvious thing to do, the truth is there are many more approaches that have been taken lately in search of a way of reducing driving accident rates. Looking into the relation between driving styles and accidents is one of these options. Moreover, there are many works [34, 35, 36] which suggest that driving traits such as speed, acceleration, braking, steering or response time have a direct implication on driving accidents. Speed is evaluated in [35], finding a positive relationship between speed and traffic injuries. Drivers apply brakes to reduce the speed of a vehicle based on the perceived risk while approaching a certain event. However, inadequate or excessive braking can lead to serious consequences [34], and the same applies to the intensity of maneuvers that are carried out in order to avoid accidents [36].

With regards to driving distractions, they represent one of the biggest threats for drivers while being on the road. There exist plenty of articles that provide an insight into how distractions affect driving performance. For example, the trends in distracted driving fatalities and their relation to cell phone use and texting volume are examined in [37], and a direct association between distraction and the type of crash drivers can have is established in [38]. What's more, the study conducted in [39] proposes a ranking with the most relevant distractions drivers can suffer, including mobile phone usage, looking for objects, eating, drinking, smoking, hands-free usage or talking to other passengers. Alcohol, drugs or drowsiness could also be considered potential causes of driver distraction, as stated in [40, 41].

In this line of work many studies have proposed more complex schemes to take into account as many accident related factors as possible. The World Health Organization published learning material in order to bring awareness about risk factors for road traffic injuries [42]. This learning material included a brief explanation about the Haddon Matrix [4]. William Haddon developed a model with the purpose of identifying risk factors before a crash, during a crash and after a crash, in relation to the driver, the vehicle and the environment. The model represents an analytical tool to help with the prevention processes that are implemented for accident avoidance.

		Factors		
Phase		**Human**	**Vehicles and equipment**	**Environment**
Pre-crash	Crash prevention	Information Attitudes Impairment Police enforcement	Roadworthiness Lighting Braking Handling Speed management	Road design and road layout Speed limits Pedestrian facilities
Crash	Injury prevention during the crash	Use of restraints Impairment	Occupant restraints Other safety devices Crash protective design	Crash-protective roadside objects
Post-crash	Life sustaining	First-aid skill Access to medics	Ease of access Fire risk	Rescue facilities Congestion

Table 2.1: The Haddon Matrix [4]

Research carried out in [43, 44] deepen the contributory factors of road accidents as well. In [43] risk factors are classified depending on the age of drivers: factors such as inexperience, lack of skill and risk-taking behaviors are associated with the collisions of young drivers and, in contrast, visual, cognitive and mobility impairment are associated with the collisions of older drivers. The work in [44] suggests a list of precipitating factors related to accidents.

All things considered, most works aim to explain the origins and causes of driving accidents or even propose systems for accident prevention, but there is not much research conducted on the estimation of accident probability based on driving styles and distractions. Fortunately, this topic has been considered in other sectors such as the construction industry. [45] suggests a method to determine accident probability in the construction industry. The approach takes into account an extensive dataset of actual construction accidents and the construction jobs that workers were carrying out when they had an accident. By means of the Poisson distribution, accident probabilities are calculated using accident rates as distribution parameters. This is the method used in the Simulation Model to estimate the accident probability of drivers, as well as a dataset of driving accidents that took place in the city of Las Vegas between the years 2015 and 2018 [46].

2.6 Agent-based Simulation Technologies

This section provides a brief description of the technologies that allow to implement the project. The Agent-based Social Simulation System is programmed with Python. Specifically, the implementation is carried out through Python's MAS simulation package Mesa.

2.6.1 Python

Python [47] was created back in 1991 by Guido van Rossum and it has nowadays become the most popular programming language in the world. Supported for applications going from advancement scripting to procedure mechanization, Python rapidly turned into the primary choice for Artificial Intelligence problems. Among its many advantages it is important to highlight its unique library environment, its adaptability, its stage freedom and the community support surrounding the language.

In this project, Python is used for the implementation of the Agent-based Social Simulation system.

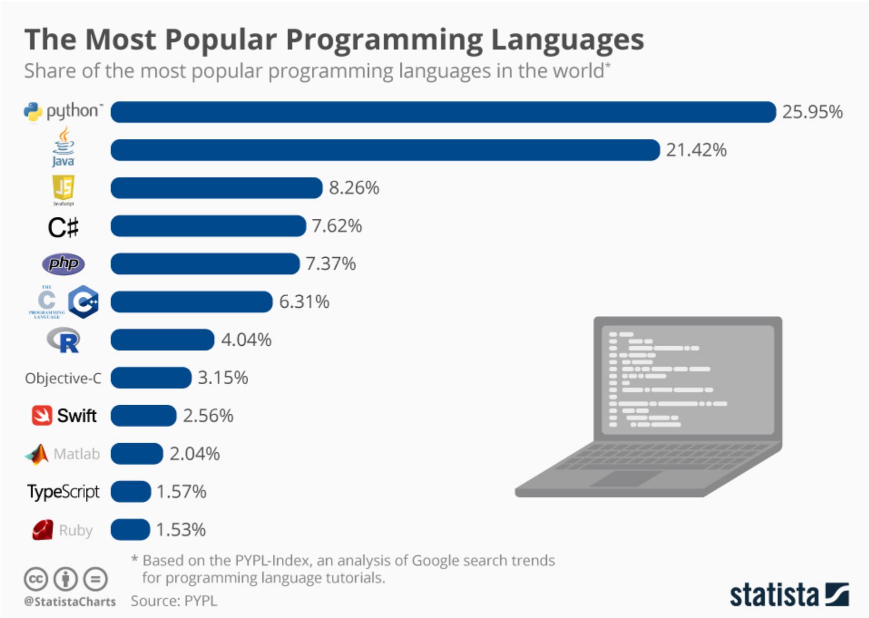

Figure 2.3: The Most Popular Programming Languages [3]

2.6.2 Mesa

Mesa [48] is an open-source, Apache 2.0 licensed Python package that allows users to quickly create agent-based models using built-in core components or customized implementations, visualize them using a browser-based interface and analyze their results using Python's data analysis tools.

The modeling components are the core of what is needed to build a model: a Model class to store model-level parameters and serve as a container for the rest of the components, one or more Agent classes which describe the model agents, a scheduler which controls the agent activation regime and handles time in the model in general, and components describing the space and/or network the agents are situated in. The analysis components are the data collectors used to record data from each model run, and batch runners for automating multiple runs and parameter sweeps. Finally, the visualization components are used to map from a model object to one or more visual representations.

In this project, every Mesa component is utilized except the space where the agents are supposed to be situated and where they perform their actions. The reason why no space is implemented in the Simulation Model relies on the fact that the data for the results validation comes from very different sources, each one of them under different conditions that no single space could fulfill at the same time.

2.6.3 Matplotlib

Matplotlib [49] is a 2D graphics Python package used for application development, interactive scripting and quality image generation across user interfaces and operating systems. This comprehensive library was created by John Hunter in 2003, and it is inspired by MATLAB visualization tools. It contains many internal resources that allow researchers to plot very different visualization graphs (bar charts, pie charts, area charts, line plots, etc.).

In this project, Matplotlib has been used in the Visualization component of the Simulation Model, since it was necessary to plot the results obtained after each run of the model.

CHAPTER 3

Simulation Model

3.1 Introduction

This section is focused on the analysis of the Simulation Model's Agents. Firstly, a general description of the simulation performing actors (driving agents) and the design process to define them is presented. Secondly, the Agent behaviour policies that allow the Model to fulfil its main goals is described.

3.2 Agent design

In Agent-based modelling, **Agents** can be used to represent a vast variety of entities: from living cells, animals or individual humans to even entire organizations or abstract entities. The following Simulation Model proposes a representation of drivers through Agents (drivers of all kind of vehicles, although most research conducted on this field is done over cars).

Therefore, Agents are the key elements of the Simulation Model, designed to get a deep understanding of how the individual characteristics of each driver behave, and allowing to see what system-level effects emerge from their interaction.

Driver Agents have many attributes. Firstly, drivers can only experience a single emotion at the same time. There are plenty of emotion representations such as the OCC Model [1], which describes a hierarchy that classifies 22 emotion types, but attending to the literature review and the project's context only 4 emotions are considered in the Model: **happiness**, **fear**, **anger** and **anxiety**. These are the most frequent emotions that drivers experience [7, 15], either elicited before the actual driving task or right after any driving related event.

Secondly, each driver is characterized by a personality profile. In order to achieve an accurate representation of all the personality dimensions that define the behaviour of a driver, the Big Five Personality Traits model [2] is adopted. Hence, a driver's personality can be described by the values scored in **extraversion**, **agreeableness**, **conscientiousness**, **neuroticism** and **openness**. Each one of the personality traits is associated with a different personality dimension: extraversion is related to sociability, assertiveness or emotional expression; agreeableness to cooperativeness, trustworthiness or good-nature; conscientiousness to competence, self-discipline or thoughtfulness; neuroticism to the tendency towards unstable emotions; and openness to the imagination, actions or ideas.

Apart from emotions and personality traits, stress is another attribute of Driver Agents. Stress can influence Agents in three different ways: **anger related stress** [31], **anxiety related stress** [33] or **no stress**. It is trivial to think that anger-related stress has a similar influence on drivers as an angry emotional state, the same way that anxiety-related stress is correlated to anxious emotional states.

All these factors together (emotions, personality and stress) can shape the way drivers behave on the road, as will be explained later. Therefore, Driver Agents are defined with specific driving traits that characterize their driving styles: **speed**, **acceleration**, **braking**, **steering** and **response time**. The literature reviewed on the most relevant emotions that affect driving styles is really heterogeneous. Most works establish their own simulation environment with different driving conditions, which means that there is no general consensus that can be followed in the present project. For that reason, a list of intensity levels for driving traits is defined in this project, implying that no numeric values (speed, acceleration, response time, etc.) are considered to analyse the influence of emotions, personality or stress on driving behaviour. Table 3.1 describes the adopted levels for each driving trait.

Driving trait	Value	Description
Speed	Slow Appropriate Fast	General tendency in speed values.
Acceleration	Slow Appropriate Fast	Intensity and suddenness when accelerating.
Braking	Gentle Abrupt	Intensity and suddenness when braking.
Steering	Low High	Movement of the vehicle's wheel.
Response time	Low High	Response time in stress-related situations on the road.

