Faculdade de Engenharia da Universidade do Porto

A Research Approach to Study Human Factors in Transportation Systems

João Sá Vinhas Gonçalves

U. PORTO
FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

Mestrado Integrado em Engenharia Informática e Computação

Supervisor: Prof. Dr. Rosaldo José Fernandes Rossetti

Second Supervisor: Prof. Dr. Peter Wagner

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Approved in oral examination by the committee:

Chair: Doctor Daniel Augusto Gama de Castro Silva

External Examiner: Prof. Doctor Luís Paulo Reis

Supervisor: Prof. Doctor Rosaldo José Fernandes Rossetti

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Abstract

This thesis proposes a new general-purpose methodology to conduct studies on Human Factors in Transportation Systems.

A full-fledged setup and implementation of the methodology is provided for validation. This setup, which uses real data to perform the simulation, includes a traffic microsimulator, a driving simulator, a traffic control centre and an Advanced Driver Assistance System, providing an experimentation laboratory, in which empirical research can be conducted. The communication between the simulation components is made interchangeably using both the European standard Datex II and the SUMO TraCI protocols.

Several usage scenarios are implemented and indications on how to extend the methodology to accommodate different requirements are provided; as to prove its usability and feasibility.

A simple Human Factors study was conducted using the implemented setup. This study uses naturalistc data and evaluates the network performance gain by using an Advanced Driver Assistance System that recommends new routes to drivers in congestion situations and provides a final validation of the methodology.

In conclusion, the methodology has been proved usable to effectively conduct Human Factors research and also to develop Advanced Driver Assistance Systems applications in a controlled, yet realistic environment.

Acknowledgements

I want to express my deepest gratitude to both my supervisor at FEUP, Prof. Dr. Rosaldo Rossetti and to my supervisors at the German Aerospace Center (DLR), Prof. Dr. Peter Wagner, Dr. Michael Behrisch and Dr. Marek Heinrich, not only for their guidance and support but also for their endless patience and contributions which made this dissertation possible.

I am also thankful to the German Aerospace Center - Institute of Transportation Systems for welcoming me hospitably within their laboratories in Berlin.

João Gonçalves

“Gut Ding will Weile haben.
Good things take time.”

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Abbreviations

ITS	Intelligent Transportation Systems
ITSS	Intelligent Transportation Systems Society
ATS	Artificial Transportation Systemst
HF	Human Factors
ADAS	Advanced Driver Assistance Systems
ATMS	Advanced Traffic Management System
VMS	Variable Message Sign

Chapter 1

Introduction

Transportation plays a crucial role in today's societies, both from an economical and social point of view. As such, studies and researches in transportation are of utmost importance and are widely present in the scientific communities. However, despite the technological advancements on the Transportation industry being undoubtedly huge, the human interaction with the composing transportation systems is still critical. As such, Human-Factors (HF) in Transportation Systems is a crucial research and development topic, specially in terms of safety, efficiency and comfort.

1.1 Context

Intelligent Transportation Systems (ITS) are those that, applying information and communication technologies, provide advanced and improved usage of the transportation's infrastructure; viz. traffic optimization, security enhancement, user awareness or cost minimization. [Qi08]

However, as conducting studies on a live transportation network is potentially dangerous, time-consuming and expensive, the prevailing approach to research on ITS is through simulation. This ranges from macroscopic simulation of urban networks, i.e. Artificial Transportation Systems (ATS), to microscopic simulation or even driving simulation.

1.1.1 Artificial Transportation Systems & Microsimulation

In the cases where the object of study is the network infrastructure itself, or its overall performance, Artificial Transportation Systems can be designed and studied resorting to macrosimulation [WS12] [RL14] [RLT11]. However, it can be interesting to study the network in more detail, such as by simulating the movement and behaviour of each individual vehicle. Even though the computational effort of this kind of simulation is much higher, this has become less of a concern with technological advances. Indeed, performing such simulations is possible with a number of microsimulation softwares, which will be discussed on the next chapter. The study of transportation networks through microsimulation is specially interesting to conduct analysis of the influence of driver's on the network or vice-versa [OMR14].

1.1.2 Human Factors, Serious Games & Driving Simulation

The synergies of transportation networks' components and drivers, i.e., the human interaction with such components, is a growing topic in scientific research [OMR14]. There are several approaches to study Human Factors (HF) on transportation, such as using Serious Games as a means to conduct behaviour elicitation, assimilation and persuasion [RAKG13].

Serious Games are "entertaining games with non-entertainment goals" [RH11]. The main objectives of Serious Games are information, education, training, and, in the case of this thesis, studying the behaviour of the players and the effects of their interactions with the transportation network. This thesis uses the concept of Serious Games intertwined with Driving Simulation.

The simulation of driving is far from being a new concept or idea, and so are driving games. Coupling different kinds of simulators has also been widely researched; such as coupling driving simulators with Advanced Driver Assistance Systems simulators [BPGF12].

1.1.3 Advanced Driver Assistance Systems

Advanced Driver Assistance Systems (ADAS), are systems that help the driver in various tasks. Several systems exist that support the driving process itself, such as lane keeping systems, safe distance maintenance or even automatic parking systems. Several others assist the driver on supplementary tasks, such as route guidance, traffic sign recognition or blind spot monitoring.

However, even though most high end cars nowadays ship with built-in embedded systems, most of the older cars don't have such devices. This brings an interesting research opportunity, which is to develop and test ADAS that run on low-cost devices, such as an Android tablet or smartphone.

1.1.4 Advanced Transportation Management Systems & Protocols

Advanced Transportation Management Systems are those which use several input data from the network and take actions in order to improve its efficiency and safety. Such systems are typically installed in Traffic Control Centres, which can, for example, use data such as video camera feeds or induction loop input to display appropriate messages to drivers using a Variable Message Sign. Typically, or ideally, such data exchanges between devices and the control centre should be standardized according to the European Datex II protocol. This thesis uses this protocol to perform most of the data exchanges. This will be explained in more detail in the following chapters.

1.2 Motivation and Novelty

The motivation of this thesis pertains the main issues of the assessment of Human Factors in ITS. Studying HF is often a complex and laborious task and can be very time consuming. Obviously, if the objective is to minimize these issues, i.e., using fully-featured and professional simulators and tools, the costs will easily become not affordable. Using state-of-the-art low-cost simulators and opensource standard tools can reliably and effectively address these issues. This, as well as being able to deploy the simulator in low-cost computers, and therefore reaching more test subjects, also leads to time compression of the tests.

There are several obvious benefits to conduct experiments on a simulated environment rather than on a real scenario. As the tests are not conducted in a real physical location, they are not subjected to travel times, traffic or other adverse conditions which could render them mute. Besides preventing the safety risks inherent to driving, simulation allows to control the test environment and manipulate it according the specificities of the study.

Introducing new concepts into the simulation, such as Serious Games and Gamification can contribute to the assessment of Human Factors and Artificial Transportation Systems [RAKG13]. The means to conduct behaviour elicitation directly lead to means of conducting experiments with Peer-Designed Agents (PDA). In turn, this leads to the opportunity of simulating accounting for different cultural and geographical aspects.

Additionally, this thesis is part of a broader spectrum research and tackles specific points of the MAS-Ter Lab project. [RB99] [ROB07] [FERO08] [RFBO08]

1.3 Goals

In order to conduct tests that permit simulators to gather data pertaining Human Factors, this thesis goal is to develop a general-purpose methodological approach that would allow researchers to couple several research and simulation tools.

To disrupt the currently existent market of simulation frameworks, a cheap solution had to be developed through which the user would interface with the simulator and the ADAS. For this thesis, the solution is the use of any low cost Android handheld device and mobile applications.

To maximize the extensibility potential of this methodological approach – by i.e. interfacing other ITS-related frameworks in future projects – it is important that all communication is performed in a standard way using a commonly used protocol. This thesis studies and adheres to the European DATEX II standard.

Finally, one of this thesis' goals is to improve the current state of the SUMO microscopic simulator [BBEK11] proposed to use in this thesis. SUMO is a widely popular free and open source simulator. However, SUMO's specific lane movement implementation makes it difficult to extend. Lanes are treated as single-dimension regardless of existing curves and intersections with a set of discrete positions where cars can occur. By implementing bi-dimensional lane movement, it becomes significantly easier to introduce a relationship between parallel lanes and intersections, as well as allowing the cars to switch to a different route more effectively. These lane movement issues will be more thoroughly detailed on the next chapters of the thesis.

1.4 Report Contents

Now that the essential context and motivation are set, the rest of this thesis is structured as follows. Chapter 2 contains the information regarding the state of the art, which includes a summary of the results of the research performed to develop this thesis as well as a discussion of related works. Chapter 3 makes an extensive overview on the essential components for the research of Human Factors, including a group of scenarios and use cases for the proposed methodological approach. Chapter 4 defines the methodological approach proposed in this thesis and is followed by the documentation of the conducted tests and validation on Chapter 5. Finally, Chapter 6 contains some discussion regarding the development of this methodology, final notes on the contributions and applications, as well as a note on future work.

Chapter 2

State of the Art Review

This chapter provides a more thorough overview of the relevant contextual background, including references and specificities on each topic. Additionally, the related work section details important research studies which contributed to the design development of the methodological approach.

2.1 Background

2.1.1 Intelligent Transportation Systems

An abstract definition of the Intelligent Transportation Systems (ITS) concept was provided on the 1.1 Context section. However, in order to fully understand the idiosyncrasies of such systems a more thorough analysis is required.

During the last centuries, since the economy transformed into a trade-based economic system, the transport turned into an essential component of our society. As transportation systems are becoming very large and complex, both in terms of structure and dimension, the whole process of acquiring information from all sources, processing the essential data and providing adequate responses timely is rather a very arduous task.

Although at the beginning the focus was put on transportation of goods new advances in technology has brought the user as a central aspect of transportation system. Now people don't travel for necessity only but also for pleasure changing thus the perspective a transportation system needs to comply with. Not only the notion of mobility system overcomes its limit, from a simple process of transportation of good and persons becomes more conscious in terms of environment, accessibility, equality, security, and sustainability of resources.

To tackle the rising issues of these new trends a new generation of mobility systems became evident with the advent of what has been coined Intelligent Transportation Systems, forcing architectures to become adaptable and accessible by different means so as to meet different requirements and a wide range of purposes. Embedded systems, wireless communications, and artificial intelligence are integrated to provide a new experience to the user. The idea of such systems is to ensure the efficient utilisation of the available road capacity by controlling traffic operations and influencing drivers' behaviour by providing proper information and stimuli.

The primary goals of traffic and transportation community are to:

- Improve travel efficiency and mobility,
- Enhance safety,
- Provide economic benefits, and business opportunities
- Conserve energy,
- and protect the environment.

In general, ITS applications have been subdivided into six interconnecting technology areas seeking to maximize the overall efficiency [Mas98] [FJM+01]:

- *Advanced Traveller Management Systems* (ATMS) - monitoring, controlling, and managing traffic in every road level. Some techniques as automated traffic signal timing, variable message signs (VMS), and virtual traffic lights, can be used to increase network efficiency and reduce congestions;
- *Advanced Traveller Information Systems* (ATIS) - provide a set of information for drivers, such as navigation, route guidance, and hazard warning, adapted to individual user's necessities;
- *Advanced Vehicle Control Systems* (AVCS)
- *Commercial Vehicle Operations* (CVO)
- *Advanced Rural Transportation Systems* (ARTS)
- *Advanced Public Transportation Systems* (APTS)

This novel scenario needs new technologies, methodologies, and paradigms that practitioners and the scientific community are hardly working on. This thesis focuses specially on ATMS, ATIS and Advanced Driver Assistance Systems (ADAS).

2.1.2 Multi Agent Systems

Multi Agent Systems (MAS) refers to a computer research domain that addresses systems that are composed of micro level entities – agents –, which have an autonomous and proactive behaviour and interact through an environment, thus producing the overall system behaviour which is observed at the macro level. Within the system, agents interact one with others pursuing to accomplish a set of goals. The goals can be consider either in individual or collective level [Les99]. MAS may contain multiple agents building up a "population". These systems are characterized by asynchronous computing and no global system control where each agent has limited and different capacity of perception and acting upon the environment. That is, each agent has a distinct circle of influence being it just able to influence certain parts of the environment [Jen00]. In addition, these circles of influence may overlap depending on the agent's relationship and from this social behaviours may arise. As such, agents negotiate coordination due to the capacity to act upon overlapped circles, or compete for a resource that might be important for achieving their goals.

Besides the amount of agents, an agent-based system can be homogeneous (all agents are of the same type), or heterogeneous (different types of agents). Several issues arise in heterogeneous MAS. Stone and Veloso [SV00] provide a thorough description of the field of MAS. Authors present a survey of MAS literature discussing a taxonomy based on the degree of heterogeneity and degree of communication in the design of MAS. A particular characteristic of some agent-based system is related to the openness of the system. As open MAS, are characterized these organizations where the actual agents that will populate the system are not known at design time and where agents may leave and join the system at any time.

2.1.3 Multi Agent Systems in ITS

The increasing interest in the (multi-) agent paradigm results from the inherent propriety of the paradigm in decomposing a system into multiple agents to achieve a global goal. The traffic domain is composed of various complex systems, where agent-based solutions can be envisaged since the constituent elements of each system can be naturally identified using the agent metaphor, e.g., air traffic control, transportation planning and scheduling or road traffic control. In many of these applications the question that arises is how various individual entities can work together to achieve a common goal.

The multi-agent research tries to answer this question. Thus, the objective designers set it is to find a decomposition of a complex problem and a proper allocation of tasks among a team of problem-solvers in such a way that the collective and co-joint actions result better than they work individually. In this context, Parunak [Par99] suggests an ideal setting for application of MAS having the following characteristics: modular, decentralized, dynamic, not completely structured and complex. The domain of traffic and transportation systems is well suited to an agent-based approach because of all the features mentioned above.

In particular, one may identify a number of main motivations for using agents and multi-agent system technologies in traffic and transportation:

- Natural and intuitive problem solving by active entities with a (potential) local perspective, instead of complex, central solutions for which the inclusion of all necessary details and constraints is not feasible. Adaptive and robust services can be provided due to their self-organization capability.

- Autonomous agents provide an appropriate basis for modelling heterogeneous systems. Every entity may possess its individual architecture, state representation, and behaviour. Thus, an arbitrary level of detail can be included into a simulation model or an arbitrarily sophisticated problem-solving framework can be applied on the agent level. The integration of legacy software is facilitated by using an 'agent wrapper'.

- Agents and their interaction can be described using high-level abstractions. Thus, they provide an intuitive level of interaction between human users or modellers and the agent-based system. Here, an important related issue is the visualization, which facilitates the analysis and control of microscopic properties of a given system.

- Agents or MAS technologies allow coping with variable structure of the system in an elegant and efficient way. If the active entities are modelled as agents – in control and management applications as well as in developing simulation models – they may control when and with whom they are interacting. These (dynamic) relations may be controlled, disconnected, or established from the local point of view. Agents may be able to adapt their behaviour to a changing organization. This flexibility is highly relevant in traffic and transportation domains.

- The agent metaphor used for modelling a traffic participant or decision-maker enables us to capture complex constraints connecting all problem-solving phases. The agents (and their reasoning capabilities) may be persistent in their context and environment. This leads to the possibility of tackling entities over their complete "life span" in a consistent and coherent way.