Table 3.1: Driving traits for each Driver Agent

Once driver's styles have been outlined, the purpose of the Simulation Model is to make an accident risk estimation. For that reason, each driver is designed with two more attributes: a **distraction** value and the **accident probability** the driver has during each step of the simulation. The distraction value only indicates whether any interference is actually taking the driver's attention away from the driving task, disregarding its origins or what could possibly could be causing it (mobile phone, road signs, other passengers, alcohol, drugs, fatigue...).

3.3 Agent behaviour

The Agent-based Social Simulation System aims to illustrate the effect of emotions, personality and stress on driving styles, as well as making an accident risk estimation based on driving behaviour and the presence of distractions. In order to achieve that goal, Driver

Agents must be designed along with some behaviour policies that model the evolution of driving styles and accident probabilities throughout the simulation.

These **behaviour policies**, described in the present section, are expected to interact with one another as shown in Figure 3.1 to fulfill the Model's objectives.

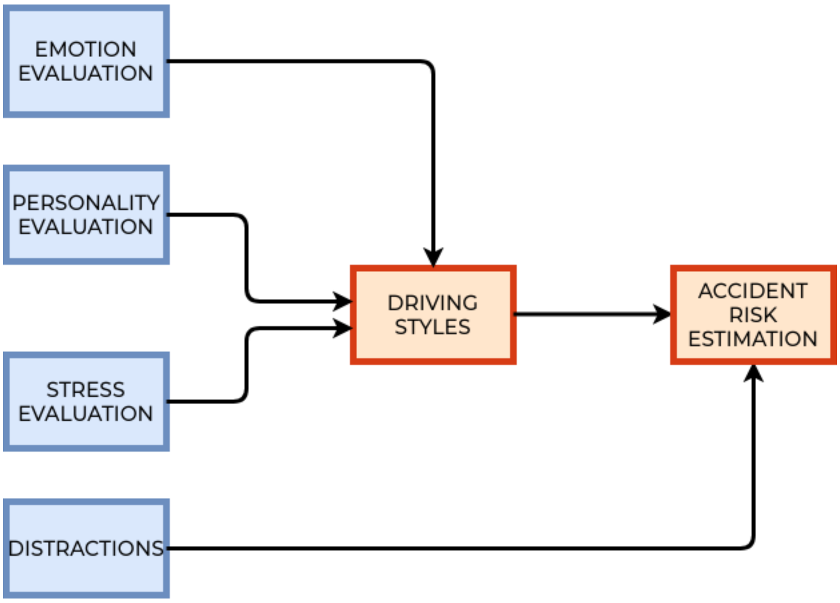

Figure 3.1: Behaviour policies and Model's goals

3.3.1 Emotion evaluation

Understanding how emotional states influence driving behaviour is crucial to determine the current state of the driver. Studies on emotional effects on driving behaviour are very heterogeneous: each work focuses on different emotions and results show significant variability. However, this can easily be explained, since multiple emotion elicitation methods which differ in the extent to which they distract attention can be employed [15].

As mentioned before, 4 emotions (happiness, fear, anger and anxiety) are considered in the Simulation Model. Each emotion is designed to have a specific effect on Driver Agents so that the driving traits that characterize drivers (speed, acceleration, braking, steering and response time) are shaped during the simulation.

With regards to **happiness**, the way it affects driving behaviour is probably the most positive for driving safety, at least when compared to the rest of the emotions included in the Model. Several simulation experiments [15] have been carried out to conclude that happiness stimulates appropriate speed and acceleration values, adapted to road and traffic conditions. At the same time, happiness increases the driver's tendency to make gentle use of the brake pedal and a soft handle of the steering wheel. Response time, however, might be increased when the driver experiences a feeling of happiness since it can induce a state of relaxation and calmness that affects the driver's reactions, making them slightly slower.

Another frequent emotion that drivers feel while driving is **fear**. Unlike happiness, fear is usually elicited after driving-related events, which means it depends on traffic conditions. The immediate effect of fear is a considerable reduction in both speed and acceleration values, as well as a stronger braking [7]. Response time tends to decrease due to a bigger safe distance selection [20], but no clear association is established between steering and fear.

On the other hand, **anger** and **anxiety** provoke similar behaviours in drivers. While anger is related to more perceived controllability which leads to optimistic risk appraisals, anxiety makes driving traits fluctuate constantly. In both cases, speed and acceleration increased after the emotion elicitation [7, 15, 20]. When it comes to steering, research shows that anger and anxiety are considered as negative emotions and steering is performed in an exaggerated manner [17]. Braking is more abrupt in the case of anger [7], but no clear association is established between braking and anxiety. Lastly, response time is different for each emotion: anxiety tends to increase drivers' response time and anger usually reduces it [15, 20]. Nevertheless, the fact that speed increases considerably when a driver feels anger might produce the opposite effect on response time. For that reason, anger can result in lower response times or its effect can be compensated by high speeds, it all depends on traffic conditions mainly.

These guidelines have been taken into consideration during the design of the Simulation Model. The contribution and effect of emotions on driving styles are summarized in the following table:

Driving trait	**Emotion**			
	Happiness	**Fear**	**Anger**	**Anxiety**
Speed	APPROPRIATE	SLOW	FAST	FAST
Acceleration	APPROPRIATE	SLOW	FAST	FAST
Braking	GENTLE	ABRUPT	ABRUPT	—
Steering	LOW	—	HIGH	HIGH
Response time	HIGH	LOW	LOW/—	HIGH

Table 3.2: Emotion contribution to driving traits

3.3.2 Personality evaluation

In order to analyse the impact of human personality in driving behaviour, the Big Five Personality Traits approach [2] is adopted. According to the mentioned model, human personality can be described through five different attributes that cover pretty much every dimension of human's mind: **extraversion**, **agreeableness**, **conscientiousness**, **neuroticism** and **openness**.

However, the proposed Simulation Model requires an association between driving styles and the Big Five Personality Traits, not just any model that describes human personality. Research conducted in [26] managed to correlate a group of four driving styles conceptualized in the multidimensional driving style inventory (MDSI) with various demographic and personality variables:

- **Reckless style**. This style refers to careless drivers who are characterized by deliberate violations of safe driving norms and thrill-seeking while driving. High speed or illegal passing are two of the most common actions for reckless drivers.

  Reckless driving presents a positive correlation with extraversion and neuroticism and a significant negative association with agreeableness and conscientiousness. Openness and reckless driving do not share a relevant correlation.

  Bearing this in mind, reckless drivers are expected to record high scores in speed and acceleration, the same way braking and steering are careless and abrupt. Therefore, response time is conditioned by the rest of the driving traits and it remains high for reckless drivers.

  Nevertheless, reckless driving does not necessarily imply that driver behaviour is characterized by high speeds and irresponsible attitudes. A driving profile that stands out for slow scores in speed and acceleration and consequently for low response times can also be considered as reckless driving, as long as it interferes with the regular traffic flow or minimum speed limits of a road.

- **Anxious style**. This style relates to feelings of alertness and tension, along with ineffective relaxation activities when driving.

  A significant positive correlation is found between anxious driving and neuroticism, but negative associations emerge between agreeableness or conscientiousness and anxious driving, specially with conscientiousness. The anxious style relates positively to openness and it does not present a clear association with extraversion.

  All in all, the anxious style conditions driving behaviour in a similar way as the anxious emotion does. Anxious drivers are expected to score high in both speed and acceleration, with an exaggerated steering and considerable high response times. Braking does not share any specific connection with anxious driving.

- **Angry style**. This driving style refers to expressions of irritation, rage and hostile attitudes and acts on the road. The angry style is typified by a tendency for aggressive behaviour, such as cursing or flashing lights at other drivers.

  The examination of the correlations between the angry style and the Big Five Personality Traits shows significant negative correlations with agreeableness and conscientiousness. While neuroticism is associated positively with angry driving, openness presents a slightly negative relation and extraversion is not clearly linked to this driving style.

  As it happened between the anxious style and anxiety, the angry style and anger have the same effects on driving traits. Speed and acceleration are usually influenced in the same manner and the angry style contributes to a tendency to score high values for these driving traits. Braking is expected to be abrupt and steering is specially frantic. With regards to response time, the fact that angry drivers are seething makes their attention rise considerably, and low response times are found sometimes. However, since fast driving produces exactly the opposite effect on response times, low response time can sometimes be countervailed by high scores in speed. Therefore, an angry style might cause a low response time or it could simply not affect drivers' response time.

- **Careful style**. This style refers to adaptive drivers who usually plan their travels ahead, pay attention to the road and are characterized by patience, courtesy, calmness and obedience to traffic regulations.

  The careful style correlates positively with most of the personality traits, specially with agreeableness, conscientiousness and openness. Neuroticism, as expected, shows a negative correlation with patient drivers.

  In conclusion, careful drivers display a good responsible performance when they are behind the wheel. Speed and acceleration values are appropriate and adapted to traffic conditions, braking is gentle, steering ensures comfortable driving and response times are low because of the driver's high attention on the road.

These are the only personality profiles considered in the Simulation Model since they are the only ones with a coherent correlation with driving styles. The impact that each profile can have on driving traits is summarized in the following table:

Driving trait	Personality profile			
	Reckless style	**Anxious style**	**Angry style**	**Careful style**
Speed	FAST/SLOW*	FAST	FAST	APPROPRIATE
Acceleration	FAST/SLOW*	FAST	FAST	APPROPRIATE
Braking	ABRUPT	—	ABRUPT	GENTLE
Steering	HIGH	HIGH	HIGH	LOW
Response time	HIGH/LOW*	HIGH	LOW/—	LOW

*Reckless style can include both types of driving (too fast and aggressive or too slow for traffic flow).

Table 3.3: Personality contribution to driving traits

3.3.3 Stress evaluation

Stress, as well as emotions or personality, can influence the way drivers behave on the road. Driver Agents in the Simulation Model include a stress attribute to help compute the impact of stress in driving traits. For the purpose of this project, two different interpretations of driving stress are adopted: **anger-related stress** and **anxiety-related stress**. Besides, Driver Agents can **avoid stress** and no effect is considered on driving styles in that case.

Stress has the potential to influence the frequency and intensity of anger experienced while driving. An inability to deal with stress has been shown to increase drivers' potential to experience driving anger and aggression, but **anger-related stress** does not necessarily have to occur while driving [31]. In the Simulation Model, anger-related stress is computed almost as if the driver was dealing with anger: speed and acceleration values tend to increase, the brake pedal is handled abruptly and the steering wheel movement becomes frantic. Response time, on the other hand, is not affected by anger-related stress. Unlike what happened with anger and the angry personality profile, anger-related stress is not designed to have the option to reduce response times. The reason behind that decision relies on the fact that anger-related stress is commonly associated with aggressive behaviours on the road, which implies that high speeds prevail over the high selective attention that drivers demonstrate under anger conditions.

In addition to anger-related stress, Driver Agents can also be influenced by **anxiety-**

related stress. Anxiety-related stress could be caused either by driving events or by the individual's life stress history [33]. The influence of this kind of stress in driving behaviour has plenty of parallelisms with anxiety itself: speed and acceleration increase, steering is frantic and clumsy and reaction time is high compared to non stressed drivers. Braking has no clear association with anxiety-related stress.

The following table represents a compilation of all the driving contributions that both types of stress considered in the Model can have in Driver Agents:

Driving trait	Stress	
	Anger-related	Anxiety-related
Speed	FAST	FAST
Acceleration	FAST	FAST
Braking	ABRUPT	—
Steering	HIGH	HIGH
Response time	—	HIGH

Table 3.4: Stress contribution to driving traits

3.3.4 Accident risk estimation

Once driving styles have been characterized, the Simulation Model is able to proceed with the Driver Agents accident risk estimation. For this purpose, both driving styles and distractions are considered.

A road traffic crash results from a combination of factors related to the components of the system comprising roads, the environment, vehicles and road users and the way they interact [42]. Previous research has been conducted on the main causes for road accidents and even some systems for accident prevention have been developed [6], but there is not general concord on an approach for traffic accident risk estimation.

Despite that, there is a way of estimating accident probability that suits this Simulation Model perfectly: the **Poisson distribution** model [45]. The Poisson distribution is a discrete probability distribution that can be used to calculate the probability of a number of event occurrences during a specific time slot. The probability mass function of a Poisson discrete random variable has the following mathematical expression:

$$f(k;\lambda) = Pr(X = k) = \frac{\lambda^k e^{-\lambda}}{k!} \tag{3.1}$$

Where k represents the number of ocurrences of the event ($k = 0, 1, 2...$), λ is the occurrence rate of the event in the specified time slot, e is Euler's number ($e = 2.71828...$) and ! is the factorial function.

Two requisites need to be fulfilled for a dataset to be eligible for use with the Poisson distribution:

- Events should have a known and constant occurrence rate during the time slot evaluated.
- Events should be independent.

Taking those guidelines into account, a dataset with the mentioned characteristics is required for the implementation of the accident risk estimation model.

The dataset chosen consists of over 50,000 road accident reports between 2015 and 2018 in the city of Las Vegas (USA) [46]. Each one of these accident reports includes the main cause that provoked the road accident (not every report has a registered accident cause) along with some other useful information such as the driver's action or whether the driver was affected by any kind of distraction when the accident occurred.

In order to determine the accident probability, the dataset is used to calculate the occurrence rate of different types of accidents. Accident reports are taken and classified into three different groups depending on the cause that produced them: **speed/acceleration**, **steering** and **response time**. **Distraction** causes are analysed as well and they contribute to the accident occurrence rate whenever they are present. The criteria used to classify each accident is unveiled in Table 3.5.

However, accident reports in the dataset took place over 4 different years. This means that the accident occurrence rates that are calculated through the dataset must be converted, since the present Simulation Model is going to consider 3 hour rides as the longest driving time that drivers can take without having a break. Once the accident occurrence rates are adapted to 3 hour time travels, the Poisson distribution can be applied to estimate the probability that any driver in the Model faces of having a single traffic accident.

Accident group	**Accident cause**
Speed/Acceleration	Driving too fast for conditions Exceeded authorized speed limit Operating vehicle in erratic, reckless, careless, negligent or aggressive manner* Failure to keep in proper lane or running off road* Unsafe lane change*
Steering	Made an improper turn Failure to keep in proper lane or running off road* Over-correcting/over-steering Unsafe lane change*
Response time	Followed too closely Operating vehicle in erratic, reckless, careless, negligent or aggressive manner*
Distraction	Inattention/distracted Had been drinking Drug involvement

*Some accident causes can be attributed to two different groups.

Table 3.5: Classification of driving accident causes

The Simulation Model checks which Agent's driving trait out of speed (or acceleration), steering and response time has received more contributions from the Emotion, Personality and Stress evaluation modules. That way each driver is classified into one of the accident groups of the previous table. Then, the accident occurrence rate of the selected accident group is employed to determine the driver's accident probability. Given the Poisson distribution mathematical expression, the driver's probability of having an accident ($k = 1$) is calculated as it follows in each simulation step:

$$f(k = 1; \lambda) = Pr(X = k) = \frac{\lambda^k e^{-\lambda}}{k!} = \frac{\lambda^1 e^{-\lambda}}{1!} = \lambda e^{-\lambda} \tag{3.2}$$

Where λ equals to the accident occurrence rate of the accident group to which the driver belongs, calculated from the dataset used to design the model [46].

CHAPTER 4

Architecture

4.1 Introduction

In this chapter, the design phase of this project is covered, as well as implementation details involving its architecture. Firstly, an overview of the project, divided into modules, is presented. This is intended to offer the reader a general view of this project architecture. After that, each module is explained separately and in much more depth.

4.2 Overview

Agent-based models are computer simulations that involve multiple entities called 'agents', which interact with the environment that surrounds them based on a programmed behaviour [48]. The development and modelling of the present simulation model is carried out as it is explained in the diagram shown in Figure 4.1. The modules that form part of the system are: (1) the **Model**, which is the core component of the simulation system in charge of the initialization and the execution of every component of the system; (2) the **Agents**, which represent the drivers; (3) the **Agent behaviour**, which is the component that allows to analyse the driver's behaviour on the road; (4) the **Configuration** component, which provides the initial features of drivers and the values of the parameters that characterize the simulation; (5) the **Data Manager**, which collects every simulation data of interest; and, finally, (6) the **Visualization** component, which is in charge of the simulation results representation.

The Simulation Model defined in this Chapter is implemented by means of the following architecture class design:

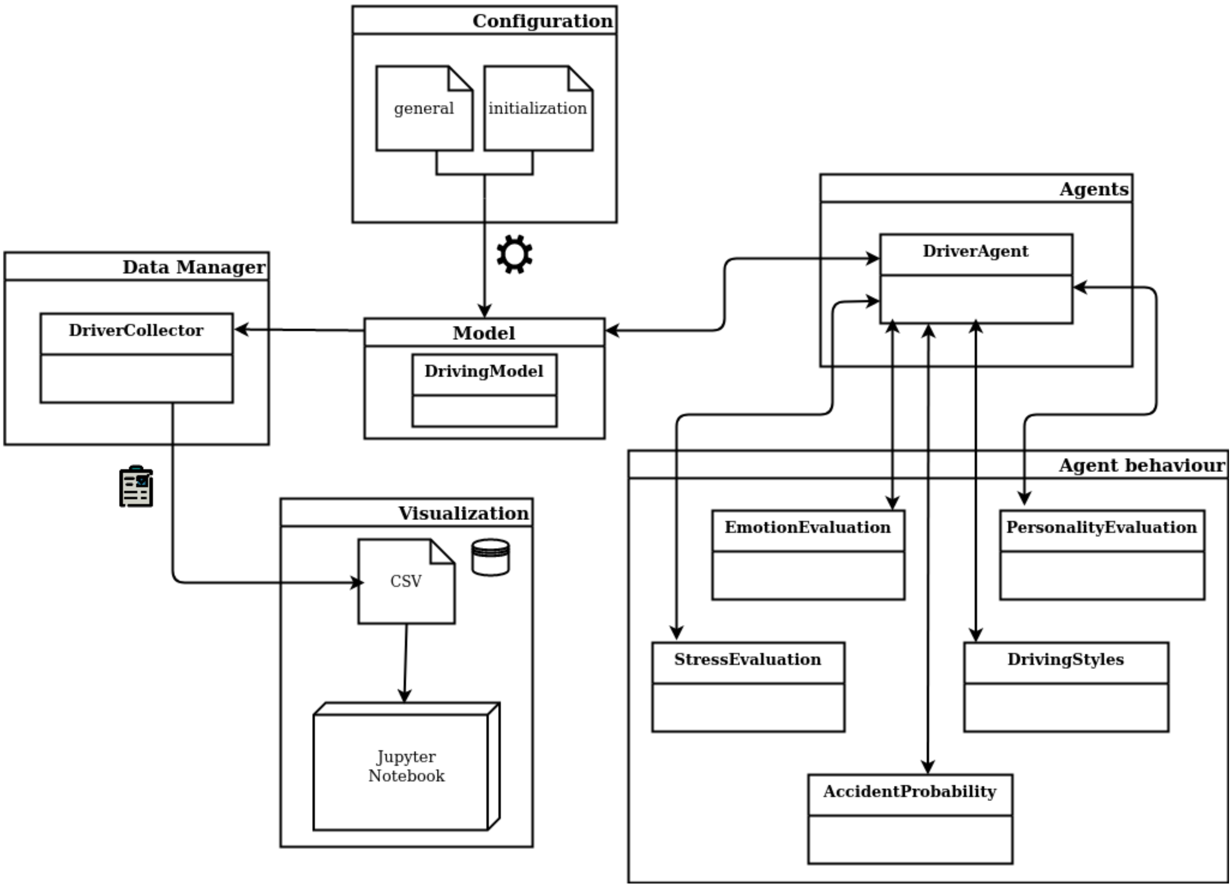

Figure 4.1: Model's architecture class diagram

The implementation of the Simulation Model is carried out with Python [3]. Specifically, one popular Python library is used in this project for the development of the Agent-based Simulation System: **Mesa** [48]. Mesa is a modular framework for building, analysing and visualizing agent-based models. Its modular property allows it to keep its three independent components (modelling, analysis and visualization) working together. In the present project, two of its three components are utilized: modelling and analysis.