There is a number of examples reported in the literature which mainly with traffic and transportation management, as well as with microscopic representation of human entities behaviour, especially drivers. Although, the number of works applying MAS in other aspects of traffic and transportation is increasing, including modelling and simulation, dynamic routing and congestion management, and decision support.

An extensive review on agent-based technology in transportation domain can be found in [CC10] [BK14], where the reviewed works are grouped into two categories: modelling and simulation, and control and management. Quite common conclusion of both the surveys is the establishing of the potential of employing agent technology to boost and advance the performance of traffic and transportation systems. Albeit the promising perspectives of the technology, most agent-based applications focus only on modelling and simulation. Few real-world applications are implemented and deployed. Following the general feelings of the industrial and business practices, also in transportation domain there is a lack of confidence in agent-based approaches [BML+06], [WHH09].

The integration of agent paradigm into existing (and future) ITS solutions should be considered to enhance the flexibility of systems and the ability to deal with uncertainty in dynamic environments.

This thesis studies agents related and directed to traffic simulation, specifically the Driver-Vehicle Agents. This term refers to the idea that a single entity, i.e. the agent, incorporates the complex human driving behaviour as well as the properties of a vehicle. The behavioural part of this entity reasoning is based on the decision-making process in a short or long term basis taking into account the characteristics of human behaviour in a given situation e.g. the quick overtaking decision or the re-routing in a network. These variations in the complex human behaviour are modelled using mathematical models whereas the external part of the agent is related to the physical properties of the vehicle, like fundamental laws of kinematics. There is a great number of examples reported in the literature which use this powerful approach mainly with traffic and transportation management, as well as with microscopic representation of human entities behaviour e.g. especially drivers.

2.2 Related Work

The Artificial Transportation Systems [Wan03] [WT05] concept has been one of the main research topics in the IEEE ITS Society [RLT11] [KMR+14] [PRK11]. A typical approach to ATS modelling and development is the MAS metaphor. In this approach each vehicle can be seen as an agent of the system. Another potentially concomitant approach to this modelling is the HLA concept. The concept is based on the idea of distributed simulation, that is, to meet the requirements of all usages and users more than a single simulation model should be used [MKS+13]. These concepts can be consolidated to integrate multiple simulators so as to achieve more realistic simulations.

2.2.1 Simulator Integration

The literature has an increasing number of studies regarding simulator integration, both in transport studies as in other areas [SKMR14] [PR12] [MKS+13]. Punzo *et al.* [PC11] propose to integrate SCANeR driving simulator and AIMSUN traffic-flow microsimulation model. Their attempt is to tackle the mutual-dependence between the driver's behaviour and traffic conditions.

Microsimulation regards simulating and tracking individual vehicle movements. Developed at DLR, the Simulation of Urban Mobility (SUMO) simulator aims at microscopic traffic simulation [BBEK11]. The MAS metaphor arises as an indisputable methodology to perform microsimulation. Using MAS capabilities and coupling SUMO with other simulators has been researched elsewhere [MSAN11]. Macedo *et al.* [MKS+13] have studied a HLA-based approach to simulate electric vehicles in Simulink and SUMO. Driver-centric simulation has been research by Gomes *et al.* [GOMFD11], where they have developed a simulation tool that provides feedback back to the network based on the driver's behaviour.

2.2.2 Human Factors in Transportation

Driving simulators are no doubt an important tool when researching ATS, specially so when studying the influence of human factors in driving faults [GROM12] [AGR+13]. These faults often occur in direct consequence of performing secondary tasks while driving [KMS+08].

The top, state-of-the-art simulators are usually the high-fidelity, human-in-the-loop simulators [Slo08]. Typically, these simulators have motion simulation and provide the driver a high field of view. The modern high-fidelity simulators have 9 DOF [SGP03] and can even include a full 360 degree dome [bYLKL06].

These simulators serve a multitude of purposes in terms of scientific research. For instance, the Leeds University simulator [Jam07] is used to research topics such as the effects of automated systems on safety and driver comprehension of traffic signs. Just as the NADS-I [DWWD+07] is used to conduct tests that are too dangerous or even illegal and/or unethical, such as the effects of illness, drowsiness, inattentiveness etc. A system comprising a large scale driving simulator, built in a 360 deg full dome with 3D scenes from real city area has been developed by [bYLKL06]. The system contains a multitude of features such as real-time hardware-in-the-loop, wireless communication devices and bio signal analysis and is used to develop and test ADAS as well as Advanced Safety Vehicle, ITS infrastructure and others.

However highly technological and high fidelity simulators are typically expensive and lack the extensibility and portability of the low-cost simulators. A low-cost and reconfigurable driving simulator with several components to accommodate different ADAS testing or training is proposed by Hassan *et al.* [HBAQS13]. A framework for ADAS assessment and benchmarking has been developed elsewhere [NEI12], with configurable scenarios and 3D scenes and multiple sensors input. Miao *et al.* [MZL+11] introduce a game-engine-based simulator for modelling and computing platform for ATS. They describe the artificial population both in their macroscopic and microscopic aspects.

Gruyer *et al.* [GPG13] developed a Full Speed Range Adaptive Cruise Control with their platform for ADAS prototyping and evaluation, SiVIC. The platform is capable of reproducing the vehicle and sensors behaviour in a realistic fashion, according with the configured environment in the simulator. The developed platform also simulates noised and imperfect data.

Another step towards low-cost simulator was made at LIACC, where the IC-DEEP low-cost serious-game driving simulator [GROM12] has been developed. This simulator can be used to conduct human factors experiments in controlled scenarios. However, it lacks extensibility, ie., the experimentation setup was hardcoded in the simulator.

2.3 Datex II

The European Commission successfully developed and deployed DATEX as a reference that makes possible the coordination of the different ITS throughout Europe. [STPC12] DATEX enables information centres to access diverse kinds of traffic information from independent sources, such as traffic levels and incidents, weather conditions and forecasting.

In its current version, different projects are currently using DATEX II. In [TBL08], a real life Spanish traffic management plan is analysed with the goal of proposing a guideline for ITS development which uses DATEX II. In [SM12], three large scale European projects are presented (CVIS, SAFESPOT and COOPERS) that intend to bring two-way communication between cars and the infrastructure. As such, they support Datex II in this interaction. In Poland DATEX II was also chosen as a communication protocol by the Polish National Traffic Management system, as a means to unify inter-regional traffic data transfer [TPM+12]. Austria has also developed a real time traffic notification system based on DATEX II [CSB08].

The Datex II standard dictates the structure of the messages exchanged between elements of a transportation system. Communication can have different intents and hold various kinds of information.

- *Traffic Elements* – Pieces of information directly related to the traffic such as incidents, abnormal congestion zones and activities on the road.
- *Operator Actions* – Contains instructions from the network management to the vehicles such as rerouting suggestions, variable road sign messages or alternate lanes and roads.
- *Lane Information* – In some roads, certain lanes may be congested or closed.
- *Non-road Events* – Information about car parking availability or data feeds for external information dashboards.
- *Measured Data* – Data measured from the vehicles in the system, including travel times, weather conditions and other statistics.
- *Elaborated Data* – Aggregated data from the measure data of multiple vehicles.

2.4 Summary

The literature review shows an interesting research opportunity at hand, viz., that there is a necessity to put together a suite of tools to support Human Factor Studies in Transportation Systems. This suite is specially interesting when coupled with driver and micro simulators. This coupling is fundamental as to support the research of the impact of application's ergonomics in a multitude of issues, such as in the driving style, in the vehicle safety, the driver's comfort. Conjointly, this coupling is also useful to study the impact of human behaviour on the traffic settings.

Chapter 3

Human Factor Research Requirements

As explained on section 1.2 Motivation and Novelty, the main goal of this thesis is to devise a general purpose methodological approach for conducting studies on the transportation research field by the means of simulation. Conjointly, the methodological approach should allow for the inherent specificities of different studies, or, at least, provide easy extensibility. In order to observe these requirements there is the need to identify the fundamental software components that generally take part in a Transportation Network.

This chapter provides an overview of the fundamental aspects taken into consideration while devising the methodological approach. It also details the foreseen use cases and scenarios. Finally, it presents a final overview of the requirements and the expected impacts on the design of the methodological approach.

3.1 Components

Transportation Networks can be quite diverse in nature, ranging from automotive to nautical or aerial. Typically a Transportation Network has a support structure to allow vehicular movement. This thesis deals with automotive Transportation Networks, as such, its supporting structure is mostly composed by roads and streets.

However, this section identifies the software and research components necessary to conduct efficient Transportation studies.

3.1.1 Microscopic Simulators

Micro Simulators provide the means to study a transportation network in detail by simulating each individual vehicle's behaviour on each simulation step. In fact, several studies on Transportation can be conducted using only microscopic simulators; such as routing studies, fuel consumption and emissions, traffic and lane ocupancy or even traffic light optimization studies.

The thesis has a special focus on the open-source Simulation of Urban MObility (SUMO) micro simulator. However, the first steps for developing a new microscopic simulator that supports lateral movement on the lane are also provided, the justification for this development is explained in .

As explained on 2 State of the Art Review, other microscopic simulators where not taken into consideration as they are either not widely used, commercial, or not open-source.

3.1.2 External Applications

This thesis considers external applications as applications that do not have a direct impact on the network, but provide its users or operators means to use it more efficiently. There are several kinds of such applications, including:

- Advanced Driver Assistance Systems (ADAS) – applications that assist the driver on the driving process, such as Google Drive or Google Waze
- Advanced Traffic Management Systems (ATMS) – typically operated by control centres for several purposes, such as to increase network efficiency, to warn its users of potential dangers by using Variable Message Signs (VMS) or radio broadcasts, to request network maintenance, amongst others
- Variable Message Signs (VMS) – provide circumstantial information to the network users; can be used to display textual messages or even to set different traffic rules
- other network components such as Traffic Cameras or Sensors

It is potentially interesting to conduct experiments on Human-Factors using such external applications; for instance, to test how the drivers response matches the expected results when developing an ADAS or when using a VMS to set a speed limit.

3.1.3 Driving Simulators

Driving simulators can also be used to conduct interesting research on Transportation, specially so on Human-Factor studies. Moreover, using driving games, or adding gaming characteristics to driving simulators is also an increasingly popular approach for such studies. [RAKG13] Several scientific research driving games exist [WEG+00], including some Human Factors studying specific [GROM12].

In fact, by coupling a driving game or simulator to a traffic simulator such as SUMO the driving user experience can be enhanced, by providing the simulation environment with more realistic traffic generated by the microscopic simulator.

However, in order to couple a driving simulator and a microscopic simulator, the data representation on both simulators has to be consistent. This poses a problem when using

SUMO, as the vehicles on the simulator only have one degree of liberty on the lane, as seen on Figure 3.1. These facts led to the development of a prototype microscopic simulator, codenamed PyRoad, which would overcome such problem.

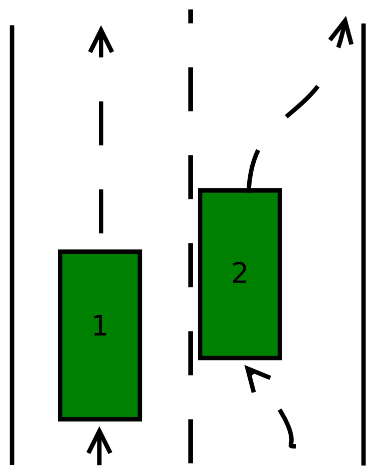

Figure 3.1: (1) 1DOF lane movement, such as in SUMO; (2) lateral lane movement, such as in PyRoad

3.2 Communication Protocols

A key component to the Human Factors research by simulation is the communication between each individual piece of the running simulation. Several methods can be used for the purpose of simulation synchronization and representation. Typically these communication methods or protocols are custom to the specificities of each research scenario. A number of studies use raw-data UDP or TCP sockets over IP; others may use higher level abstractions such as JSON or XML, even using XSD files to ensure data consistency. Others yet might be dependent on the specific tools used in the development, such as using the TraCI protocol for the SUMO microscopic simulator. [WPR+08]

A better approach to solve this problem is obviously the standardization of the communication protocols. Datex II, with its increasing usage and its European Comission backing is the obvious choice and is used on this thesis; specially on the communication between ADAS and ATMS, ADAS and simulators, and ATMS and simulators.

3.3 Scenarios and Use Cases

There are several scenarios and use cases for the proposed methodology. This section presents a number of them in order to show the methodology's usability in several distinctive ways.

3.3.1 ADAS Testings

Human Factors research of Advanced Driver Assistance Systems is the main use case of this thesis. Typically, such studies can be conducted be integrating the tested ADAS onto a driving simulator. The driver uses the ADAS, which has access to all the necessary information from the simulator; this perceptive use of the ADAS information has a possible impact on how the user is controlling the vehicle, as seen on Figure 3.2. The ergonomics of the ADAS and its impacts on the network is what remains to be studied by a Human Factors research.

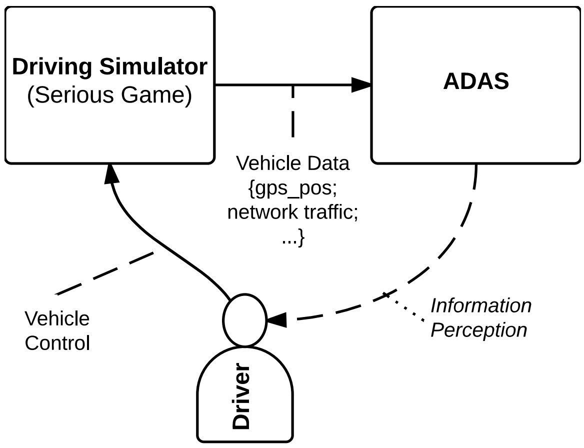

Figure 3.2: ADAS Testing with driving games

For the purpose of this thesis the tested ADAS are developed for mobile handheld devices and as such they should be coupled with the driving simulator by means of a communication protocol. The ADAS can receive information such as the current position of the vehicle and emulate it on the device, thus allowing for GPS ADAS testing. Passing other information to the ADAS, such as local speed limits, network traffic or traffic light information should also be possible.

This exchanged information is potentially limitless, so the protocol should allow custom data exchanges. Using Datex II is again interesting as this protocol not only foresees quite a big number of transmitted data but also provides the necessary tools for the protocol extensibility.

3.3.2 Living Labs & ATMS

Having a naturalistic data pool is invaluable in terms of research validation [MTT14]. Providing a living lab to conduct Human Factors studies is therefor an even more interesting, yet challenging, research concept.

Living labs are typically user centered, which means that the subjects of the study are, simultaneously, sources of data. [LRB09][FRK+14][C+12][ZRC14]

In Transportation studies such input data can be obtained, for instance, via an ADAS which is simultaneously providing the users with network information, while feeding back the handling and reactions of the users.

Another example would be to have a microscopic simulator which would have input data provided by real life network sensors, such as induction loops and traffic cameras, such as depicted on Figure 3.3.