Mesa's modelling component consists of a model and agent classes, as well as a scheduler to determine the sequence in which the agents are activated and a space for the agents to interact with one another. The analysis component, on the other hand, provides all necessary tools to collect the data of interest generated by the model, even to run the model as many times and in as many different conditions as desired.

With regards to the data management, **Pandas** [50] is the Python library chosen to handle the complex data structures involved in the Model. The plotting and graphs generated in the Visualization module are created with Python library **Matplotlib** [49].

4.3 Model

The **Model** is the regulator of the simulation, every possible interaction in the system goes through it. The Model is in charge of the creation and activation of the Agents, as well as providing the simulation variables and parameters to the Data Manager module.

The operation of the Model and the Agents is regulated by means of a single policy: Agents are assigned a personality profile, an starting emotion and an stress value (stress can be absent for some drivers as well). Each driver's personality profile remains constant during the whole simulation, since it is considered that changing a personality attribute would imply a much more complex process [25], which is not the purpose of this project. However, drivers' emotions and stress values are set to keep changing throughout the simulation so that their effect on driving styles can be evaluated step by step. Distractions have a sporadic intervention in the model and their contribution is only taken into account in the accident risk estimation.

The Model is controlled through **Class DrivingModel**. The main purpose of this class is to initialize the simulation and define the Model's step. In order to initialize the simulation, the total number of drivers that form part of the Model must be specified. The *general* configuration file defines the number of Driver Agents to be created and the Model initializes the simulation retrieving the data from the configuration file. Apart from that, the initialization requires from seven auxiliary methods, mostly employed for the creation and activation of Driver Agents:

- *emotionChoice(self).* In order to ensure that each driver has a different combination of attributes, an emotion is assigned randomly. The choice, however, is carried out in even probability conditions for all the emotions (25%).
- *personalityChoice(self).* In order to ensure that each driver has a different combination of attributes, a personality profile is assigned randomly. The choice, however, is carried

out in even probability conditions for all the personality profiles except for the **careful style**, which gets twice the odds of being assigned as the rest of profiles (40% for the careful style and 20% for the rest of the styles). This decision is justified by stating that careful drivers are usually the predominant kind in real traffic conditions, making up for the fact that the rest of the styles have negative contributions to safe driving behaviours.

- *stressChoice(self).* In order to ensure that each driver has a different combination of attributes, stress is assigned randomly. The choice, however, is carried out in even probability conditions for all the possible stress scenarios (33.33%).
- *loadEmotions(sel, emotion).* Once the emotion random choice has been made, this method takes the choice and retrieves the corresponding emotion values from the *initialization* configuration file.
- *loadPersonality(self, personality).* Once the personality profile random choice has been made, this method takes the choice and retrieves the corresponding personality values from the *initialization* configuration file.
- *loadStress(self, stress).* Once the stress random choice has been made, this method takes the choice and retrieves the corresponding stress value from the *initialization* configuration file.
- *addCollectors(self).* This method creates a Class DriverCollector instance specifying the variables that are collected by the Data Manager module in each step of the simulation: emotions, personality, stress, distractions, speed, acceleration, braking, steering, response time and accident probability.

Besides, the Model also defines the system's behaviour in each simulation step. In this case, the *step(self* method created for that purpose only activates the scheduler and calls the data collector in each simulation step. The scheduler chosen for this Simulation Model is a *RandomActivation* scheduler, which means that every Agent is activated once per step in random order.

4.4 Agents

Agents in the Simulation Model are created to have a deeper understanding of how individual drivers behave in a system in which features such as emotions, stress or distractions can be elicited. For that reason, an Agent class is created to model drivers: **Class DriverAgent**. This class is expected to define drivers' attributes and the Driver Agent's step.

With regards to driver attributes, each Driver Agent is characterized with variables that keep score of the emotions drivers might be feeling, the assigned personality profile, the stress value, the distraction value, every driving trait included in the model (speed, acceleration, braking, steering and response time) and the estimated accident probability.

Driving traits are defined by different levels that depend on the driver's intention regarding each trait. Therefore, driving traits characterization requires auxiliary classes that include the levels explained in section 3.2 for each trait, as well as a dominant property to store the trait's level that drivers stand out for. Five classes are created to cover each driving trait:

- **Class Speed**. Speed class instances have three levels (slow, appropriate and fast) and an extra parameter to store the dominant Speed level that distinguishes each driver during the simulation.
- **Class Acceleration**. Acceleration class instances have three levels (slow, appropriate and fast) and an extra parameter to store the dominant Acceleration level that distinguishes each driver during the simulation.
- **Class Braking**. Speed class instances have two levels (gentle and abrupt) and an extra parameter to store the dominant Braking level that distinguishes each driver during the simulation.
- **Class Steering**. Speed class instances have two levels (low and high) and an extra parameter to store the dominant Steering level that distinguishes each driver during the simulation.
- **Class ResponseTime**. ResponseTime class instances have two levels (low and high) and an extra parameter to store the dominant ResponseTime level that distinguishes each driver during the simulation.

In addition to driving attributes, the Agent's step is included in DriverAgent class. For each simulation step, emotions and stress contributions to driving traits are recalculated, and each trait's dominant level is retrieved in order to use them in the accident risk estimation.

4.5 Agent behaviour

The Agent behaviour module regulates the interactions between drivers and the system. In order to consider the effect of emotions, personality and stress on driving styles and be able to carry out accident risk estimations, 5 classes have been implemented:

- **Class EmotionEvaluation**. This class adds the emotion contributions to driving traits to the Simulation Model. The class main method, *evaluateEmotions(self, emotions)*, receives the Driver Agent's emotion values as parameter and figures out the emotion the driver is feeling at that moment. Emotion contributions are then included to the Agent's driving traits, following the criteria described in table 3.2.

  Emotions are evaluated both when the Driver Agent is created for the first time and later in each simulation step, since the emotions that a driver can feel might vary throughout the simulation. The emotional contribution to driving traits is unitary (+1 for the count of the affected trait's level).

- **Class PersonalityEvaluation**. This class adds the personality contribution to driving traits to the Simulation Model. The class main method, *evaluatePersonality(self, personality)*, receives the Driver Agent's personality profile as parameter (drivers are only assigned one of the four personality profiles considered in this project). After checking the extraversion, agreeableness, conscientiousness, neuroticism and openness values that characterize the driver's personality, the corresponding contributions to driving traits are added (see table 3.3).

  Unlike emotions, personality is just evaluated once at the beginning of the simulation, when the Model activates the Driver Agent for the first time. The reason behind it relies on the fact that personality does not change throughout the course of the simulation. Therefore, personality contribution is only taken into account once, but the contribution has a bigger impact on driving styles than the one that emotions have in order to give personality profiles more weight in the Model:

$$PersonalityContribution = \frac{SimulationSteps}{3} \tag{4.1}$$

- **Class StressEvaluation**. This class adds the stress contribution to driving traits, in case the driver is affected by driving stress. The class main method, *evaluateStress(self, stressOutcome)*, receives the Driver Agent's stress value as parameter and adds the corresponding contribution depending on whether it is anxiety-related stress, anger-related stress or simply no stress is present (see table 3.4).

  Stress contributions are evaluated both after the Driver Agent activation and in each simulation step. This contribution, as happened with emotional contribution, is unitary (+1 for the count of the affected trait's level).

- **Class DrivingStyles**. This auxiliary class aims to find the dominant level in each one of the driving traits that define the Agents' behaviour. For that purpose, the methods of this class are designed to compare which trait's level has the biggest contribution after the emotion, personality and stress evaluations. This way the Model receives information regarding the general driving styles and preferences of each one of the drivers in the system. The driving style evaluation is carried out in each simulation step since this information is crucial for the accident risk estimation carried out afterwards.

- **Class AccidentProbability**. Once driving styles have been characterized and distraction values have been retrieved, this class makes an estimation of the Driver Agent's accident risk in each simulation step. Several methods are defined to get the occurrence rate of each accident group (speed/acceleration, steering and response time) as explained in section 3.3.4, and the Poisson distribution is applied to determine the accident probability of drivers.

  The accident risk estimation takes place in each simulation step. Then, if the dominant speed (or acceleration) level is *fast*, the dominant steering level is *high* and the dominant response time level is *high*, the three level contribution counters are compared. The biggest contributor out of the three represents the accident group that the driver belongs to, and, therefore, the occurrence rate employed to estimate the accident probability through the Poisson distribution. For instance, if a driver has *speed.FAST = 15*, *steering.HIGH = 9* and *rt.HIGH = 7*, then *speed.FAST* would be the level with more contributions out of the three traits and, therefore, the driver would automatically be assigned to the speed accident group, taking its accident occurrence rate to determine the accident probability. Moreover, if distractions are detected in the driver, the total occurrence rate increments, affecting the final driver's accident probability that is estimated.

After having revised the function of the Agent behaviour module in the Model's architecture, the following diagram is presented aiming to provide a better understanding of the Driver Agent's step.