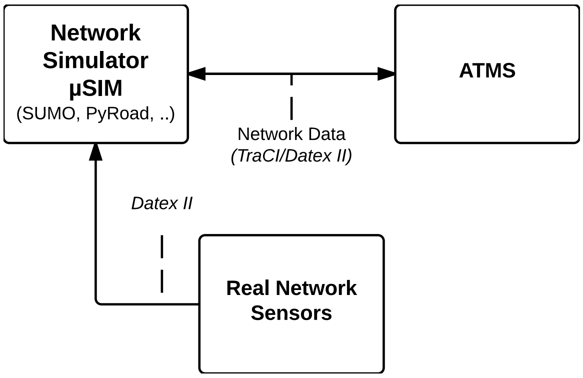

Figure 3.3: Living Lab with ATMS & Micro Simulators

This would provide a valuable test-bed for Transportation Control Centres, which could then study on a simulated, safe, yet realistic way their Advanced Traffic Management Systems.

3.3.3 Others

The studies of behaviour elicitation, assimilation and persuasion are common in the Human Factor research field [RAKG13]. In fact, studies show how gamification techniques applied to realistic driving simulators can have a significant impact on the users real-life driving style. [GROM12] [GGROM14]. A depiction of a possible architecture for such systems is seen on Figure 3.4.

Other studies should be possible on the methodology, even if at the cost of some minor development in order to provide data and scenario extensibility. Indications of how to achieve such extensibility are given on the project code documentation.

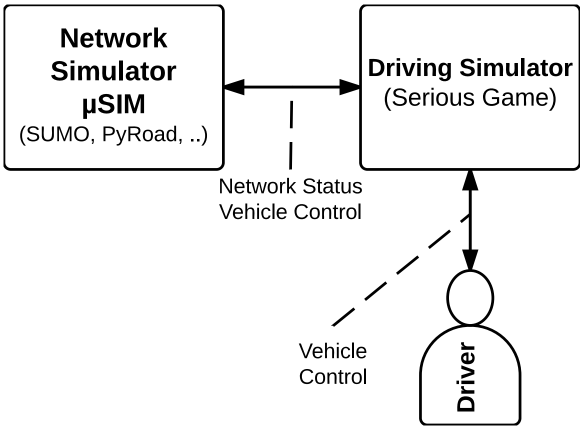

Figure 3.4: Living Lab with ATMS & Micro Simulators

3.4 Summary

A complete list of the typically-present components in Human Factors in Transportation Systems research was elaborated. This, as well as the interesting technological contributions, such as standard protocols usage, provided the basis for the use cases composition.

Several use cases and scenarios are foreseen. These scenarios are developed and deployed later on the thesis, as seen on Chapter Validation.

Chapter 4

Methodological Approach

Following the research and identification of the major components of Transportation Systems along with those required to conduct Human Factors studies, this chapter details the proposed methodological approach.

4.1 Proposal

The proposed methodology takes into consideration the identified Transportation network components, the communication protocols and the usage cases and scenarios. A high-level overview of the methodology is depicted on Figure 4.1.

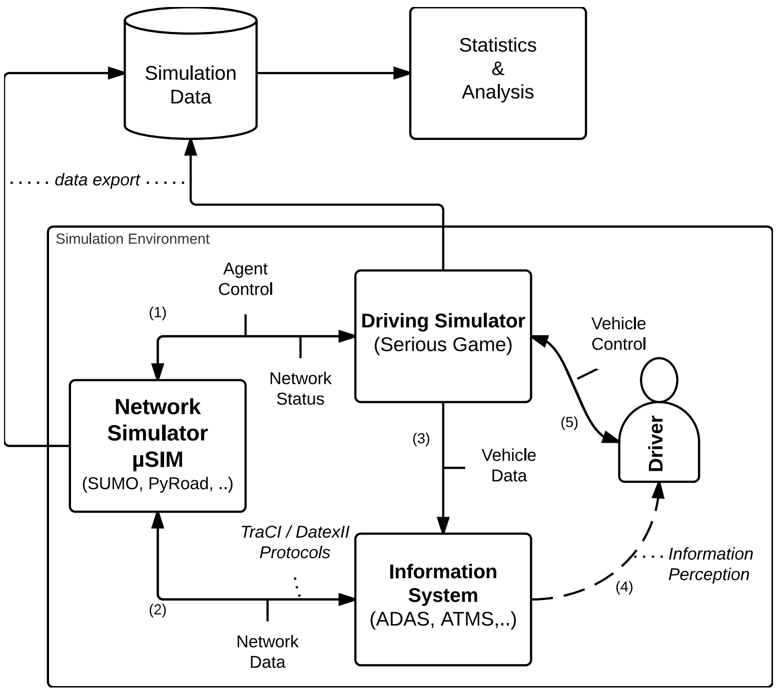

Figure 4.1: Proposed methodology

The methodology has an agent-like approach to the interaction between Driving Simulators and Traffic Micro Simulators (1), i.e., at each simulation cycle the network information is updated to the Driving Simulator which is then requested to inform the Micro Simulator of the taken action, if any. There are no specificities as to what protocol to use on this data exchange as this is highly variable. The Micro Simulator can, in fact, be considered the main module of the system; it is responsible for the network's multi-agent microscopic simulation, and has multiple driving agents. This also makes the proposed methodology a convenient approach to study Multi-Agent Systems (MAS). In such cases, the Micro Simulator component is responsible by providing an overview of the whole MAS and can be manipulated directly. The Micro Simulator component also acts as a "central server", providing the other components with the updated network status.

The interaction between the Micro Simulator and the various Information Systems is done using Datex II data exchange protocol (2). This standardization allows for easily pluggable components and for results verifications amongst different simulators and systems.

The exchanged data between the driving simulators and the Information Systems, such as an ADAS, is also done using Datex II protocol (2). However, there are cases where using Datex II is unnecessary, such as when the exchanged data is not so complex. For such cases the methodology recommends using JSON dictionaries.

Depicted on the figure above are also the typical "Human Interactions" with the systems and the basis for the Human Factors studies. The user perceives the incoming information by the information Systems (4) and takes a corresponding action by controlling the vehicle (5).

Finally, the methodology also incorporates a Statistics & Analysis suite which resorts to the saved simulation data.

4.2 Micro Simulator Prototype – PyRoad

The vehicles on the simulation can be defined as agents [RBB+02] [RL05b] [RBL+00] [RL05c] [RL05a] [WEG+00], and, more specifically, as Practical Reasoning Agents, i.e., agents that reason in order to perform some action [Woo09]. The Beliefs-Desires-Intentions (BDI) is a commonly used conceptualization for designing and building such agents. The architecture of the simulator somewhat follows the main concepts of the BDI approach. Defining cars as the agents in our environment, beliefs or perceptions about the world are then implied from the inputs that each car receives through it's sensors. The information provided by these sensors is related to the status of the network, the status of other agents (such as their position, speed, acceleration etc.) or the status of the own agent in the world. In the prototype's conceptualization, the desires of each car can vary from achieving a certain destination to following a certain set of points in the network. The available plans to each car in a given moment in time are a set of all the action possibilities at that moment, viz., the actions that it can perform in order to presumably reach the specified goal. Filtering functions are used in order to trim out actions that don't lead to the fulfillment of the goals. Finally, in order to achieve their desires, cars should perform some means-ends reasoning about possible plans, ie., according to the available means, they should figure out how to reach their end goal. In order to perform a rational reasoning, cars use filtering and utility functions.

The architectural implications of this concept are seamlessly integrated with the overall simulation tool. There is a given output to the agents and they are "simply" expected to provide some output. This is to say, agents can be seen as functions and indeed they can also be programmed as such. The internal calculations or algorithms of the function are not important to the overall simulation tool, ie., there is merely a "request for action" to each car on each simulation step and a calculation of the new simulation state based on the set of all actions.

4.3 Development Focus

Due to time constraints there was the need to prioritize the thesis development. As such, the development focus was mostly on the communication protocols and on the prototype Micro Simulator. Specifically, the main components developed on the thesis were:

- A bidirectional conversion tool for Datex II and TraCI, as in (2) in Figure 4.1
- The lateral-movement Micro Simulator prototype, codenamed PyRoad
- An Advanced Traffic Management System – which communicates with the Micro Simulator using Datex II, providing it with "real-data", as in (2) in Figure 4.1
- A second Advanced Traffic Management System – which communicates with an ADAS to reroute drivers in case of traffic disruption
- An Advanced Driver Assistance System – which is connected with a driving simulator, warning the driver in case of over speed, as in (3) in Figure 4.1
- A second Advanced Driver Assistance System – which communicates with either the Micro Simulator or with an ATMS, and indicates the user both the speed limits and eventual traffic reroutes, as in (2) in Figure 4.1
- A complete usage scenario – containing an ATMS, an ADAS and the SUMO micro simulator – using realistic data from the municipality of Bologna. This usage scenario provides the final validation of the methodology and is explained with more detail on the Validation chapter.

Chapter 5

Validation

The validation process of this dissertation is divided into two main components. Firstly, there are validations of individual components such as the Advanced Driver Assistance Systems and the Advanced Traffic Management Systems and also validation of connection between components such as connecting an ADAS to SUMO to check for data consistency, or connecting an ATMS to SUMO to check for "living-lab"-like input.

Secondly there is a validation by using a complete setup of the methodological approach, much as in a real Human-Factors study. This applicational example of the methodological approach provides the definitive proof of its usability and feasibility.

5.1 Advanced Driver Assistance Systems

The developed Advanced Driver Assistance Systems were coupled both with the driving simulator and with the microscopic simulator SUMO.

5.1.1 Speed Limit ADAS

This application was coupled both with the driving Serious Game IC-DEEP and warned the users of overspeed according to the current maximum speed of the lane, as shown of Figure 5.1.

The validation of the application was basically that of the data consistency between the simulation state of the driving game and the displayed information on the ADAS. As the tests were run on a local network the results were almost always perfectly accurate, only exceptions being small delays when the network usage was too high.

The exchanged data between the IC-DEEP driving game and the ADAS was done using a JSON dictionary over a TCP/IP socket as the contents of each message are not complex,

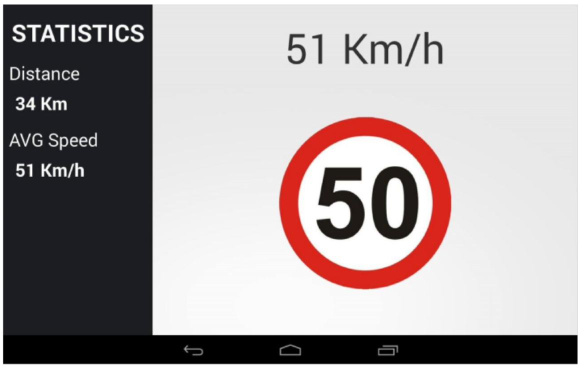

Figure 5.1: Example run of developed Speed Limit ADAS

i.e., the values of the GPS coordinates and the current speed limit; however it could easily be adapted to use Datex II if the situation would require it.

5.1.2 Rerouting ADAS

The developed application is similar to the Speed Limit ADAS, however it provides the user with broadcasted information about traffic incidents and suggests appropriate rerouting instructions, as shown on Figure 5.2.

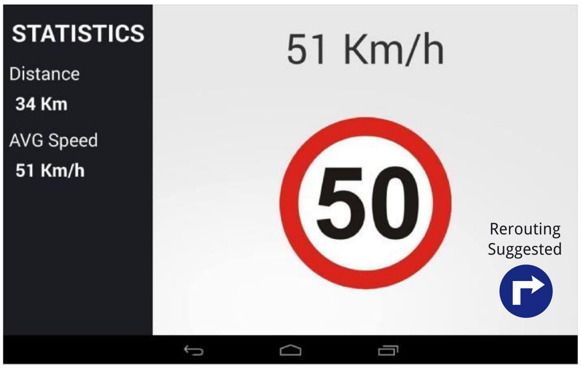

Figure 5.2: Developed Rerouting ADAS

The information is broadcasted to the by an ATMS which is shown on the next section. The data exchanged is done using the standard Datex II protocol. As such, if the developed conversion library is integrated into SUMO, it would be safe to say that in the future such communication could happen directly from it.

5.2 Advanced Traffic Management Systems – Rerouting

In order to test the coupling of an Advanced Traffic Management Systems with the Microscopic Simulators a rerouting application was developed. A simple network was constructed with only one possible rerouting strategy, as seen on Figure 5.3.

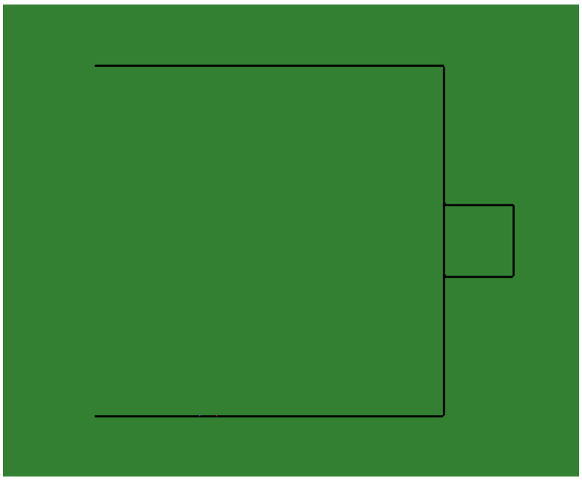

Figure 5.3: Validation scenario for ATMS Rerouting

The application, which is here acting as a traffic control centre operator, scans the network for traffic incidents such as a stopped vehicle. If a stopped vehicle is detected, the ATMS automatically warns all the vehicles approaching the incident location and aditionally suggests an alternative route that, potentially, takes into consideration each vehicle's destination. Figure 5.4 shows the scenario's traffic incident with an approaching vehicle.

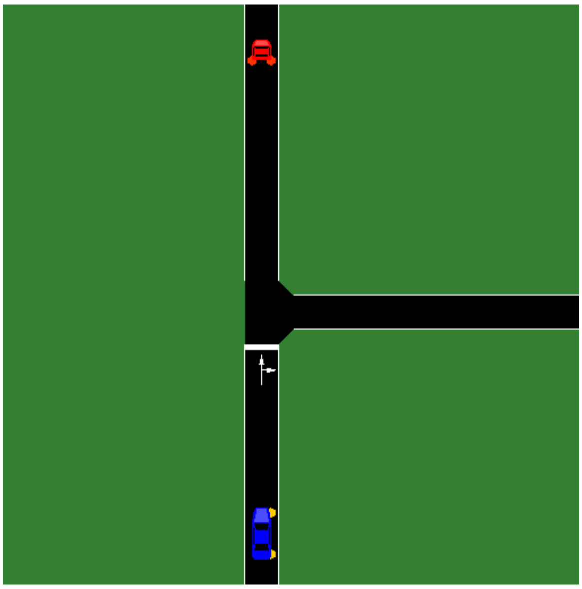

Figure 5.4: Vehicle turning right upon being informed of network congestion

The approaching vehicle already has the turn signals turned on as it was informed of the incident via the ATMS directly; however, such information could easily be transmitted by the Rerouting ADAS ilustrated on the previous section.

5.3 Bologna SUMO Scenario

This full-featured usage of the methodological approach attempts to provide a clear and indisputable validation of the thesis. It uses naturalistic data obtained from Bologna municipality [BKM+15], both in terms of the network infrastructure, but more importantly, in terms of network demand and usage. With this kind of data available it is much easier to experiment with network operations such has traffic light optimization or vehicle rerouting.

Indeed, this scenario includes an ATMS application that provides SUMO vehicles with rerouting instructions to overcome a traffic incident or an overload lane. This is particularly interesting and it would prove useful for control centers to simulate the impacts on the network of the possible rerouting strategies, before actually transmitting them to the real network itself.

This "real-data" experiment is detailed on Figure 5.5. Firstly, the real, or naturalistic, data is inputed to the SUMO microsimulator. Then, upon detecting a network anomaly, a traffic control operator can experiment different operations and test them on the simulator. When a viable solution is found, it can be transmitted back to the real network by means of a Variable Message Sign, an ADAS or radio broadcasting.

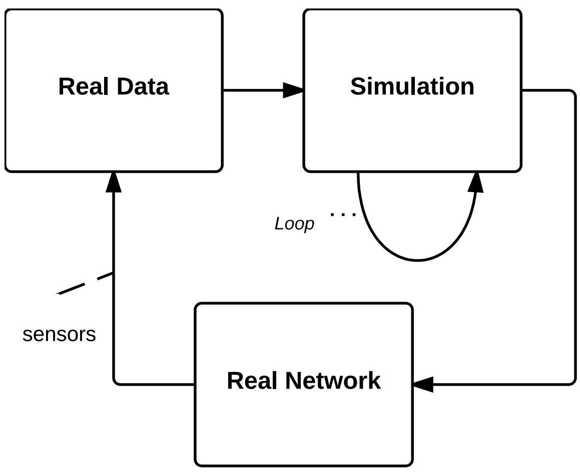

Figure 5.5: Living-Lab-like experimentation

This scenario attempts to mimick such interaction using a traffic jam situation near the Bologna football stadium. The ATMS applications sends rerouting instructions to the current vehicles on the affected lanes by using an ADAS. This information is also transmitted to SUMO directly, as the ADAS communication only serves demonstration purposes for the thesis as a mimicking the broadcast.

Figure 5.6 shows the real world location of the simulation study and Figure 5.7 shows the the same location represented on the SUMO microscopic simulator.

Figure 5.6: Corresponding Bologna map

Figure 5.7: Bologna scenario on SUMO

A proposed routing is then sent to the simulation and transmitted to the vehicles which are currently stopped on the lane, which immediately start following their new route. This new rerouting is a bit challenging, however, as having the pre-knowledge of the routes the vehicles intend to follow could greatly optimize the route, and not knowing it might make them take unnecessary paths. However, SUMO vehicles after a clearly defined route which can be accessed and also substituted at any moment. It is worth noting that if the ATMS application was not communicating with SUMO, i.e., there would be not suggestion of new routes, the vehicles would simply wait until a timeout was reached, only to then teleport on the next lane of their route. As such, it would defeat the purpose of having naturalistic data, and so, it is arguable that the ATMS application could enhance SUMO rerouting capabilities. In the course of the SUMO experiments, values of fuel consumption and travelling speed were gathered to demonstrate the effect of the use of the rerouting mechanism on the behaviour of the vehicle.

In Figure 5.8 and Figure 5.9, the vehicle's fuel consumption are compared. The difference is that in the first one the rerouting was not enabled. Therefore, when the car jam hapenned, this vehicle was notified ahead of the time. It is evident that the vehicle never stopped driving the Figure 5.9.

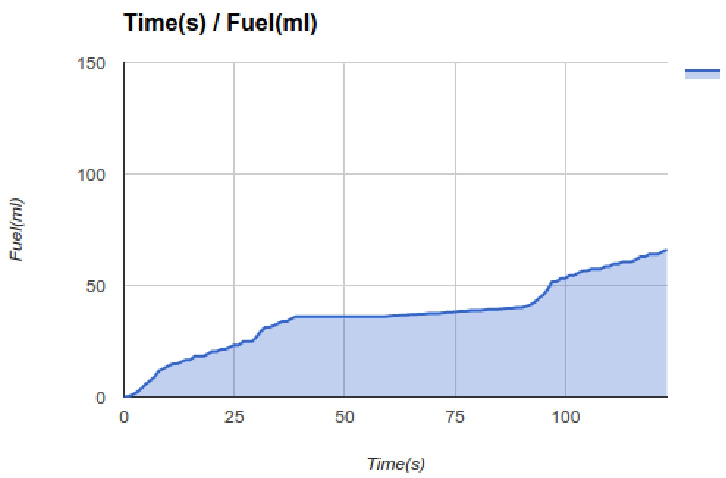

Figure 5.8: Fuel vs time chart

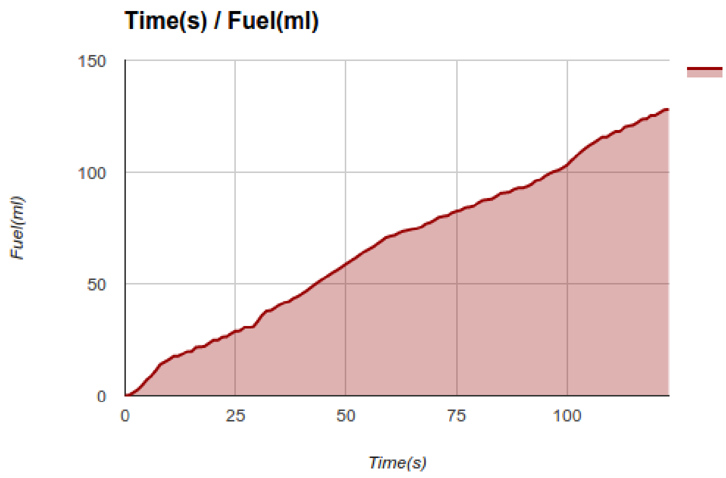

Figure 5.9: Fuel vs time chart with ATMS

Figure 5.10 and Figure 5.11 reinforce the demonstration of this effect. The vehicle was able to maintain its speed by rerouting while it was completely still in the first case. These results show that the simulation and rerouting were working as expected.

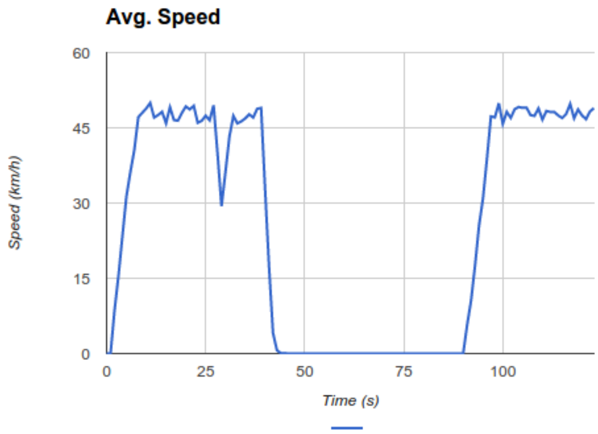

Figure 5.10: Average speed chart

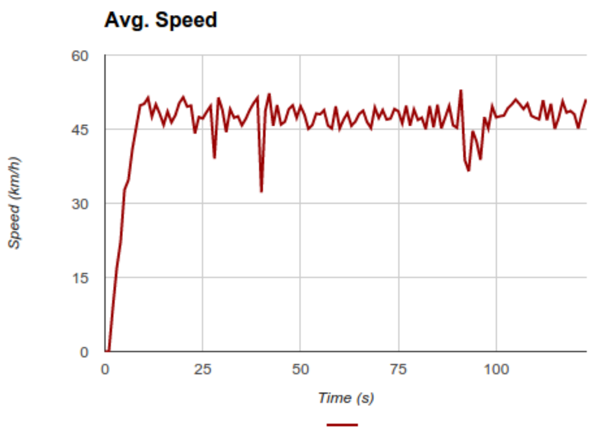

Figure 5.11: Average speed chart with ATMS

The integration of all the components of the methodological approach as well as being able to conduct a simple study which includes concepts of the Human Factors research field provides the final validation of the methodological approach usability.

5.4 PyRoad

The validation of the Microscopic Simulator prototype was conducted by experimenting with the vehicles "route following" mechanisms.

As mentioned in the Methodological Approach chapter, agents can be abstract as mathematical functions. Therefor, the implemented prototype deals with the vehicle routes in such fashion, i.e, the "routes" of a given vehicle for a given time period are defined by a mathematical function. Such inputs were provided by an input file or by an external entity which would be able to control a vehicle by the means of a TCP/IP socket.

Figure 5.12 shows a screenshot of the prototype, containing two vehicles moving with two degrees of freedom on an open field.

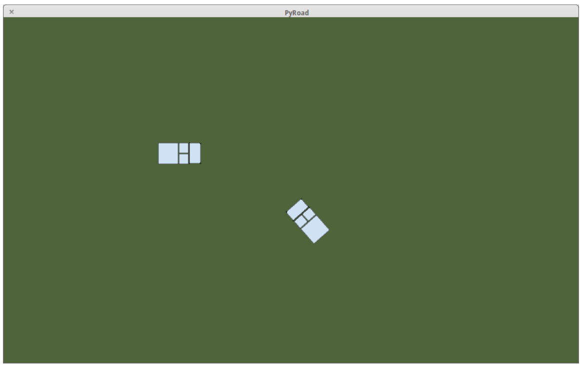

Figure 5.12: Screenshot of microsimulator prototype – PyRoad

The PyRoad Microscopic Simulator does provide a collision detection mechanism, however, the developed agents do not consider such information into their decision process.

Tests regards the communication protocols were conduct and proved the interoperability of the prototype with the SUMO microscopic simulator.

5.5 Summary

The validation of the methodological approach has proven its usability and feasibility when applied to the foreseen usage scenarios. Several applications were developed and assessed using the developed methodological approach. The more fundamental usages paved the way for a full featured implementation using naturalistic data from the SUMO Bologna scenario. This full featured implementation lead to the analysis of a possible rerouting situation on a traffic incident scenario.

Additionally, the developed microscopic simulator prototype was empirically tested to meet the fundamental basis of such a simulator. However, further testing regarding the coupling of such simulator should be conducted.

Chapter 6

Conclusions

Human Factors on Transportation Systems is a challenging and interesting research topic. The literature has an uncountable number of such studies, however there isn't a clearly defined methodology to implement and conduct them. This thesis proposes a novel approach to test and experiment with human factors in Intelligent Transportation Systems.

6.1 Proposal Overview

The proposed methodological approach establishes a base simulation scenario and setup to conduct HF studies. The main advantages of using simulation to conduct HF studies are related with costs, time-compression and safety. The proposed system has a wide spread of applications such as testing driving behaviours and ergonomics, conduct experiments with Peer-Designed Agents to simulate driver's idiosyncrasies effects on the ATS and prototyping and validating Advanced Driver Assistance Systems.

More specifically, the thesis has five identifiable focus:

1. Development of a SUMO/TraCI bidirectional conversion library, justified by using a European standards on an widespread and popular (big community and active development) opensource microsimulator.

2. Development of a microsimulator prototype with lateral lane movement which should be couplable with the overall system.

3. Development of a mobile application prototype which communicates using Datex II protocol

4. Development of an ATMS application which uses DatexII/TraCI and communicates with SUMO and an ADAS.

5. Planning and development of a methodological approach to study Human Factors on Transportation.

6.2 Contributions & Applications

The thesis has a number of identifiable applications, both on applicational and scientific level. The development of a prototype microscopic simulator with lateral movement, the development of a Datex II/TraCI conversion tool, the two mobile Advanced Driver Assistance Systems applications and the development of an ATMS to deal with traffic rerouting on SUMO are the main applicational contributions. The literature review, the novel methodological and the published papers compose the scientific contribution of this thesis. A first attempt at defining an architecture for conducting ADAS testing and experimentation was published to the Intelligent Vehicles conference [GRJ+14]. An extension of this attempt was published on the SUMO conference and was selected to appear on the Springer Lecture Notes on Mobility [GJR+15]. An Human Factors study using the IC-DEEP driving simulator was also published on the Intelligent Transportation Systems (ITSC), 2014 IEEE 17th International Conference [GGROM14]

There are several applications for the developed methodological approach, other than the traditional microscopic simulator applications. For instance, by the means of allowing users to control a single car, the methodological approach has the potential of being applied in a variety of Serious Games studies. In fact, the proposed simulator would be perfectly fit to research on drivers' behaviour. For instance, studying behaviour elicitation, i.e. the effects of the user in the general traffic or how the user adapts to the traffic; and also behaviour assimilation, as trying to "educate" the user in some specific way.

Supporting Multi-Agent-System studies Another is an obvious corollary of previously shown examples, i.e most of the proposed applications use an agent-like abstraction. In particular, peer-designed agents would be an interesting research follow up, as shown by previous studies. [RAKG13]

6.3 Future Work

There is a number of identifiable future work. The most obvious and immediate one would be to provide an implementation of Driving Simulator and Microscopic Simulator coupling, with respective validation of its feasibility.

The microscopic simulator prototype – PyRoad – has several interesting research and development opportunities. Such has developing a collision detection and avoidance mechanism, applying different MAS-based approaches to the driving vehicles and also improve the physics engine.

Other minor enhancements would also be desirable, more specifically, it would be interesting to increase the supported Datex II and TraCI communications in order to support more elaborate research studies. It would also be useful to develop a quick-deploy guidelines document to minimize the initial setup time.

Appendix A

Published Research

This appendix contains the related scientific papers published with this dissertation work.

16 Towards a Mobile-based ADAS Simulation Framework

João S. V. Gonçalves[1], João Jacob[2], Rosaldo J. F. Rossetti[1], António Coelho[2] and Rui Rodrigues[2]

Departamento de Engenharia Informática, Faculdade de Engenharia da Universidade do Porto
[1] Laboratório de Inteligência Artificial e Ciência de Computadores
[2] INESC TEC
R. Dr. Roberto Frias s/n, 4200-465 Porto, Portugal
{joao.sa.vinhas, joajac, rossetti, acoelho, ruirodrig}@fe.up.pt

16.1 Abstract

The increasing number of vehicles and mobile users has led to a huge increase in the development of Advanced Driver Assistance Systems (ADAS). In this paper we propose a multi-agent-based driving simulator which integrates a test-bed that allows ADAS developers to compress testing time and carry out tests in a controlled environment while using a low-cost setup. We use the SUMO microscopic simulator and a serious-game-based driving simulator which has geodata provided from standard open sources. This simulator connects to an Android device and sends data such as the current GPS coordinates and transportation network data. One important feature of this application is that it allows ADAS validation without the need of field testing. Also important is the suitability of our architecture to serve as an appropriate means to conduct behaviour elicitation through peer-designed agents, as well as to collect performance measures related to drivers' interaction with ADAS solutions.

Keywords: Mobile ADAS, Driving Simulators, Serious Games, SUMO.

16.2 Introduction

The technological advances on both the mobile and transportation industries are remarkable. This has made the development of ADAS an interesting topic [1]. However, even though most high-end cars nowadays ship with built-in embedded systems, most of the older cars do not have such devices. This brings about an interesting research oportunity, which is to develop and test ADAS that run on low-cost devices, such as an Android tablet or smartphone.

The main goal of this paper is to describe the methodology of our MultiAgent System (MAS) based driving simulator, integrating SUMO microscopic simulator with driving simulators. We also intend to describe our implementation of a test-bed to easily develop ADAS using the system, simulating their use in a low-cost and controlled environment.

There are several benefits to testing an ADAS in a simulated environment rather than on a real scenario. As the tests are not conducted in a real physical location, they are not subjected to travel times, traffic or other adverse conditions which could render them mute. This, as well as being able to deploy the simulator in low-cost computers, and therefore reaching more test subjects, leads to time compression of the tests. Noticeably, cost reduction is another significant benefit as the eletrical cost of running a simulator is dismissive when compared to fuel costs of real world testing. Besides preventing the safety risks inherent to driving, simulation allows us to control the test environment and manipulate it according the specificities of the ADAS being tested.