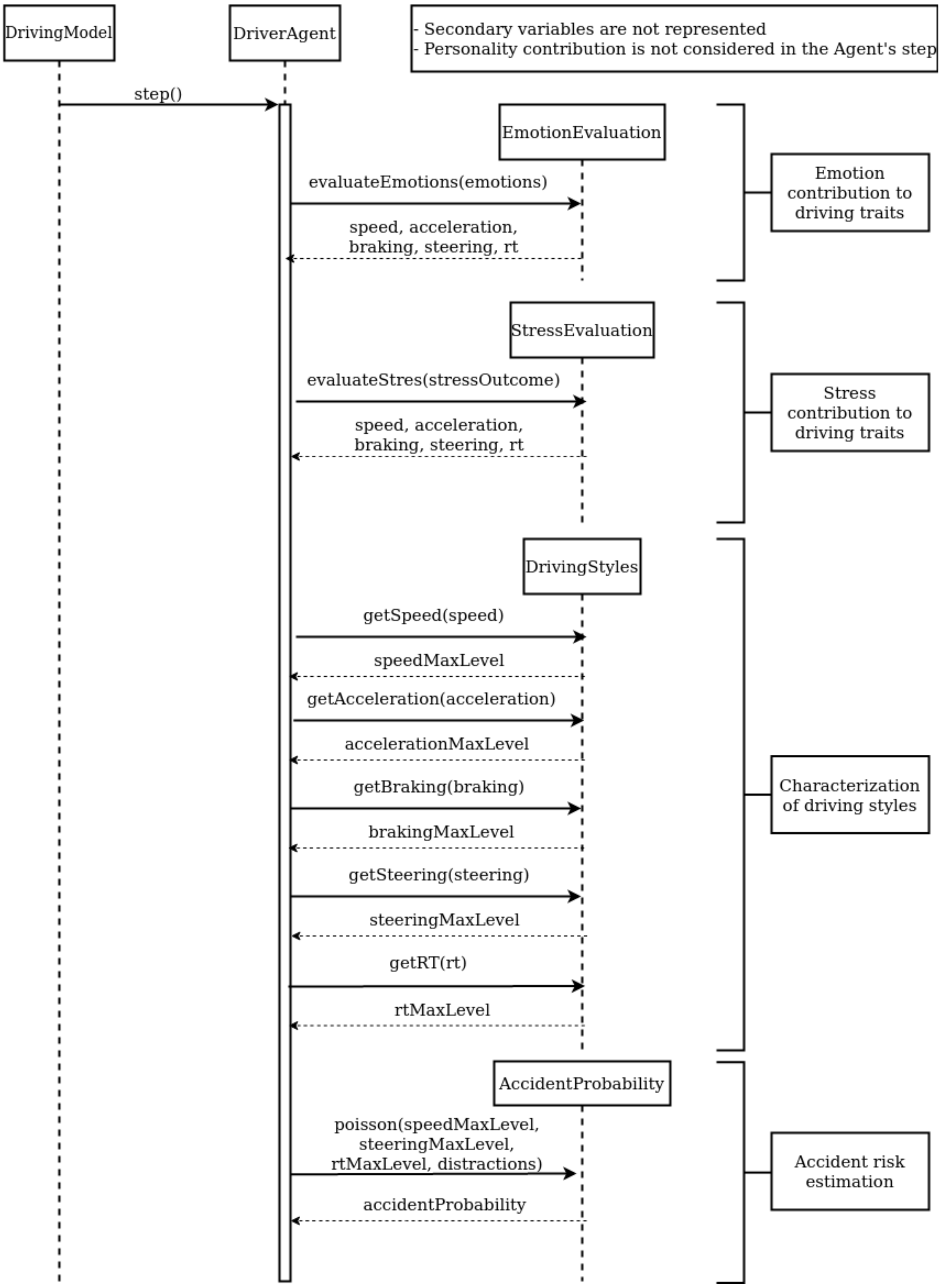

Figure 4.2: Driver Agent's step

4.6 Configuration

The simulation is configured by two different settings files: ***general*** and ***initialization***. The configuration files were introduced with the purpose of designing a Model as configurable and scalable as possible, allowing the user to easily add new features or modify the existing ones.

The main parameters affecting the simulation are contained in the *general* configuration file. Both the total number of Agents that take part in the simulation and the simulation steps are specified in this configuration file.

The *initialization* configuration file, on the other hand, is used to define the main emotion, personality and stress values that drivers can take during the simulation. The Model takes these values from the configuration file when Agents are created for the first time or whenever any of the mentioned properties are modified.

4.7 Data Manager

The Data Manager module is meant to collect all the simulation-related data relevant for the analysis of results. By means of the **Class DriverCollector**, which extends Mesa's Data Collector, an extended group of parameters and variables are extracted from the Model.

The collected data focuses on the evolution of the Agent parameters throughout the whole simulation. For each simulation step, the following data is stored:

- Emotion values of the driver, which can change during the simulation.
- Personality profile assigned to the driver at the beginning of the simulation. The driver's personality traits do not change during the simulation.
- Stress value and whether the outcome of driving stress results in anger or anxiety.
- Distraction value affecting the driver (disregarding if it comes from inattention, alcohol, drugs or fatigue).
- The Agents' driving traits: speed, acceleration, braking, steering and response time. These values are the key elements of the simulation since they can be utilized for both driving behaviour analysis and accident risk estimation. Only the dominant level or driver intention of each driving trait is stored.

- Traffic accident probability of each driver.

After the data is collected, the module creates a *CSV* file in which all the simulation related information is stored. The *CSV* file is sent to the Visualization module in a later stage for result presentation.

4.8 Visualization

In order to analyse the simulation results in an effective and more intuitive way, the system is integrated with a Visualization module. This module receives a *CSV* file from the Data Manager module containing the most relevant simulation-related data.

For result analysis, numerous graphs and plots are made thanks to the Matplotlib Python library. The data from the *CSV* file is extracted and separated by means of the Pandas Python library, which allows to get plenty of datasets with the desired format.

A more thorough analysis of the simulation results is carried out in Chapter 5.

CHAPTER 5

Results

5.1 Introduction

In this chapter the simulation results extracted from the Agent-based Social Simulation System are presented. First, the simulation conditions under which the results have been obtained are described. Then, the impact of emotions, personality and stress on driving styles is addressed. Finally, the results referents to the accident risk estimation are presented and evaluated.

5.2 Simulation results

The Simulation Model is tested and the results collected by the Data Manager module are sent as a *CSV* file to the Visualization module for graphical analysis. The results generated represent the driving styles and the accident probabilities of drivers during a 3 hour uninterrupted ride. For that purpose, 500 Driver Agents are set to take part in the simulation process, which consists of 180 steps (if the ride lasts 3 hours then each step would be equal to 1 real time minute) in which drivers can be influenced by different emotions, stress outcomes and distractions.

5.2.1 Driving styles results

The main results regarding the impacts of emotions, personality profiles and stress on driving styles are presented in the first place. Each bar chart is dedicated to a driving trait and represents the amount of drivers under the influence of a single conditioning factor that showed prevalence in each trait's level. For instance, Figure 5.1 represents the amount of drivers who had each speed level as dominant, depending on the emotions they were feeling. As a result, a driver who had anxiety as main emotion during the simulation (emotions that drivers feel can vary throughout the simulation, but there is always an emotion which is experienced during more time) had a tendency to score *fast* speed values.

In the below graphs, **emotion** results are presented. Figures 5.1 and 5.2 show how speed and acceleration are conditioned by emotions. Since both driving traits provoke the same kind of behaviour on drivers, the two graphs present multiple similarities. Only drivers under the influence of fear presented speeds and accelerations in the *slow* level, and the same reasoning applies to happiness and the *appropriate* level. When it comes to the *fast* level, mainly angry and anxious drivers scored high values. The most interesting detail about these graphs is the influence that the other conditioning factors (personality and stress) have on driving styles. That is the reason why even though happiness contributes to *appropriate* speed values, there were even more happy drivers which showed a general tendency to *fast* values, because of their personality profile or the stress they might have experienced during the simulation.

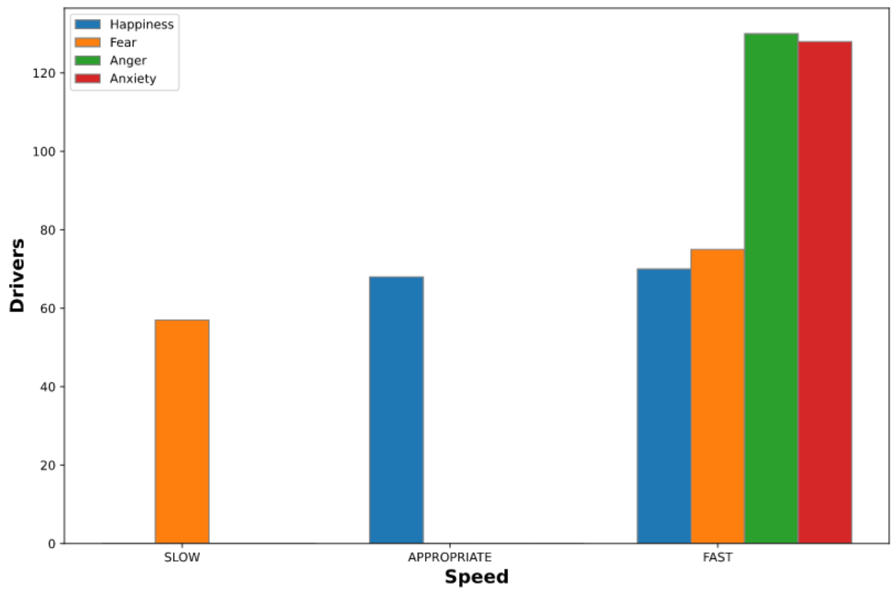

Figure 5.1: Speed level scores for each emotion

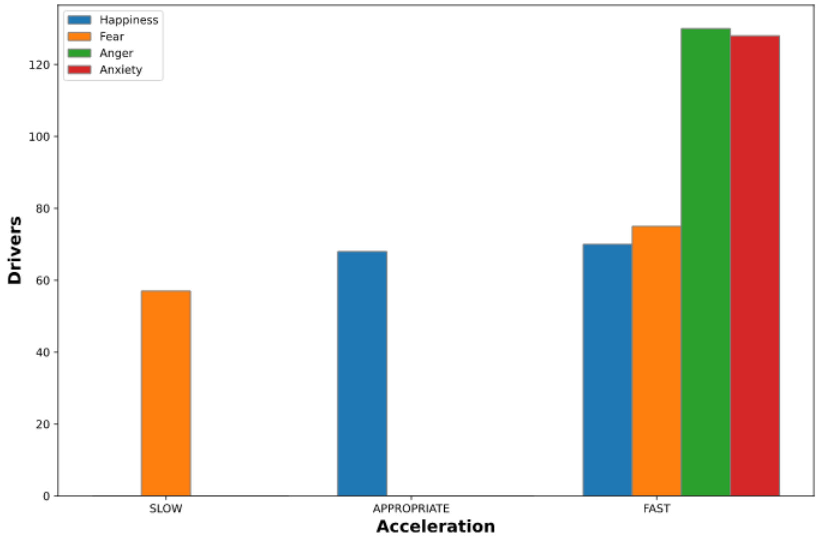

Figure 5.2: Acceleration level scores for each emotion

Braking (Figure 5.3), as expected, had most drivers score in the *abrupt* level. Only happy drivers presented a clear preference for a *gentle* brake handle, followed by anxious drivers. Anxiety, however, did not show any clear association with braking intensity. The explanation relies on the fact that anxious drivers who were found in the *gentle* level might as well have been assigned a careful personality profile in most cases.