The objective of our work was to develop the MAS and include a test-bed that was easy to implement and replicate in low-cost environments. We aimed to combine SUMO microscopic simulator with IC-DEEP, which is a driving simulator developed at LIACC [2], with the GeoStream framework developed at SI&CG, as well as to enhance them with logs of simulated GPS positions in a mobile device. To achieve so, a mobile application/service was developed in order to receive this communication from the simulator and override the default GPS sensor of the device. We wanted to make it easy to extend the comunication between the simulator and a mobile device, providing the latter with more information such as the current speed limit, semaphoric information, or other data from the network.

This work aims to contribute with a novel multi-faceted methodology to simulate and research multiple human factors in Intelligent Transportation Systems (ITS) and, particularly, with a novel approach to test ADAS that will enable developers to validate and test their applications more easily and efficiently while reducing costs.

In the following sections we describe the development and results of our implementation. In section 3 we introduce some related state-of-the-art works on the subject of ITS, focusing on simulation, on the integration of different scope simulators and also on the topic of serious games. We then decribe our approach, architecture and development details. Finally we present our preliminary verification as well as their analysis in section 5. We finish this paper with a set of conclusions and interesting future work.

16.3 Background & Related Work

The Artificial Transportation Systems (ATS) [3], [4] concept has been one of the main research topics in the IEEE ITS Society [5]. A typical approach to ATS modeling and developement is the MAS methapor. Another potentially concomitant approach is the HLA concept. The concept is based on the idea of distributed simulation, so as to meet the requirements of all usages and users rather than of a single simulation model and analysis perspective [6].

In [7], authors propose to integrate a driving simulator and a traffic microsimulator, in an attempt to tackle the mutual-dependence between the driver's behavior and traffic conditions.

Combining SUMO microscopic traffic simulation [8], using MAS capabilities, with other simulators has also been researched [9]. Authors in [6] have studied a HLA-based approach to simulate electric vehicles in Simulink and SUMO. Driver-centric simulation has been researched by authors in [10], where they have developed a simulation tool that provides feedback back to the network based on the driver's behaviour.

Driving simulators are no doubt an important tool when researching ATS, specially so when studying the influence of human factors in driving faults [2]. These faults often occur in direct consequence of performing secondary tasks while driving [11]. In [12] authors introduce a game-engine-based for modeling and computing platform for ATS. They describe the artificial population both in their macroscopic and microscopic aspects.

Regarding driving simulators with ADAS testing capabilities, authors in [13] propose a reconfigurable driving simulator with several components to accomodate different ADAS testing or training. A framework for ADAS assessment and benchmarking has been developed by [14], with configurable scenarios and 3D scenes and multiple sensors input.

Authors in [15] developed a Full Speed Range Adaptive Cruise Control with their platform for ADAS prototyping and evaluation, SiVIC. The platform is capable of reproducing vehicle and sensor behaviors in a realistic fashion, according to the configured environment in the simulator. The developed platform also simulates noised and imperfect data.

A system comprising a large scale driving simulator, built in a 360 deg full dome with 3D scenes from real city area has been developed by [16]. The system contains a multitude of features such as real-time hardware-in-the-loop, wireless communication devices and bio signal analysis and is used to develop and test ADAS as well as Advanced Safety Vehicle, ITS infrastructure and others.

16.4 Methodological Approach

The proposed system architecture is as described in Figure 16-1. The main module of the system is the SUMO simulator, which is responsible for the network's multi-agent microscopic simulation, and has multiple driving agents. This module provides an overview of the whole MAS and can be manipulated directly.

The SUMO module also acts as a “central server”, providing all the essential information for both IC-DEEP and the High Fidelity Simulator. This information consists of the network infrastructure and the agents in the system, whereas terrain morphology and road or building geometry are provided by the GeoStream framework.

Both of the driving simulators have a local representation of the whole MAS and are capable of controlling any driving agent. The simulators are also able to connect to an Android device and pass along all the information deemed necessary, such as the GPS coordinates of the current driving agent being controlled. The Android device is running a service that receives the incoming connections from the simulator and also the ADAS being tested. The dotted area in Figure 16-1 corresponds to the developed components as of the writing of this paper.

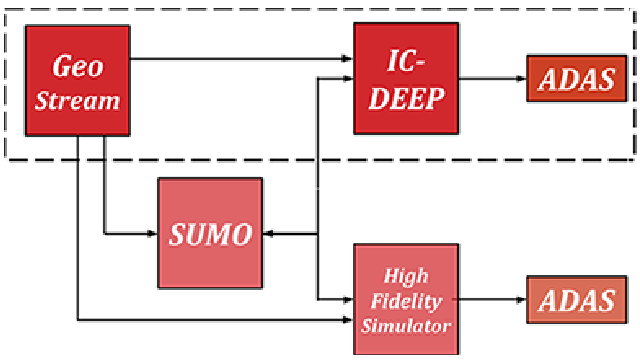

Figure 16-1: Overview of the system’s architecture

16.4.1 Simulators & GeoStream Framework

The proposed system architecture has two simulators; however, as of the writing of this paper, only the IC-DEEP simulator has been enhanced and integrated into the framework. The latter is implemented in Unity3D and has the GeoStream framework embedded directly. The GeoStream framework connects with OpenStreetMaps, Google Geolocation API, Google Altitude API and other data providers in order to fetch the required geographical information of a given location and remodel it in a fashion which can be interpreted by all the simulators in a coeherent and consistent way. This is specially important to the SUMO microscopic simulator as the raw network data imported from OpenStreetMaps, typically, generates unrealistic ways and intersections. The information generated by GeoStream framework is then parsed into both simulators to generate a 3D scene that is representative of the chosen test location.

16.4.2 Mobile Device

The Android service sets the current GPS location using *MockLocation* API to override the default location provider. All applications running on the mobile device that use or perceive the current location will also be affected by the running service.

The new GPS coordinates are sent from the simulator every second; however, this value is a parameter of the simulator and so can be adjusted to the specific needs of each scenario. The developed service can be run as a standalone application, and thus testing the ADAS mobile applications independently, as shown in the left side of Figure 16-2. There is also the option to use the service as a library in any Android application, as long as it matches API level 19, as shown in the right side of Figure 16-2.

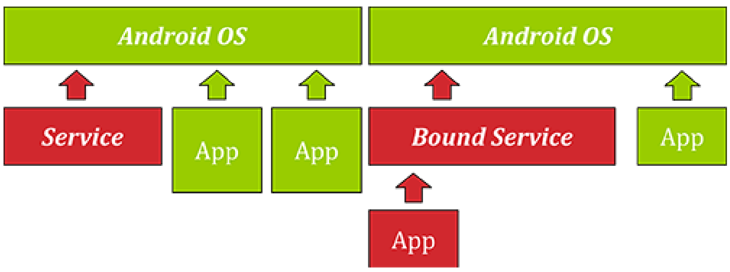

Figure 16-2: Standalone mobile application (left) and mobile application with included library (right)

16.4.3 Interaction of Driving Simulators and Android

A typical interaction between the simulators and the mobile devices is shown in Figure 166-3. The modules are connected via TCP-IP sockets due to implementation simplicity. The communication messages are formatted in JSON and therefore the message contents can be easily changed to add different kind of data.

The basic message template contains two compulsory fields, which are *latitude* and *longitude*. Other optional fields are the current *speed*, the GPS *accuracy*, the message *timestamp* or even the *speed limit* from the current location. A specific instantiation of this interaction is discussed in the next section.

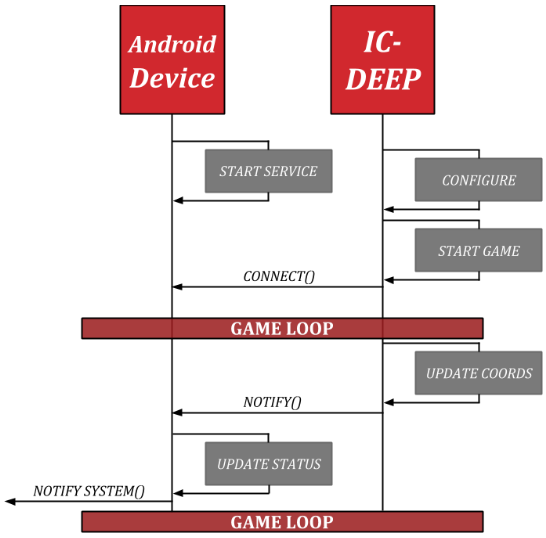

Figure 166-3: Typical interaction between IC-DEEP simulator and an ADAS

The coupling of SUMO microscopic simulator with the driving simulators, namely with IC-Deep, uses the same methodology as implemented and described elsewhere [17]. However, this raises some issues regarding the communication channel, as the SUMO TraCI protocol uses sockets and currently does not support more than one active socket. This is obviously a bottleneck when controlling multiple driving agents and a possible SUMO extension to support parallelism in terms of communication is in study.

16.5 Preliminary Verification

The preliminary verification to assess the proof of concept and also the efficiency of the developed architecture focused on the modules in the dotted area of Figure 16-1, the remainder of the system will be developed later on, as mentioned in the next chapter. We have divided the verification into two independent tests. Both of the tests were performed in the same geographical location, which was Porto's downtown, on *Avenida dos Aliados*, as seen in Figure 16-4.

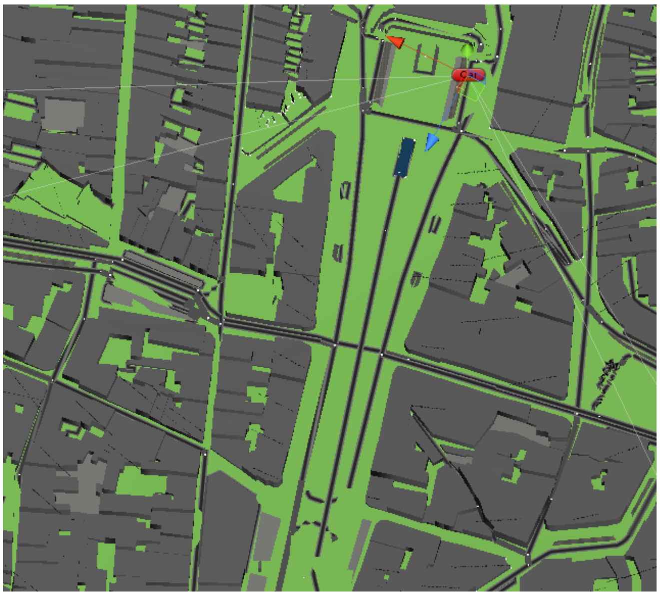

Figure 16-4: Generated 3D Scene ortographic view

In the first experiment we test the simulator accuracy to represent real-world scenarios using the GeoStream framework. The other test aims to emulate the GPS signal on the mobile device.

16.5.1 Simulator Accuracy

To test the simulator accuracy we have collected multiple GPS trace logs while driving a real car in the selected geographical location. We have then overlayered a visual representation of the obtained traces on the simulator and on Google Earth both, the results can be seen in Figure 166-5. The results show that the generated 3D scene is highly representative of the real world location. In one of the trace logs we have noticed an error and highlighted it in Figure 166-5, this error happens due to the data being collected as raw, untreated GPS, where the *road matching* algorithm [18] has not been applied. This is also an interesting result, as the error can been seen in both the simulator and Google Earth alike.

Figure 166-5: GPS traces on the simulator (left) and Google Earth (right)

Apart from testing the fidelity of the simulation with GPS trace logs, it is also noticeable that the ortographic view of the generated 3D scene very much resembles the satellite image of the same location, as it can be seen in Figure 16-6.

Figure 16-6: Satellite image of Av. dos Aliados

16.5.2 Mobile Device ADAS

To test the communication and emulation in the mobile device the setup consisted of a basic usage scenario, using a simple *ADAS* that shows the user his current and average speed, the total kilometers traveled, and, most importantly, warns him when he exceeds the speed limit of the current location as shown in Figure 166-7.

The interaction between the simulator and the mobile application followed that of Figure 166-3. To run the simulation the mobile application must be started and the device's IP address, which is shown in the application initial screen, must be entered in the simulator configuration screen. After this the simulation can start and the simulator internally updates the geographical coordinates as the driver traverses the network. These coordinates are passed on to the mobile device as described above, every second and via a JSON formatted message over a TCP-IP socket.

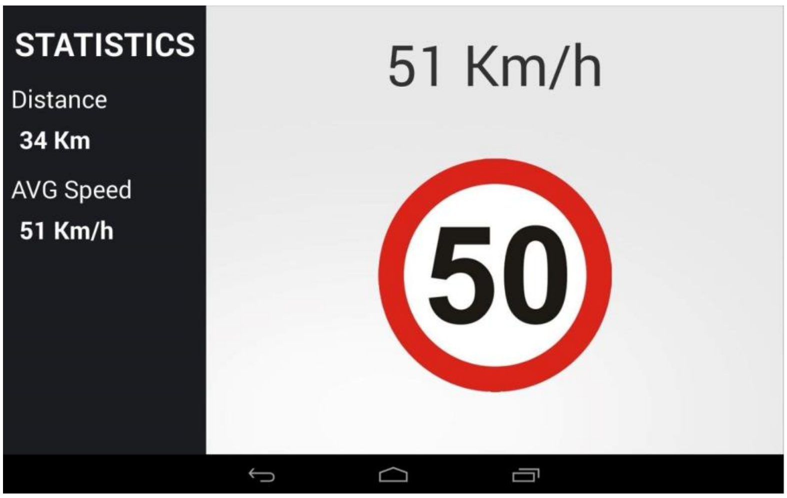

Figure 166-7: Developed ADAS

In this particular simulation the information sent to the mobile device consists of the current GPS coordinates and the speed limit of the current location. The heading of the vehicle is calculated internally by the mobile application using a simple algorithm that computes the bearing with the last two known locations and thus, even though this can be done easily, there is no need to pass on an orientation variable from the simulator.

The main goal of this experimentation was to understand whether or not the mobile device simulated GPS position and calculated speed matched those of the simulator. We have used the driving simulator and Google Maps application to compare the marked position while driving. To compare the driving speed we have used the developed ADAS.

Even though the results from the simulator and the mobile device were not recorded, any inaccuracies were not noticed when testing. The only possible minor differences would be due to the fact that the Google Location API on the Android device automatically adjusts the current position to the nearest road, which is, as mentioned above, a technique called *road matching*.

16.6 Conclusion

In this paper we presented a multi-faceted MAS-based driving simulator methodology. The presented framework can be used to simulate and test multiple aspects in human factors in ITS, generally. Among others we identify some that we consider more expressive of the system's spread, such as supporting a Serious Game [19] to test driving behaviours and ergonomics, simulating driver's idiosyncrasies effects on the ATS with peer-designed agents, and also prototyping and validating Advanced Driver Assistance Systems.

The preliminary verification has illustrated the system efficiency and usability, as well as its ability to accurately represent real-world scenarios without the need of extensive 3D modeling or expensive hardware setups. This ability allows researchers to conduct studies regarding singularities of the different geographical locations.

As a great advantage over other systems we point out the fact that our system is always up to date in terms of real-world mapping, and also that there is no need to waste any time creating a scene when the sole purpose is to test an ADAS or do any other kind of simulation.

In addition to implementing the remaining components of the proposed methodology, there is an ambitious workload of further developments. We would like to point out some that we consider prioritary and more challenging. We believe it would be interesting to support batch simulations, in order to collect significant data and extract more elaborate conclusions. There are also improvements specific to driving simulators that we envisage, such as more detailed scenarios and improved physics.

It would also be interesting to develop cache servers that could store the responses from external services, and thus improve loading times. Another interesting enhancement would be to allow multiple agents to connect to multiple ADAS, simulating distributed ADAS applications while extending SUMO capabilities. There are also refinements to be done in the GeoStream framework, specially regarding road generation and also importing models and textures for different buildings.

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Smartphone Sensor Platform to Study Traffic Conditions and Assess Driving Performance

Joel Gonçalves[1], João S. V. Gonçalves[2], Rosaldo J. F. Rossetti[2], *Member, IEEE*
and Cristina Olaverri-Monreal[1,3,*] *Member, IEEE*

***Abstract*—Sensor technology available in smartphones enables the monitoring of mobility patterns, which could be of particular interest for the transportation sector. For example, driving time information can help to determine if a selected path is the most convenient. Moreover, measurements related to the time expended on the road and origin destination matrices can lead to conclusions related to the organization of travel schedules and routes, enhancing reliability and resulting in a shorter total traveling time. Relying on GPS-based Floating Car Data (FCD), we designed a platform to acquire data for the evaluation of traffic conditions and driving performance using mobile phone sensors. Users control the activation of the tracking activity themselves and can benefit from information provided by other users' records. Additional metrics related to the travel time and vehicle's speeds contribute to the assessment of traffic management issues. Conclusions regarding possible applications of the tool are outlined.**

I. INTRODUCTION

Todays smartphones are adhering progressively to sensor technology and they already include equipment that can be applied to recognize and monitor a wide repertoire of activities. Additionally, they contain communication resources and enable the quick deployment of new applications [1]. These applications are of particular interest for the transportation sector, as they provide valuable information regarding the monitoring of mobility patterns [2], [3], [4] that can be used to study driving behavior for road safety purposes. Their cost efficient embedded sensors (i.e. accelerometer, digital compass, gyroscope, GPS, microphone, camera) allow for the collection of pertinent data to gain information related to current traffic situations and is therefore in accord with advanced traffic applications as fostered within the Intelligent Transportation Systems (ITS) research. Based on this information, it is also possible to characterize and classify arterial/freeway systems. Specifically, data related to travel time constitutes an important factor to consider in traffic management, as instrumental for congestion measurement based on the real travelers experience [5] that can be used to improve existing systems [6], [7]. For example, driving time information can help to determine if a selected path is the most convenient. Moreover, measurements related to the time expended on the road can lead to conclusions related to the organization of travel schedules, enhancing reliability through shorter total traveling times. In the planning, transportation, supply and maintenance of goods, this knowledge can positively affect delivery costs, increasing the reliability of delivery and improving the quality of service, but from a global perspective it can also significantly reduce the environmental impact. New forms of traditional traffic detectors offer methods for the acquisition of data that can lead to an improvement of traffic management and control, but even these new technologies present a number of difficulties that must be overcome to effectively utilize the full potential of the ITS concepts. Sensor-equipped mobile phones for the monitoring of traffic conditions overcome these difficulties. They enable capturing not only highway but also minor roads data for extended periods of time, being that the smartphones are deployed without location restrictions. Additionally, the tracking through smartphone devices occurs through a unique process, from the device independent address. Through encryption mechanisms personal information privacy can be guaranteed ensuring an anonymous source of information. The ubiquitous use of smartphones makes them the perfect data acquisition tool for human mobility patterns, including pedestrian information.

This work hinges upon the adoption of the smartphone technology by the traffic community in order to study and characterize traffic and road conditions. For this purpose, relying on GPS-based FCD we have built the Iris geographic information system (GIS)- based platform using the smartphone Android default API for geolocation. The server side of the Iris platform complements the Android Mobile-Sensing System to collect data by storing, pre/postprocessing, analyzing, managing and presenting the results. Additional metrics related to the travel time and vehicle's speeds contribute to the assessment of traffic management issues. The remainder of this paper is organized accordingly: The following section presents related work in the areas of traffic management using similar technologies. Section III presents a description of the application implementation. Section IV describes the methodology followed to acquire and process data for this study as proof of concept. Section V reports on the results of the data evaluation. Finally, Section VI concludes the paper.

[1] Institute of Ergonomics, Department of Mechanical Engineering, Technische Universität München, Germany goncalves@lfe.mw.tum.de
[2] Department of Informatics Engineering and the Artificial Intelligence and Computer Science Lab (LIACC), Faculty of Engineering, University of Porto, Portugal {joao.sa.vinhas, rossetti}@fe.up.pt
[3] AIT Austrian Institute of Technology, Business Unit Technology Experience, Innovation Systems Department Vienna, Austria cristina.olaverri@ait.ac.at
* Corresponding author

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II. RELATED WORK

To achieve an enhancement of traffic management and dissemination of traveler information, both important components of Intelligent Traffic Systems (ITS), reliable and ubiquitous traffic information is required. Therefore, the deployment of different kind of sensors relying on several technologies has been the focus of several works. For example, through a network of stationary sensors, or sensors located in mobile vehicles relying on Bluetooth technology [8], [9] particularly for the collection and use of travel time records for travel mobility metrics in diverse scenarios (i.e. work zones, highways, urban arterials) [10], [11], [12]. Additionally, cooperative traffic information systems based on vehicular ad hoc networks (VANET) exchange sensor information between vehicles via wireless communication, to improve traffic safety and efficiency [13], [14], [15].

Mobility sensors available in smartphones have already been proposed as a source of traffic estimation and therefore, some recent works present traffic related data collected through Global Positioning System (GPS) technology [4], [16], [17].

Moreover several mobile applications have been recently implemented for the monitoring of traffic conditions and record of geographic data [18], [19]. The authors in [20] combined Dynamic Time Warping (DTW) and smartphone based sensor-fusion to classify patterns and styles regarding non-aggressive vs. aggressive driving without external data processing. In a further work the authors in [21] acquired data through sensors located in smartphones to investigate changes in driver behavior patterns compared with patterns of traditional vehicles with combustion engines after having acquired the necessary adjustments needed for driving an electric vehicle.

Some mobile applications include capabilities to monitor driver attention [22], [23], [24] even alerting the driver when a certain behavior has been detected. This has been, exemplified by the application created by the authors in [25]. In the study they analyzed driving patterns collected through mobile phone sensor technology that were compared with typical drunk driving patterns extracted from real driving tests. Also data providers like Google elicit geographical information of a given location in real-time. The GPS-based Waze application relies on contributions from an online community of drivers reporting on traffic conditions that allow the computing of the most convenient navigation routes [26].

We similarly draw on the crowdsourcing practice and adopt in our approach the sensor technology included in mobile phones to develop an application to collect and analyze driving related data. In contrast to the works previously cited, this information is automatically logged by our system. We focus on driver performance metrics and combine several approaches in order to:

- assess driving performance;
- influence drivers' behavior with feedback about unsafe driving actions;
- monitor driving performance improvements to encourage safer driving;
- determine travel times and distances and provide the driver with records related to the selected routes.

System's users control the activation of the tracking activity and can benefit from information provided by other users' records. Similar to the approach presented in the serious games based application to assess the ergonomics of in-vehicle information systems [27], [28], [29] drivers are alerted when speed limits have been surpassed [30].

Our system bases on a client-server approach in order to be able to provide online feedback about unsafe driving actions. To encourage the use of our platform, users that provide us with data additionally benefit from a set of services such as recommendation of alternative route paths, recommendation of driving patterns for a shorter traveling time or for fuel saving reduction. In the next section we describe the system architecture of our Iris tool.

III. SYSTEM ARCHITECTURE

The general context for which we designed the system is depicted in Figure 1. Different means of transportation are regularly used to travel between locations. The smartphones track data related to these travels that is sent to the servers. Therefore, the server cluster provides a parallel computing platform for processing the incoming data. As a consequence our architecture ensures ubiquitous access through the integration of smartphones in the system.

Due to the still limited processing capabilities of some mobile devices, from the server side we guarantee a scalable solution that handles huge amounts of data by paralleling the processing. Regarding the analysis of the system, network traffic and cloud usage on the server side directly affect the performance. As the amount of users increases linearly, the complexity of the algorithms implemented by the data analytic modules increase exponentially. To palliate this effect, the applications implemented in our cloud based on the Service-Oriented Architecture (SOA), with focus on data selection algorithms for data entry and multiple services communicating with each other and connected through graphs.

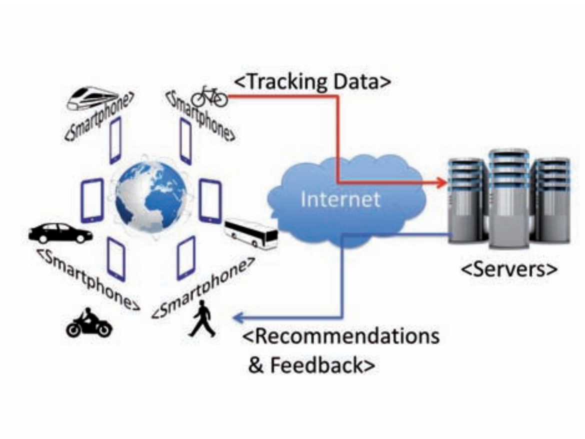

Fig. 1. Overview of the Iris platform designed to capture, store, manipulate, analyze, manage, and present traffic conditions data using smartphone sensors.

We designed the system to analyze the driving performance in terms of speed metrics in real time using mobile phone GPS sensors. The developed application for mobile phones based on the Android operative system (OS) was reliable and non-intrusive, having been previously downloaded and activated by the user for automatic execution on the scheduled days.

A. Server Side

In order to handle large amounts of data in a reasonable time, we aimed for a separate layered structure for each data, processing and visualization process as illustrated in Figure 2. The layers are detailed below.

1) Data Layer: The "Data Layer" hosts multiple databases that store information regarding regular travels or driver behavior. It also synthesizes data persistence and availability. The "Data Sink" element aggregates messages and files from external sources and also performs the preprocessing of the data through message routing previously to its storage in the database. After it, a request to analyze the new data is sent to the processing elements. All the input data is stored in the "Historical Database". Additionally, the "Data Access Layer" (DAL) ensures a uniformed and controlled access to the databases.

2) Processing and Visualization Layers: As the data becomes available, it is processed to extract relevant knowledge. Meta data information is provided to the elements that are responsible for the analysis of the data contained in the "Historical Database". Additionally, several analyzer activation rules contain information related to the specific processing and storage of the data. Figure 2 shows three analyzers with different databases. The stream with the name "Raw Data 1" corresponds to real time data that can be used to detect driving behavior, "Raw Data 2" contains origin destination related data important to infer information relevant to travel times, while "Raw Data 3" contains similar data as Raw Data 1, but instead of being real-time it is logged data that needs to be verified or modified. After the data has been processed and saved in the respective database, the "Visualization Layer" presents information in a meaningful fashion to the user.

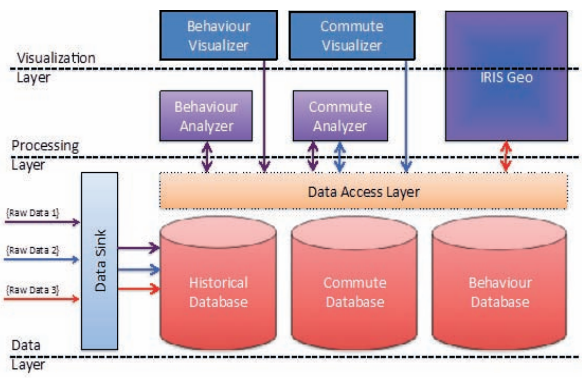

Fig. 2. Layered structure for the data, processing and visualization processes.

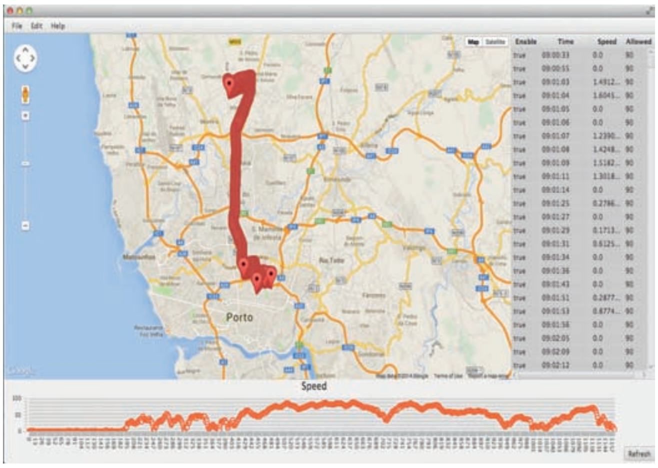

Fig. 3. User interface of the Iris Geo Tool with the different information that can be selected for further processing.

3) Iris Geo Tool: The "Iris Geo" application is a multilayer component of the server framework able to process and visualize data. A screen shot of the "Iris Geo Tool" graphical user interface (GUI) is provided by Figure 3.

It depicts the definition of the maximum velocity allowed on some specific road segments. The GUI is divided in three windows with different information. The window on the right upper side of the interface provides a detailed view of the data that can be selected to edit specific fields. Data rows that are not relevant for a specific analysis can be hidden (i.e. trip ended but data is still being logged). Additionally, GPS tracks are visualized through a map view in the mid window of the interface with pins to signalize the selected rows. The perspective is automatically centered and adjusted for optimal map navigation. The third window on the bottom side of the GUI shows a speed plot that provides a quick overview of the speed behavior from the selected records in the first window. The resulting file from the data set selected can then be exported to the server.

B. Client Side

In this section we describe the structure of the client application. Figure 4 shows the user interface. After the user has been registered into the application, a calendar shows day and time options to enter the schedule to log the data. The application is then automatically activated on the programmed days and times.
The client side of the system architecture is depicted in Figure 5. It is comprised of the following three main elements:

1) Activities: To enable interaction with the user interface, our application performs four specialized activities: "Introduction", "Registration", "Schedule" and "Control". As the user launches the application the "Introduction" activity checks the user's registration state, and the current tracking schedule. If any issue appears, e.g. not registered or no schedule defined, then the activity launches the associated activity "Registration"

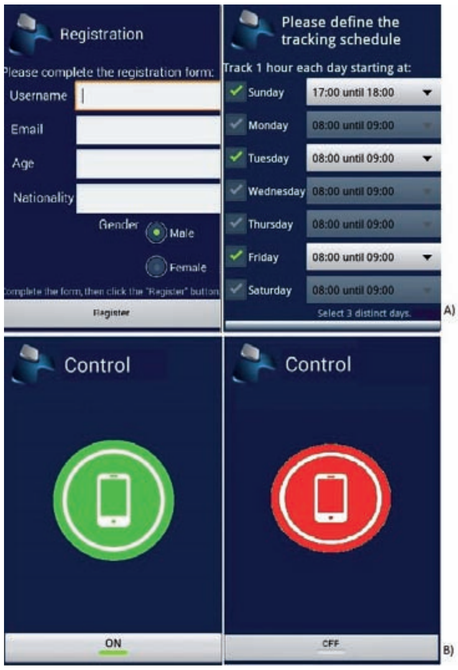

Fig. 4. User interface of the Iris client application. A shows the registration form and the schedule that can be selected for tracking the driving data. B shows the control interface to activate or deactivate the tracking functionality.