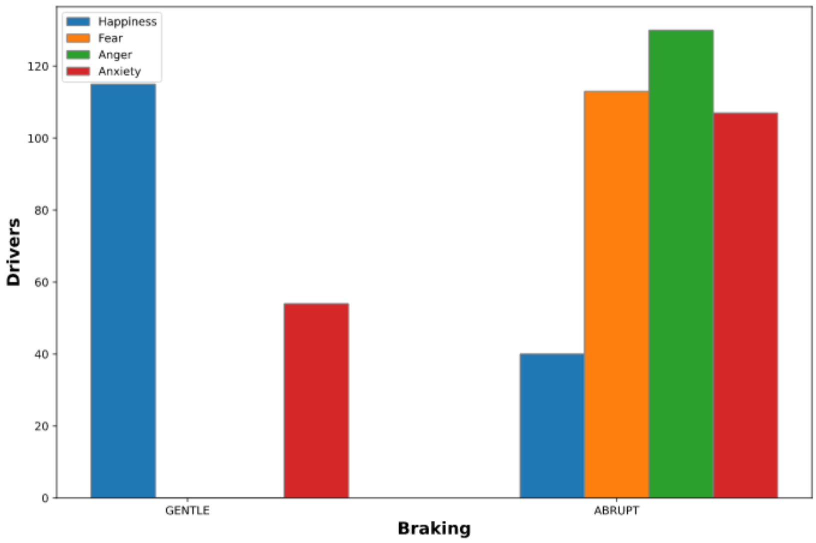

Figure 5.3: Braking level scores for each emotion

In the case of steering (Figure 5.4), happiness showed a positive correlation with the *low* level but it was evenly present in the *high* level. Fear, anxiety and anger were significantly linked to the *high* steering wheel movement. The response time related chart, in Figure 5.5, provides very conclusive results. Fear, because of the increase in safety distance that compels in drivers, and anger, because of the state of high selective attention that induces in drivers, were strongly associated to *low* response times. Happiness (usually provokes an state of excessive relaxation) and anxiety, on the other hand, were correlated to higher response times.

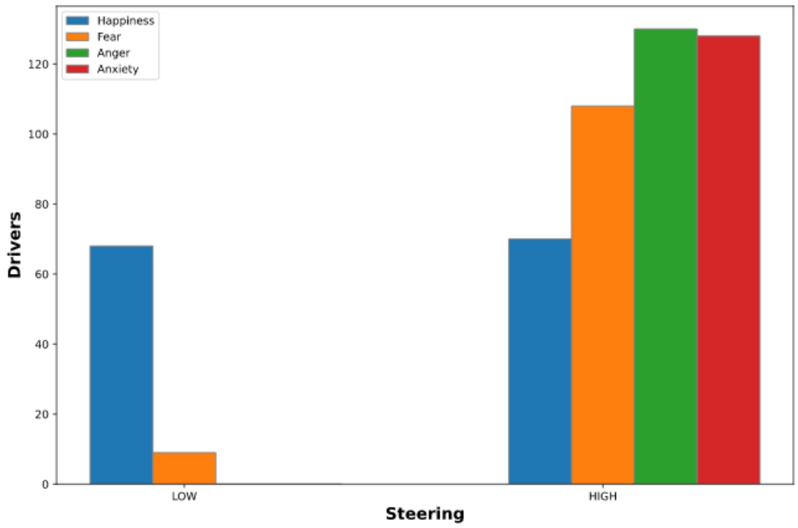

Figure 5.4: Steering level scores for each emotion

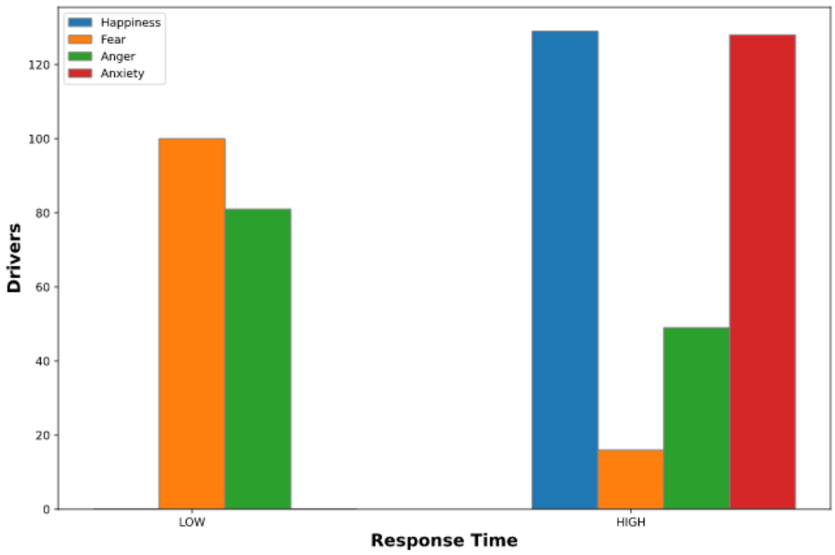

Figure 5.5: Response time level scores for each emotion

The following Figures summarize the contribution of **personality profiles** to driving styles. It is important to highlight that, since personality is only considered during the Agent creation stage, personality might have a minor effect on driving traits when compared to emotions or stress.

Firstly, speed and acceleration are analyzed. Again, as happened with emotions, both traits have a similar behaviour. All the personality profiles are significantly correlated to the *fast* level. The only profile that stands out in both the *appropriate* and the *slow* levels is the careful style. This kind of personality is characterized by a great sense of responsibility and decision making skills, which makes it reasonable that almost 40 drivers were classified into the *appropriate* level.

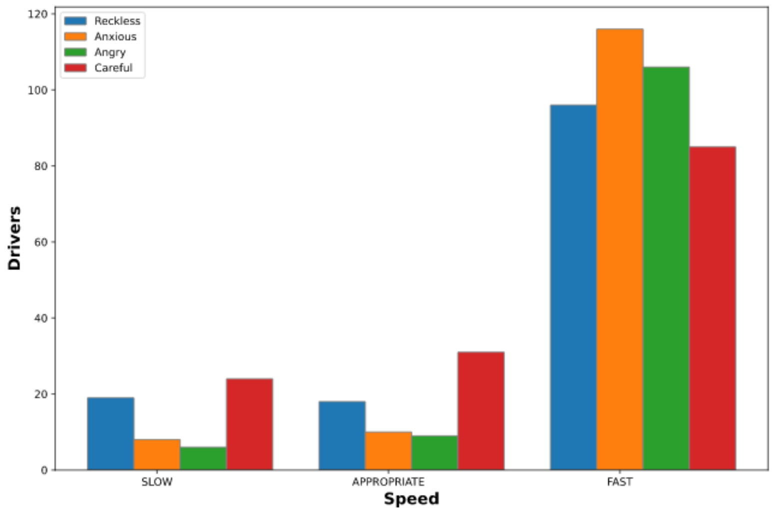

Figure 5.6: Speed level scores for each personality profile

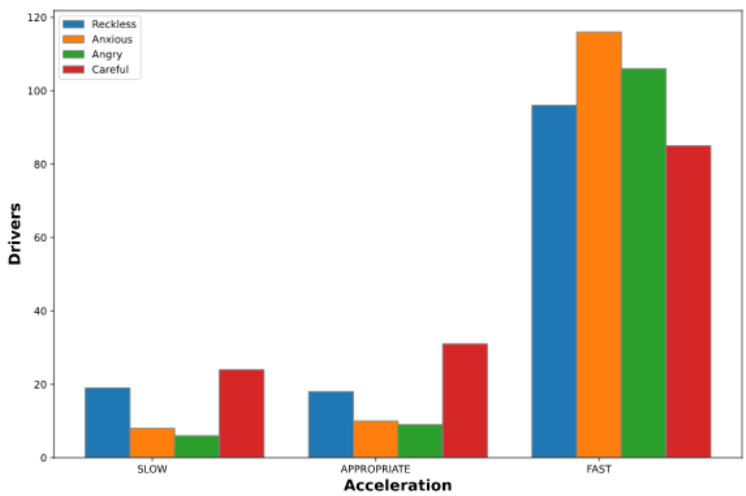

Figure 5.7: Acceleration level scores for each personality profile

In the below figures, braking (Figure 5.8) and steering (Figure 5.9) results are evaluated. Bad and sudden braking decisions are taken by most drivers, since every personality profile except for the careful style score high in the *abrupt* braking level. Drivers with a careful style are more even, but still are slightly more related to *abrupt* than *gentle* levels.

With regards to steering, not only personality has little influence in the *low* steering level, but it also shows an extremely positive correlation with the *high* level.

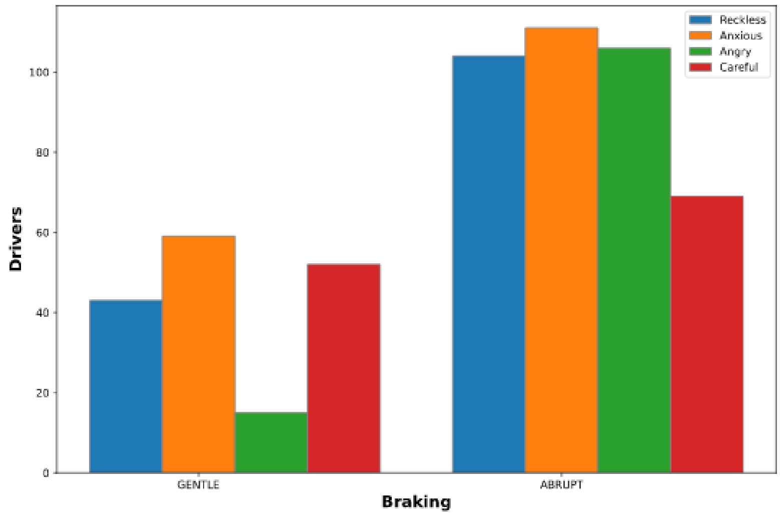

Figure 5.8: Braking level scores for each personality profile

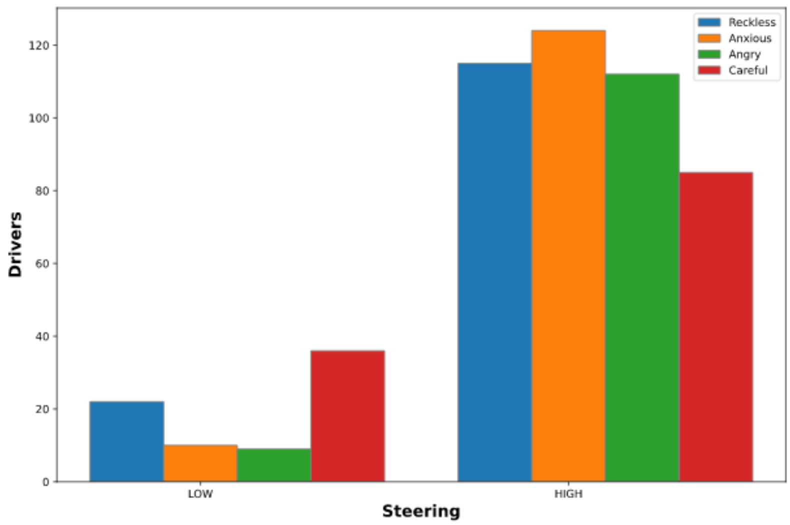

Figure 5.9: Steering level scores for each personality profile

Response time is presented in Figure 5.10. In this case, angry and careful styles are the ones with a bigger impact on *low* level response times. The evident explanation to this relies on the fact that the angry style shows a significant parallelism with the emotion of anger. In the case of the careful style, good driving practices usually lead to an increase in driver reaction times. On the other hand, drivers who were assigned the anxious style were mainly associated to *high* response times.