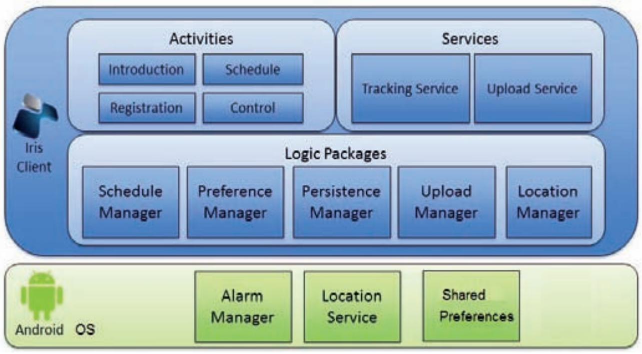

Fig. 5. Client side of the Iris system architecture.

or "Schedule" to handle the issue. When the setup is complete, the "Introduction" activity terminates.

The "Registration" activity, prompts the user with a form to fill in personal data. Once clicked on register button, the data is sent to the server, and the user is registered. The "Schedule" activity allows the user to specify which days the application can automatically track. By default, the application tracks from 8 am to 11 am. The "Control" activity is only available by a notification in form of an icon in the system to provide the user with feedback related to the activation of tracking and whether or not it has occurred. The user can stop the application through this control option when tracking is not desirable (e.g. privacy, battery saving, etc). Figure 4B show the user interface for this option.

2) Services: This element handles automated tasks and facilitates the application management. Specifically, vehicle position tracking over a time window is handled through the "Tracking Service" that interacts with the "Android's Location Manager" for subscribing updates concerning the device's location. Tracked data is uploaded after the "Upload Service" has verified connection availability.

3) Logic Packages: The "Logic Packages" contain the application logic and interact with the operating system. This element consists of the following components:

- The "Schedule Manager" is a package designed to perform the operations required to set up a tracking schedule. This component serves as the operation which saves the schedule and also manages the "Android's Alarm Manager" software component of the Android operating system. In our approach, we use it to control time in the effect of triggering the desired tasks needed in our application. For example, the "Schedule Manager" registers in "Android's Alarm Manager" a daily alarm at 8 am to verify if the current day is scheduled for tracking and in the affirmative case, proceed in executing the application.
- The "Preference Manager" package stores the application setup configuration. Data concerning registration and the schedule itself are saved persistently using the hash table akin to the Android OS component "Shared Preferences", to information that is available while the application is installed in the form of key-value pairs without handling file operations (i.e. schedule for tracking and registration data).
- The "Persistence Manager" accesses the Android's file system, through internal/external storage and proper file initialization, writing, and closing. This ensures the integrity of collected data and allows for the "Upload Service" to detect the new files and upload them.
- The "Upload Manager" is mainly used by the "Upload Service" to manage the network connectivity changes and the files network transfer.
- The "Location Manager" interacts with the Android component "Location Service", preprocesses the information to the application's supported format, and sends it to the "Persistence Manager" for storage.

IV. Experimental Setup

In order to demonstrate the feasibility of our approach, we deployed our Iris app through the play store web shop and made available a free version for download.

A. Data acquisition and processing

To verify that our application was behaving in the expected manner we logged encrypted driving data from 3 drivers and a total of 30 trips. No personal data was recorded. The drivers had previously selected which days and times were the most suitable for them. We then stored the data in a database from where it was downloaded for further evaluation. We addressed origin destination matrices calculating the mean point of the 10 first and last coordinate points of the trip. Additionally, speed patterns determined driving behavior. The collected data length allowed for a comparison at every point overlapping similar speed data sections and determining differences in the speed variation. We could determine travel times through the time and location data that was inherent to every device calculating the difference in time between two locations. We started to log the time at the point where the driver exceeded 40 km/h at least 500 m from the origin in order to filter data that was not related to a particular travel. Similarly we set the time where the trip finished at the last point where the driver exceeded 10 km/h at least 500 m from the destination. The system evaluated traffic conditions through the following algorithm: if in a restricted time window (e.g. 5 min) the average of the vehicles was equal or above the speed limit then we considered the traffic congestion to be low. The lower the vehicles velocity, the higher the congestion. This technology allowed us to study and characterize the traffic conditions over selected roads to determine if the selected travel path was the most convenient compared to the fastest suggested routes from Open Street Maps [31].

B. *Driving performance assessment*

The collected driving related data enabled to assess the driving performance in terms of speed metrics so that drivers could be influenced with feedback about an excessive speed limit. Feedback could be provided to the driver during the trip through an acoustic signal programmed in the smartphone and after a certain trip through the average fuel consumption or time saving selecting a different route.

V. Results

A. *Travel time and distance*

Results regarding travel times and travel distance showed slight differences based on the real traveler's experience over the suggested routes in Open Street Maps. These differences can be due to a routing algorithm that considers an incomplete or outdated road infrastructure. Figure 6 depicts the results for the second driver.

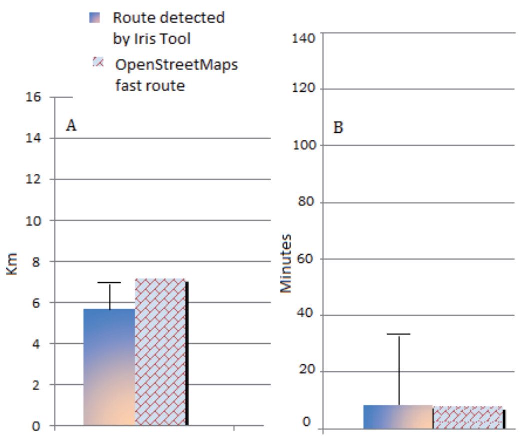

Fig. 6. Travel distance (A) and time (B) logged for the selected roads by driver 2 over the fastest suggested routes from Open Street Maps [31].

B. *Driving performance*

Figure 7 depicts the results concerning driving performance by driver in terms of speed limit over different travel paths. We analyzed the percentage of the trips per driver that exceeded the speed limit in 10 km/h and more (110-120 km/h). A high variability on the speed behavior could be observed depending

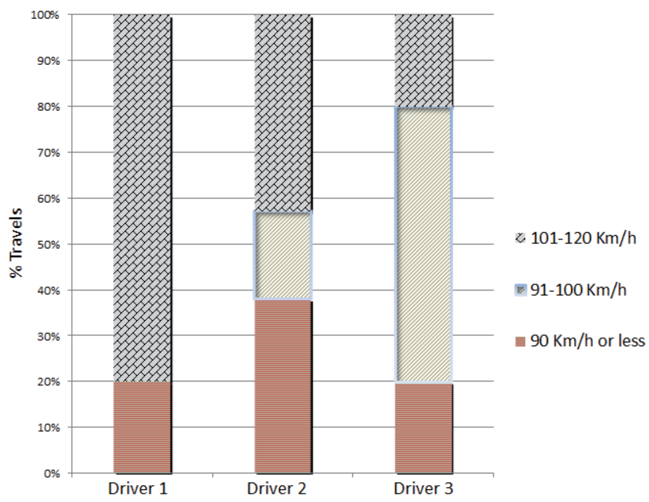

Fig. 7. Driving performance by driver in terms of the speed limits over different travel paths

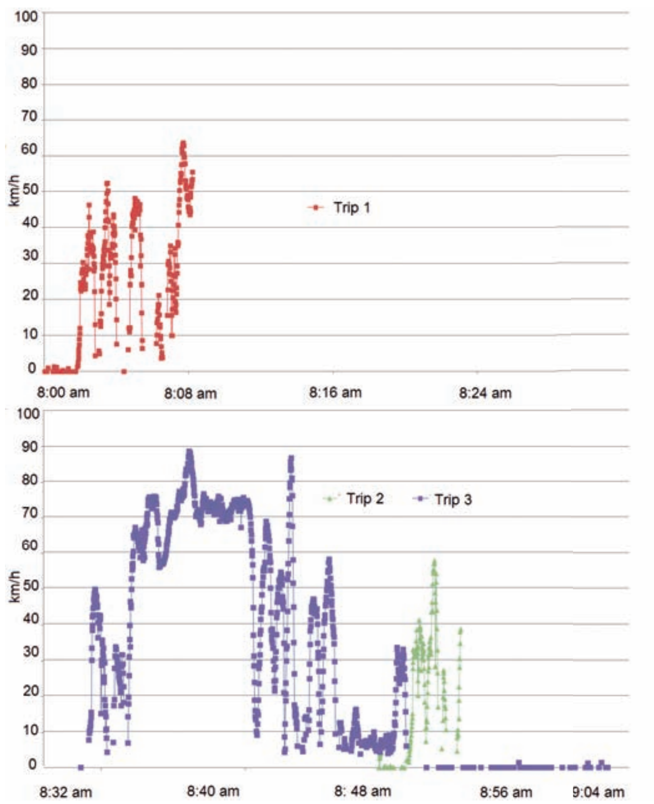

Fig. 8. Velocity over time of 3 trips

on the driver. However, a common thread could be observed in all cases, namely, the percentage of travels where the speed limit was respected, was inferior to 38%. Figure 8 shows the velocity course of three different trips.

VI. CONCLUSION AND FUTURE WORK

In this paper, we proposed the Iris platform to acquire data for the evaluation of traffic conditions and assessment of driving performance using mobile phone GPS. As a proof of concept we showed that data collected by our tool can lead to conclusions related to the organization of travel schedules, enhancing reliability through shorter total traveling times. Particularly, the information related to the selected path compared to suggested routes can be used to improve existing systems. Additionally, the low percentage of travels where the speed limit was respected might be used to provide the driver with feedback about unsafe driving actions so that it can be corrected in future trips. The feedback capabilities of the proposed platform will be presented in future work in which we will increase the sample deploying the tool through the internet and collect and evaluate data from heterogeneous drivers to make driver classification and a better driving assessment and feedback possible.

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Testing Advanced Driver Assistance Systems with a Serious-Game-Based Human Factors Analysis Suite

João S.V. Gonçalves, Rosaldo J. F. Rossetti, *Member*, *IEEE*, João Jacob, Joel Gonçalves, C. Olaverri-Monreal, *Member*, *IEEE*, António Coelho and Rui Rodrigues

Abstract— **The development of Advanced Driver Assistance Systems (ADAS) is rapidly growing. However, most of the ADAS require field test, which is expensive, unpredictable and time consuming. In this paper we propose a multiagent-based driving simulator which integrates a human factor analysis suite and enables rapid and low-cost experimentation of mobile-device ADAS. Our architecture uses a microscopic simulator and a serious-game-based driving simulator. The latter allows the user to control a vehicle and change the correspondent simulation state in the microscopic simulator. The driving simulator also connects to an Android device and sends several kinds of data, such as current GPS coordinates or transportation network data. One important feature of this architecture is its suitability to serve as an appropriate means to conduct behaviour elicitation through peer-designed agents, so as to improve modelling of various driving styles accounting for different aspects of preferences and perception abilities, as well as other performance measures related to drivers' interaction with ADAS solutions. The potentials of our approach to aid experiments in human factor analysis are still to be tested, but are undoubtedly huge and encouraging.**

I. INTRODUCTION

The mobile and transportation industries both have had remarkable technological advances. The bridge between these two industries results in a huge increase in the development of in-vehicle Advanced Driver Assistance Systems (ADAS). However, even though most high-end cars ship with built-in embedded systems, most of the older cars do not have such devices. An interesting research opportunity arises from these facts, which is to develop and test ADAS that run on low-cost devices, such as an Android tablet or smartphone. This development, however, requires a thorough investigation regarding the safety and efficiency of performing secondary tasks while driving. [1].

The main goal of this paper is to describe the methodology of our MultiAgent System (MAS) based driving simulator and its usage as a means to conduct experiments regarding human factors analysis. We discuss our architecture which comprises both a microscopic simulator and driving simulators. We also detail our implementation of a test-bed to easily develop ADAS, simulating their use in a low-cost and controlled environment.

There are several benefits to testing an ADAS in a simulated environment rather than on a real scenario. As the tests are not conducted in a real physical location, they are not subjected to travel times, traffic or other adverse conditions which could render them mute. This, as well as being able to deploy the simulator in low-cost computers, and therefore reaching more test subjects, leads to time compression of the tests. Noticeably, cost reduction is another significant benefit as the electrical cost of running a simulator is dismissive when compared to fuel costs of real world testing. Besides preventing the safety risks inherent to driving, simulation allows us to control the test environment and manipulate it according the specificities of the ADAS being tested.

The objective of our work was to develop the MAS and the human factors analysis suite. We also wanted to include a test bed that was easy to implement and replicate in low cost environments. We aimed to integrate SUMO microscopic simulator with IC-DEEP, which is a driving simulator developed at LIACC [2] and with the GeoStream framework developed at SI&CG. We also enhanced them with communication of the simulated GPS positions to a mobile device. A mobile application/service was developed as well, in order to receive this communication from the simulator and override the default GPS sensor of the device. Finally, we wanted to make it easy to extend the communication between the simulator and a mobile device. This communication provides the mobile device with more information such as the current speed limit, semaphoric information, or other data from the network.

This work aims to contribute with a novel multi-faceted methodology to simulate and research multiple human factors in Intelligent Transportation Systems (ITS). Particularly, contributing with a novel approach to test ADAS that will enable developers to validate and test their applications more easily and efficiently while reducing costs.

In the following sections we describe the development and results of our implementation. In section 2 we introduce some related state-of-the-art works on the subject of ITS, focusing on simulation, on the integration of different scope simulators and also on the topic of serious games. We then describe our approach, architecture and development details. Finally we present our preliminary verification as well as their analysis in section 4. We finish this paper with a set of conclusions and interesting future work.

J.S.V Gonçalves and R.J.F. Rossetti are with the Department of Informatics Engineering and the Artificial Intelligence and Computer Science Laboratory, Faculty of Engineering, University of Porto, Portugal {joao.sa.vinhas, rossetti}@fe.up.pt (R. J. F. Rossetti is the corresponding author).

J. Jacob, A. Coelho and R. Rodrigues are with Instituto de Engenharia de Sistemas e Computadores, Porto, Portugal and with the Department of Information Systems, Faculty of Engineering, University of Porto, Portugal {joao.jacob, acoelho, ruirodrig}@fe.up.pt

J. Gonçalves and C. Olaverri-Monreal are with the Institute of Ergonomics, Faculty of Mechanical Engineering, Technische Universität München, Germany, {goncalves, olaverri}@lfe.mw.tum.de.

II. Background

The Artificial Transportation Systems (ATS) [3] [4] concept has been one of the main research topics in the IEEE ITS Society [5]. A typical approach to ATS modelling and development is the MAS metaphor. In this approach each vehicle can be seen as an agent of the system. Another potentially concomitant approach to this modelling is the HLA concept. The concept is based on the idea of distributed simulation, that is, to meet the requirements of all usages and users more than a single simulation model should be used [6]. These concepts can be consolidated to integrate multiple simulators so as to achieve more realistic simulations.

Punzo *et al.* [7] propose to integrate SCANeR driving simulator and AIMSUN traffic-flow microsimulation model. Their attempt is to tackle the mutual-dependence between the driver's behaviour and traffic conditions.