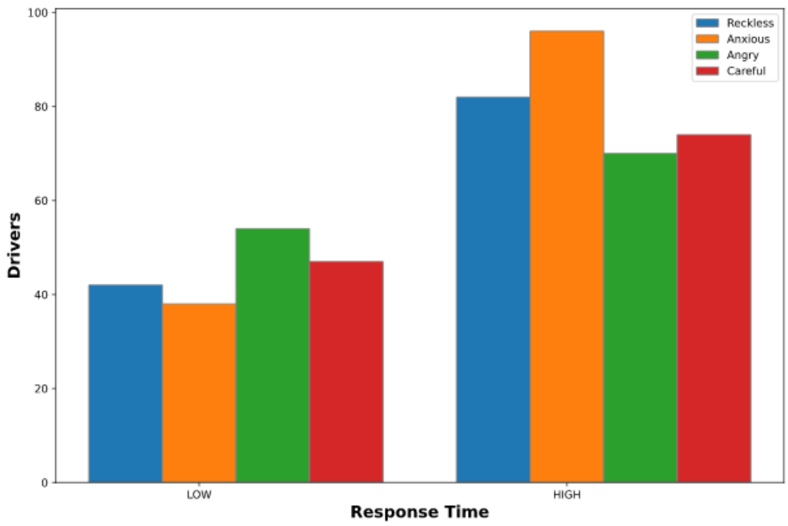

Figure 5.10: Response time level scores for each personality profile

Finally, the influence of stress in driving traits is displayed. Stress, as happened with emotions, adds its own contribution to driving styles in each simulation step. However, stress has a peculiarity that makes it different to other conditioning factors in this Model: some drivers are able to avoid stress and, therefore, it has no effect on their behaviour while they are behind the wheel.

Firstly, speed and acceleration, with equal contributions, are measured in Figures 5.11 and 5.12. Both anger-related stress and anxiety-related stress are related to *fast* level values. Drivers without signs of stress are also associated with *fast* speed and acceleration values, which proves a clear influence of emotions in drivers that do not suffer from driving stress, specifically anger and anxiety, the emotions that are positively correlated to *fast* levels.

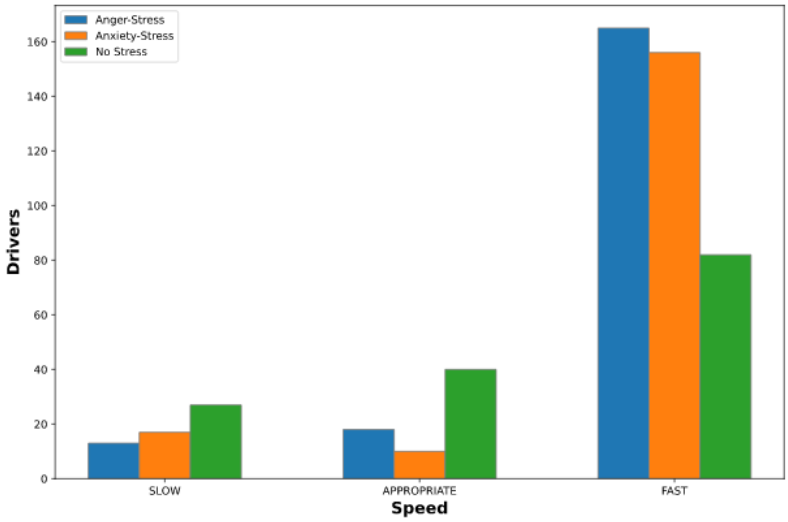

Figure 5.11: Speed level scores for each stress scenario

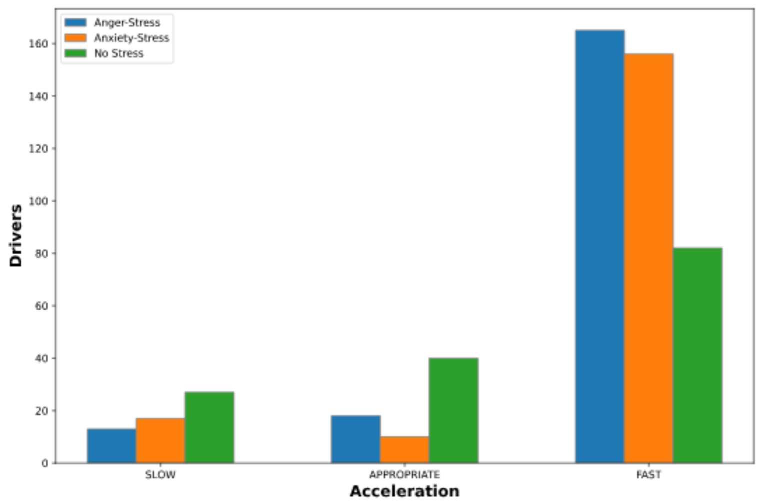

Figure 5.12: Acceleration level scores for each stress scenario

Braking (Figure 5.13) and stress results, unlike other driving traits analysed in this section, present a clear pattern. The more positive correlation that a stress scenario presents with a specific braking level, the more negative the association is with the opposite level. In this case, all stress scenarios score higher values in the *abrupt* braking level. Drivers without stress, though, are close in both braking levels since the influence of emotions and personality in drivers without stress is very important.

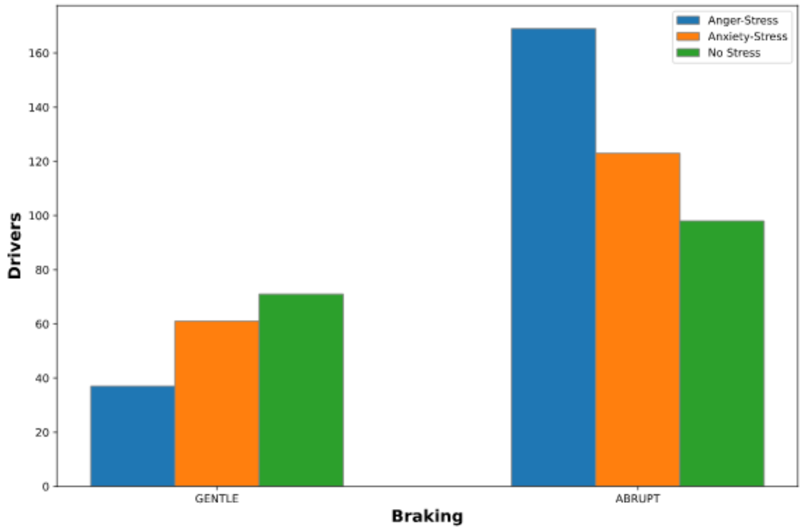

Figure 5.13: Braking level scores for each stress scenario

Regarding steering (Figure 5.14) and response time (Figure 5.15), both driving traits evidence the relationship between stress, anger and anxiety. For instance, few drivers were linked to the *low* steering wheel movement, since anger-related-stress and anxiety-related stress are manifested in the form of *high* level steering values. When it comes to response times, the most remarkable result shows that drivers with anger-related stress, which does not have a direct contribution to any of the response time levels, are equally distributed between both the *low* and *high levels* (emotion influence emerges again).

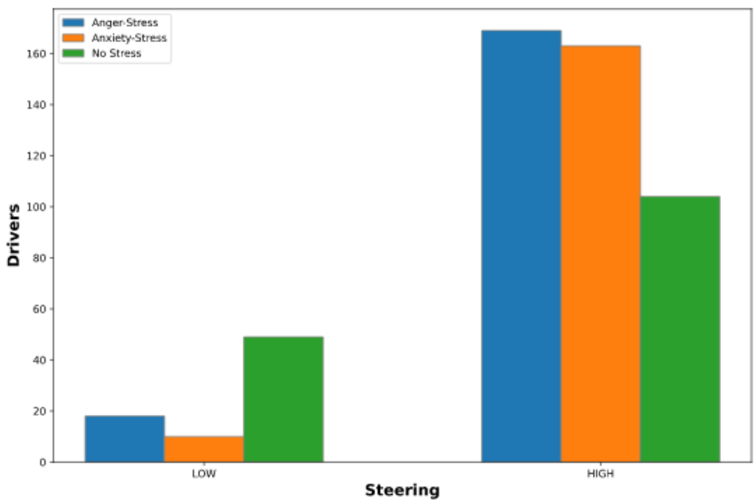

Figure 5.14: Steering level scores for each stress scenario

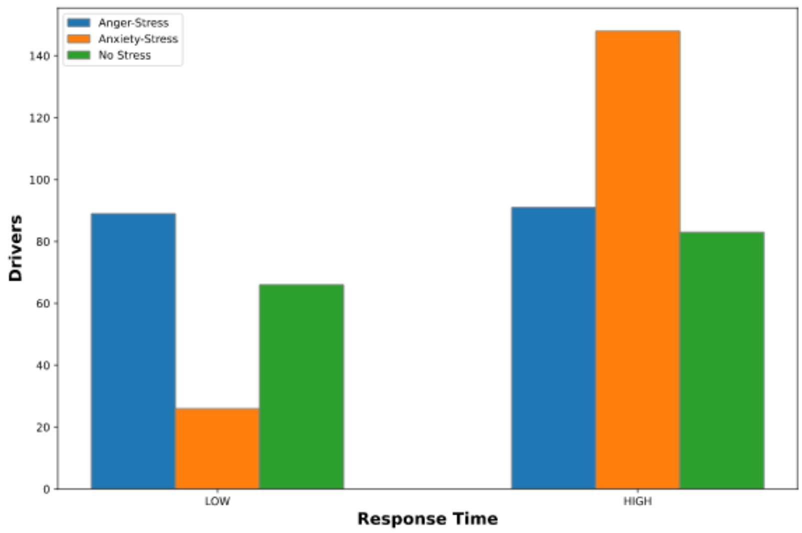

Figure 5.15: Response time level scores for each stress scenario

5.2.2 Accident risk estimation results

This section covers the analysis of the results obtained from the Accident risk estimation module in the Simulation Model. As explained in Chapter 3, this module is designed thanks to a dataset which consists of accident reports that include the main cause that provoked the traffic accident. After the evaluation of the most common causes of accident reported in the dataset, three accident groups which depend on speed (or acceleration, both driving traits have similar behaviour), steering and response time are considered.

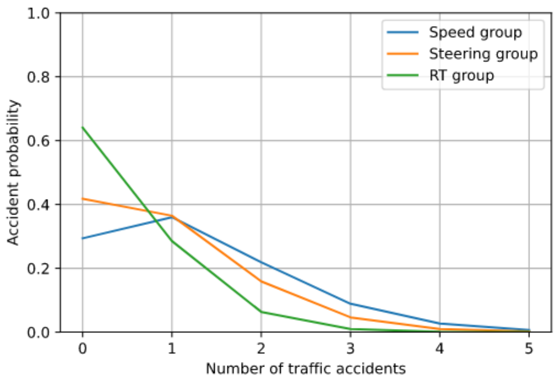

Figure 5.16: General accident probability without considering distraction

As can be seen, this graph (Figure 5.16) reflects the accident probability for each one of the accident groups considered in the Model. The Poisson distribution is applied to each accident group for different amount of event occurrences (from 0 to 5 traffic accidents). The *Speed* group, which involves accident causes such as speeding or operating the vehicle in a reckless speed-related way (see Table 3.5), is the one that shows higher accident probabilities due to its accident occurrence rate. In Figure 5.17 the **distraction** factor is added to the accident probability of each accident group, disregarding the cause or the origin that produced such distraction (mobile phones, talking to other passengers, alcohol or drug consumption, drowsiness, etc.). Therefore, higher accident probabilities are reached when the driver faces a distraction, but the *Speed* accident group remains as the main cause of driving accidents according to the results obtained in the Simulation Model.

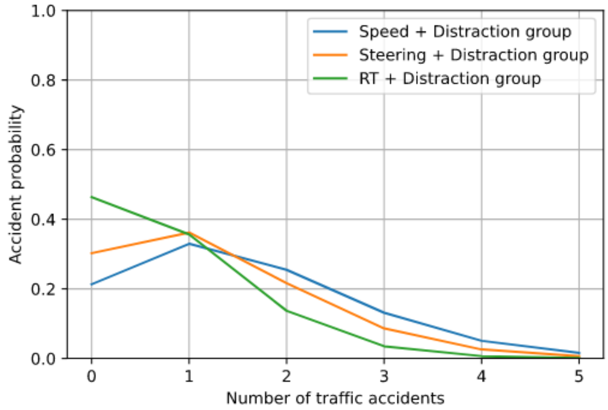

Figure 5.17: General accident probability considering distraction

Lastly, the following Figure shows the evolution a single driver's accident probability throughout the simulation. The driver has a careful personality profile and is experiencing anxiety during the first 20 steps of the simulation, and then distraction strikes in step 14.

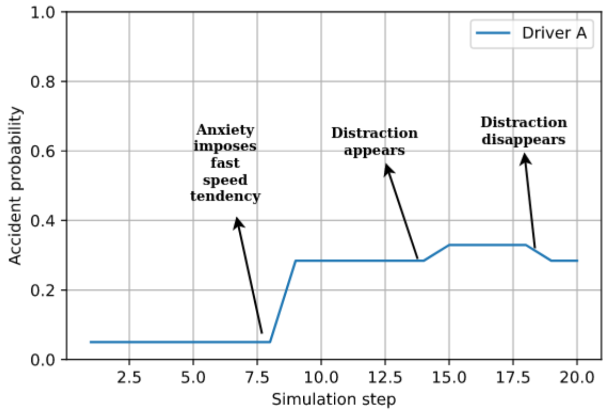

Figure 5.18: Individual accident probability of 1 driver during the simulation.

CHAPTER 6

Conclusions and future work

6.1 Conclusions

In this project, an Agent-based Social Simulation System for analysing the way emotions influence driver behaviour has been developed. Apart from the emotion characterization, personality aspects and driving stress were also considered during the design stage of the process. In the end, a model for accident risk estimation was included to correlate driving styles, driving distractions and road safety.

Firstly, a literature review was conducted in order to get a deep understanding of the problem. Four emotions were selected to be implemented in the Model based on the project's context: happiness, anger, fear and anxiety. Secondly, a series of personality profiles obtained from combining the Big Five Personality Traits (extraversion, agreeableness, conscientiousness, neuroticism and openness) were introduced. Besides, three different scenarios of driving stress were contemplated: anger-related stress, anxiety-related stress or stress absence.

According to previous research carried out on this field, each one of these factors can have an individual contribution in driving styles that shapes the way drivers behave on the road. Therefore, the following driving traits -along with the corresponding contributions of the mentioned conditioning factors- were defined: speed, acceleration, braking, steering and response time. However, studies on systems that model driving behaviour are very heterogeneous and in same cases even inconclusive, since no general consensus is reached and each system proposes its own simulation environment. For that reason, a model of levels based on the driver's intention regarding each driving trait was proposed, with the purpose of designing an objective method to compute emotion, personality and stress contributions to driving styles.

After the identification of driving styles, the accident risk estimation was implemented. A model based on the Poisson distribution was applied, taking into account both driving styles and the presence of driving distractions. In order to determine accident probabilities, several accident groups were designed and their corresponding accident occurrence rates were calculated.

The results obtained from the simulation were quite revealing. Emotions and stress have a bigger impact on driving behaviour than the driver's personality profile, since they act instantaneously and they do not imply such a complex cognitive process like the one that comes along with human personality. On the other hand, the analysis of the accident risk estimation showed that most factors considered in the system have a negative effect on road safety. From road rage or anxiety to driving stress, driving can become a dreadful activity that ends up being harmful for our health.

6.2 Future work

This section describes the future improvements and characteristics that could be implemented in this project:

- **Numeric validation** (speed in km/h, steering in degrees/s, response time in seconds, etc.) of the influence of emotions on driving behaviour that substitutes the current level based model.
- **Space implementation** to analyse the interaction among drivers in a fixed environment.
- Design of a **GUI** that records the drivers' patterns of behaviour after the elicitation of certain emotions.
- Further **testing** of the accident risk estimation module that allows to compare it with real accident probability data.

APPENDIX A

Impact of this project

This appendix reflects on the possible impacts that might come along with the realization of this project from a qualitative point of view.

A.1 Social impact

Nowadays, with the manufacturing of faster and well-equipped vehicles, road safety is one of the main global concerns. The fact that driving is not an easy task, requiring from total attention and in many cases from previous experience, makes it crucial to develop systems than can aid drivers in such difficult situations.

In addition, the COVID-19 pandemic has had multiple consequences that are going to shape the new society in which we are going to live in the future. The forced lockdowns, the sudden stop of the economy or the lack of socialization have provoked severe side effects in us, especially when it comes to mental health. There is an urgent need for systems that deal with such mental problems and help people when carrying out simple tasks in our lives like driving.

Therefore, the emotion analysis carried out in this project for the characterization of driving styles and a posterior accident risk estimation could have a very positive impact in our current society. Besides, the use of this project could be taken as starting point for future research projects on the same field in the future.

A.2 Economic impact

The economic impact of this project can be appreciated from an entrepreneurial point of view. Companies could take advantage of a project like the one being presented here by integrating it in any car assistant models that they might have developed.

What's more, this project could be used to provide companies with an innovative tool to both gather personal information about customers and analyze their sentiment towards certain situations, not only driving situations.

A.3 Environmental impact

With regards to the environmental impact that this project might cause, it is important to remember the fact that this kind of software could require a considerable amount of computational resources, with the associated electrical energy consumption used for data processing and hardware cooling.

On the other hand, the integration of emotion analysis systems for road safety in private cars contributes to increase both pollution and traffic, specially in cities. However, if this kind of systems were to be used in public transport services this work could have a major positive environmental impact.

A.4 Ethical impact

The main ethical implications of this project are related to data compilation and protection. This system could be used to gather personal information from clients or from potential clients, and private data management has been an issue for multiple people over the years.

APPENDIX B

Economic budget

This appendix details a budget in terms of physical resources, human resources, software and taxes, the necessary to bring about the project.

B.1 Physical resources

A personal computer of the following characteristics has been utilized to proceed with the project's implementation:

- CPU: Intel(R) Core i7-1165G7 @ 4.70 Hz
- RAM: 8GB DDR3, CL10
- Disks: 512 GB SSD PCIe

A computer like that, with those specifications, can cost up to **700€** in Spain.

B.2 Human resources

In this case, the project has been undertaken by a single researcher and it has been funded by the Intelligent Systems Group (GSI), which at the same time is part of the Department of Telematic Systems Engineering (DIT) at Universidad Politécnica de Madrid (UPM).

The monthly salary of this researcher rises up to 550€ for 20 hours of weekly work. Therefore, the estimated fee is equivalent to 6.875€ per hour. If an average time of 500 hours has been dedicated to the project, the total project expenses for human resources go to **3437.5€**.

B.3 Software and licenses

All software and licenses employed in this project were public and the total expense to have in them equals to **0€**.

B.4 Taxes

For a company interested in buying the created product, the taxes to pay will depend on the VAT (Value Added Tax) for an advanced software project in the country where it has been carried out. As a result, this tax must be added to the total price of the product's final cost.

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