Microsimulation regards simulating and tracking individual vehicle movements. Developed at DLR, the Simulation of Urban Mobility (SUMO) simulator aims at microscopic traffic simulation [8]. The MAS methapor arises as an indisputable methodology to perform microsimulation. Using MAS capabilities and coupling SUMO with other simulators has been researched elsewhere [9]. Macedo *et al.* [6] have studied a HLA-based approach to simulate electric vehicles in Simulink and SUMO. Driver-centric simulation has been research by Gomes *et al.* [10], where they have developed a simulation tool that provides feedback back to the network based on the driver's behaviour.

Our methodological approach to integrate multiple simulators is discussed in the next section.

III. Methodological Approach

The proposed system architecture is as described in Figure 1. The main module of the system is the SUMO simulator, which is responsible for the network's multi-agent microscopic simulation, and has multiple driving agents. This module provides an overview of the whole MAS and can be manipulated directly. The SUMO module also acts as a "central server", providing all the essential information for both IC-DEEP and the High Fidelity Simulator. This information consists of the network infrastructure and the agents in the system, whereas terrain morphology and road or building geometry are provided by the GeoStream framework. Both of the driving simulators have a local representation of the whole MAS and are capable of controlling any driving agent. The simulators are also able to connect to an Android device and pass along all the information deemed necessary, such as the GPS coordinates of the current driving agent being controlled. The Android device is running a service that receives the incoming connections from the simulator and also the ADAS being tested. Finally, the most significant modules of the system are those that allow us to conduct human factor analysis studies. We describe these modules in more detail in the next sections. The dotted area in Figure 1 corresponds to the developed components as of the writing of this paper.

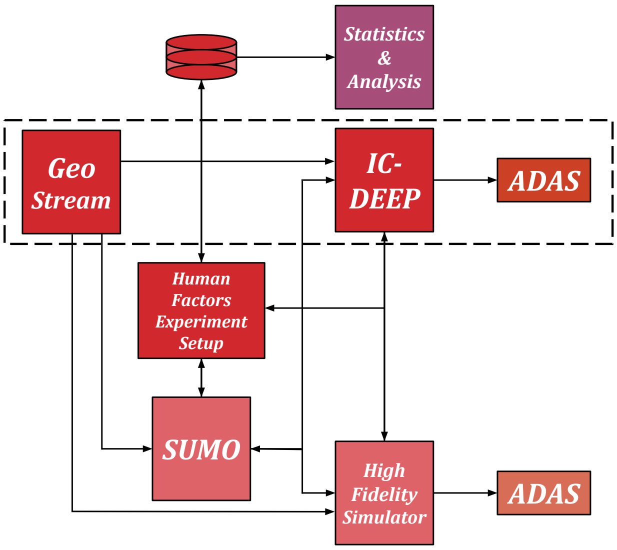

Fig. 1. Overview of system architecture

A. Simulators & GeoStream Framework

The proposed system architecture has two simulators, however, as of the writing of this paper, only the IC-DEEP simulator has been enhanced and integrated with the system. The latter is implemented in Unity3D and has the GeoStream framework embedded directly. The GeoStream framework connects with OpenStreetMaps, Google Geolocation API, Google Altitude API and other data providers in order to fetch the required geographical information of a given location in real-time. This information is parsed in both simulators to generate a 3D scene that is representative of the chosen test location.

B. Human Factors Analysis Suite

The most relevant modules of the system are those that comprise the Human Factors Analysis Suite. The "Human Factors Experiment Setup" module has tree responsibilities: i) defining the experiment scenario and preparing the simulators for the relevant data extraction ii) inducing changes in the simulation state in order to achieve the desired outcomes iii) collect and analyze the run-time data in order to adapt the simulation state in response to the driver's behaviours. This module also connects to a database to log all the required data necessary to conduct the studies. The collected data is then processed by the "Statistics and Analysis" module. Data preparation and presentation are the key responsibilities of this module. As discussed in the conclusions section, this module can also be used in a myriad of studies and experiments, such as peer-designed agents and behaviour elicitation.

C. Mobile device

The Android service sets the current GPS location using *MockLocation* API to override the default location provider.

All applications running on the mobile device that use or perceive the current location will also be affected by the running service.

The new GPS coordinates are sent from the simulator every second, however, this value is a parameter of the simulator and so can be adjusted to the specific needs of each scenario. The developed service can be run as a standalone application, and thus testing the ADAS mobile applications independently, as shown in the left side of Figure 2. There is also the option to use the service as a library in any Android application, as long as it matches API level 19, as shown in the right side of Figure 2.

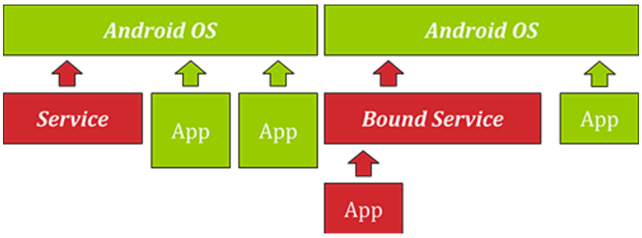

Fig. 2. Standalone mobile app. and mobile app. with library

D. Interaction

A typical interaction between the simulators and the mobile devices is shown in Figure 3. The modules are connected via TCP sockets due to implementation simplicity. The communication messages are formatted in JSON and therefore the message contents can be easily changed to add different kind of data. The basic message template contains two obligatory fields, which are **latitude** and **longitude**. Other optional fields are the current *speed*, the GPS *accuracy*, the message *timestamp* or even the *speed limit* from the current location. A specific instantiation of this interaction is discussed in the next section.

IV. Preliminary Verification

The preliminary verification to assess the proof of concept and also the efficiency of the developed architecture focused on the modules in the dotted area of Figure 1, the remainder of the system will be developed later, as mentioned on the next chapter. We have divided the verification into two independent tests. In the first one we test the simulator accuracy to represent real world scenarios using the GeoStream framework. The other test aims to test the emulation of the GPS signal on the mobile device. Both of the tests were performed in the same geographical location, which was Porto's downtown, at *Avenida dos Aliados*, seen in Figure 4.

A. Simulator Accuracy

To test the simulator accuracy we have collected multiple GPS trace logs while driving a real car in the selected geographical location. We have then overlayered a visual representation of the obtained traces on the simulator and on Google Earth both, the results can be seen in Figure 5. The results show that the generated 3D scene is highly

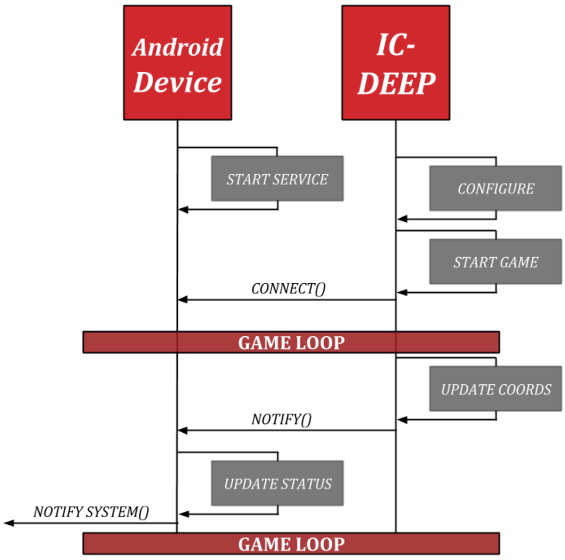

Fig. 3. Typical interaction between IC-DEEP simulator and an ADAS

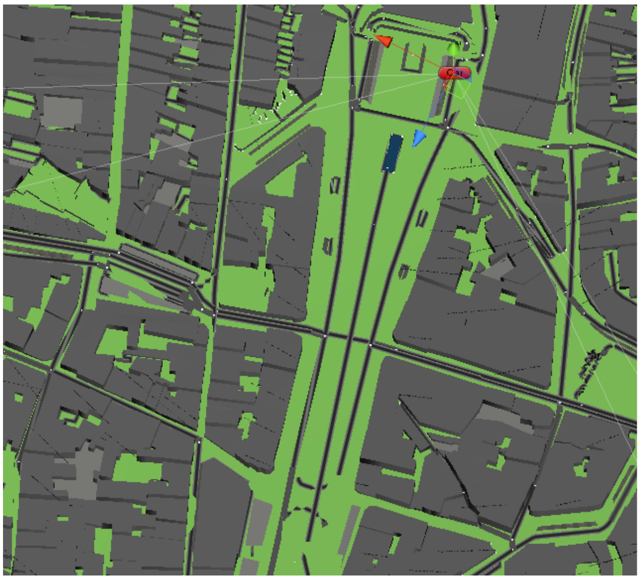

Fig. 4. Generated 3D Scene orthographic view

representative of the real world location. In one of the trace logs we have noticed an error and highlighted it in Figure 5, this error happens due to the data being collected as raw, untreated GPS, where the *road matching* algorithm [11] has not been applied. This is also an interesting result, as the error can been seen in both the simulator and Google Earth alike.

Apart from testing the fidelity of the simulation with GPS trace logs, it is also noticeable that orthographic view of the generated 3D scene very much resembles the satellite image of the same location, as can be seen in Figure 6.

B. Mobile device ADAS

To test the communication and emulation in the mobile device the setup consisted of a basic usage scenario, using a simple *ADAS* that shows the user his current and average speed, the total kilometers travelled, and, most importantly, warns him when he exceeds the speed limit of the current location as shown in Figure 7.

The interaction between the simulator and the mobile application followed that of Figure 3. To run the simulation the mobile application must be started and the device's IP address, which is shown in the application initial screen, must be entered in the simulator configuration screen. After this the simulation can start and the simulator internally updates the geographical coordinates as the driver traverses the network. These coordinates are passed to the mobile device as described above, every second and via a JSON formatted message over a TCP socket.

Fig. 5. GPS Traces on the simulator (left) and Google Earth (right)

In this particular simulation the information sent to the mobile device consists of the current GPS coordinates and the speed limit of the current location. The heading of the vehicle is calculated internally by the mobile application using a simple algorithm that computes the bearing with the last two known locations and thus, even though this can be done easily, there is no need to pass an orientation variable from the simulator.

The main goal of this experimentation was to understand whether or not the mobile device simulated GPS position and calculated speed matched those of the simulator. We have used the driving simulator and Google Maps application to compare the marked position while driving. To compare the driving speed we have used the developed ADAS.

Even though the results from the simulator and the mobile device were not recorded, any inaccuracies were not noticed when testing. The only possible minor differences would be due to the fact that the Google Location API on the Android device automatically adjusts the current position to

Fig. 6. Satellite image of Av. dos Aliados

the nearest road, which is, as mentioned above, a technique called *road matching*.

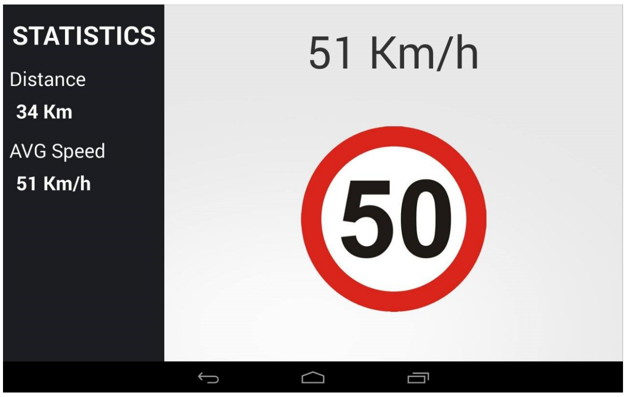

Fig. 7. Developed ADAS

V. Related work

Driving simulators are no doubt an important tool when researching ATS, specially so when studying the influence of human factors in driving faults [2]. These faults often occur in direct consequence of performing secondary tasks while driving [12].

The top, state-of-the-art simulators are usually the high-fidelity, human-in-the-loop simulators [13]. Typically, these simulators have motion simulation and provide the driver a high field of view. The modern high-fidelity simulators have 9 DOF [14] and can even include a full 360 degree dome [15].

These simulators serve a multitude of purposes in terms of scientific research. For instance, the Leeds University simulator [16] is used to research topics such as the effects of automated systems on safety and driver comprehension of traffic signs. Just as the NADS-I [17] is used to conduct tests that are too dangerous or even illegal and/or unethical, such as the effects of illness, drowsiness, inattentiveness etc. A system comprising a large scale driving simulator, built in a 360 deg full dome with 3D scenes from real city area has been developed by [15]. The system contains a multitude of features such as real-time hardware-in-the-loop, wireless communication devices and bio signal analysis and is used to develop and test ADAS as well as Advanced Safety Vehicle, ITS infrastructure and others.

However highly technological and high fidelity simulators are typically expensive and lack the extensibility and portability of the low-cost simulators. A low-cost and reconfigurable driving simulator with several components to accommodate different ADAS testing or training is proposed by Hassan *et al.* [18]. A framework for ADAS assessment and benchmarking has been developed elsewhere [19], with configurable scenarios and 3D scenes and multiple sensors input. Miao *et al.* [20] introduce a game-engine-based simulator for modeling and computing platform for ATS. They describe the artificial population both in their macroscopic and microscopic aspects.

Gruyer *et al.* [21] developed a Full Speed Range Adaptive Cruise Control with their platform for ADAS prototyping and evaluation, SiVIC. The platform is capable of reproducing the vehicle and sensors behaviour in a realistic fashion, according with the configured environment in the simulator. The developed platform also simulates noised and imperfect data.

Finally, the IC-DEEP low-cost serious-game driving simulator [2] has been developed in LIACC. This simulator can be used to conduct human factors experiments in controlled scenarios. However, it also lacked extensibility, ie., the experimentation setup was hardcoded in the simulator. Therefore, in order to achieve the intended methodology, it as been integrated with the GeoStream framework and enhanced with communication with an Android mobile device.

VI. Conclusion

In this paper we have proposed a multi-faced MAS-based driving simulator architecture. We have also proposed a methodology to use the system as a means to simulate and test multiple aspects in human factors in ITS, generally. More specifically, we have introduced a test-bed to easily develop ADAS and test them regarding the safety of the drivers or their influence on the transportation network.

We consider the system to have a wide spread of applications. Among others, we identify some that we find more expressive, such as: i) supporting a Serious Game [22] to test driving behaviours and ergonomics ii) conduct experiments with peer-designed agents to simulate driver's idiosyncrasies effects on the ATS iii) prototyping and validating Advanced Driver Assistance Systems.

The preliminary verification has proved the system efficiency and usability, as well as its ability to accurately represent real world scenarios without the need of extensive 3D modelling or expensive hardware setups. This ability allows researchers to conduct studies regarding singularities of the different geographical locations.

As discussed in the methodological approach section, one major issue of the system is the coherency in the representation and modelling of the real-world transportation network. This is a current limitation to the SUMO microscopic simulator as it generates unrealistic ways and intersections. However, we plan on tackling this issue by introducing a higher-level representation of the network which is parsed consistently by all the simulators.

In addition to implement the remaining components of the proposed methodology, there is an ambitious workload of further developments. We would like to point out some that we consider to be a priority and more challenging. We believe it would be interesting to support batch simulations, in order to collect significant data and extract more elaborate conclusions. There are also driving simulator specific improvements that we envisage, such as more detailed scenarios and improved physics. Another interesting improvement would be to allow multiple agents to connect to multiple ADAS, simulating distributed ADAS applications while extending SUMO capabilities. There are also improvements to be done in the GeoStream framework, specially regarding road generation and also importing models and textures for different buildings.

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