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Development of a Human Factors Evaluation Procedure for Network-wide Road Safety Assessments

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Author biography

Andrea Paliotto (Firenze, 18 January 1989) had a master's degree cum laude in Civil Engineering at the University of Florence in 2016. He has been working in the university since 2017. After his master's degree he also worked as a consultant engineer. Since June 2018 he has been enrolled as a PhD student at the Department of Civil and Environmental Engineering Science of the University of Florence and the Technical University of Darmstadt. His main research topic is road safety and design with a focus on Human Factors.

He participated to several research projects, such as PRACT, Skillfull, CoEXist, and Tuscany Region CMRSS, with a focus on road safety. He is member of PIARC national committee on road safety since 2018 and he also contributed to PIARC international TC-C.2 Design and Operation of Safer Road Infrastructure activities in 2018-2019. He is co-author of some papers and technical documents and participated to international conferences.

To all those wonderful people who care about me

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I hope that this work could be a starting point for further research and for the development of further procedures aiming at analyzing road safety conditions taking care of the relationship between the road and the driver.

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Executive Summary

Road safety is a central issue in the management and development of the road infrastructure network. Alongside efficiency and functionality, a road must allow you to reach your destination not only fast but safely. Unfortunately, even today, the number of accidents that occur on our roads is high, as the number of accidents involving deaths and injuries. Considering all the existing roads, single carriageway rural highways roads are among the most dangerous.

Road agencies must therefore try to cope with this situation, identifying the most dangerous sections of their network, and acting on them through interventions to improve safety. One of the main difficulties of the road safety management system is therefore that of identifying the sections of the network that require priority intervention. The most used procedure for this purpose is to consider specific indicators based on the number of accidents observed over the years. An approach of this type, certainly useful, however, has some limitations, one among all that it allows to intervene only after accident occurrence. A more mature road safety management system, on the other hand, must be able to assess the safety of a road section before accidents occur. The European Community is moving in this direction. With the update of Directive 2008/96 / EC (updated through Directive 1936/2019), it makes explicit the need to define network analysis procedures based on an analysis of the intrinsic safety of the road and not only on the number of accidents observed over the years.

This work aimed exactly at the definition of a Network-wide Road Safety Assessment procedure for two-lane two-way rural roads, namely Human Factors Evaluation procedure, which accounts for the influence of Human Factors in accidents triggering factors. The purpose of such a procedure is to provide an instrument to evaluate the risk of accidents occurrence because of wrong perceptions and expectations caused by the road. This often translates in operational errors, which may become driving errors that finally results in accidents, if uncorrected. The need of a Network-wide Road Safety Assessment procedure which accounts for Human Factors, together with an overview of considered methodologies, is discussed with a focus on Road Safety Inspection procedures. Indeed, visual site inspections and surveys allow to identify specific critical issue that may otherwise be missed while using big data analysis. Moreover, it has been decided that the Human Factors Evaluation procedure must follows the requirements of the updated 2008/96/EU directive (European Parliament and the Council, 2019). This will let it be a usable instrument for road agencies.

To better address the importance of Human Factors in road safety, and to understand which mechanisms influence drivers' behavior, a wide literature analysis has been carried out, starting from the analysis of the processes at the basis of the driving task. Different driving models have been analyzed for this purpose, underlying which factors may contribute to increase the probability of an accident. A special focus was placed on risk perception as a key factor of drivers' behavior, which in turn determines the real risk of an accident. The risk perception has been found to be related to many factors. Some of these factors do not directly concern the road and its environment, but most of them are directly related to the road perception. For this reason, additional insights have been provided about the relation between sensation and perception and the way human beings "manage" and perceive reality. This clearly reflects on driving. The characteristics and properties to consider understanding how the world is perceived and responded by human beings, are exactly Human Factors. Comprehension of Human Factors allow to understand if the road and its environment can be easily driven and comprehended by drivers.

After having clarified the relevance of Human Factors, it is highlighted how and why expectations play a fundamental role. Expectations are part of Human Factors, and they influence the way the world is perceived and responded. Two different types of expectations have been identified: general expectations and punctual expectations. The first mainly account for the whole road stretch configuration (e.g., concept of self-explaining roads), while the latter account for the specific road and road environment layout close to an approached potentially critical location. Potentially critical locations are points of the road where a change in the driving program is required (e.g., curve, intersections, pedestrian crossings). Together with expectations, the visibility of potentially critical locations influences the risk of an accident. The greater the provided sight distance, the higher the time to realize wrong expectations and to correct them.

The identification of two types of expectations and the analysis of visibility, is a crucial part of this work. Indeed, within this research a significant effort has been made to translate these theoretical concepts into usable engineering parameters.

To develop the procedure, the PIARC Human Factors principles has been taken as reference. PIARC Human Factors principles consider three rules of Human Factors: one accounting for the visibility of potentially critical locations, one accounting for the influence of the field of view, and one accounting for the driving logic. Visibility, punctual expectations, and general expectations, fit exactly the principles stated in those PIARC rules. Moreover, PIARC proposed an instrument, namely Human Factors Evaluation Tool, to quantify road safety for single potentially critical locations accounting for Human Factors principles. It provides numerical scores. The Human Factors Evaluation Tool has been considered has the core instrument of the Human Factors Evaluation procedure.

The first theoretical part set the main objectives of the procedure and set the instruments for its development. Six main objectives must be considered in the procedure development.

Main objectives

a) Definition of Network-wide Road Safety Assessment procedure, that
b) Is based on Human Factors (expectations should have a major role in the analysis)
c) Includes visual inspection of the road (European Parliament and the Council, 2019)
d) Is a pro-active procedure (European Parliament and the Council, 2019)
e) Provides at least three level of risk (European Parliament and the Council, 2019)

f) Includes the Human Factors Evaluation Tool

Therefore, the first stage to develop the procedure was to assess strengths and weaknesses of the Human Factors Evaluation Tool both considering its application on single potentially critical locations and considering applying it at a network level. Therefore, the Human Factors Evaluation Tool has been applied to two road stretches and the outcomes of the application have been analyzed. Some slight modifications of the tool have been identified as mandatory for its inclusion in the procedure. Moreover, to include the Human Factors Evaluation Tool in a network analysis, the procedure considered the following main requirements.

a) A double segmentation should be considered: one for the application of the Human Factors Evaluation Tool, and one for summarizing the results for a Network-wide Road Safety Assessment. Segmentation required for the application of the Human Factors Evaluation Tool should be made after identifying the area of influence of each potentially critical location. The sections representing the segmentation for the Network-wide Road Safety Assessment must be long enough to be representative and should be the same length as far as possible.
b) The number of potentially critical locations to analyze must be reduced, without compromising the results.
c) The results should account also for the results from each Human Factors Rule, and not only for the total (all rules together).

To achieve all the objectives set, following the identified requirements, the procedure has been structured into three different steps, each one aiming at reaching specific objectives.

The **first step** is the most relevant part of this research. It allows to make a first screening of the road to identify the potentially critical locations which have a high possibility to be at high-risk. In this step the road is divided into different sections which have the same characteristics in terms of factors influencing expectations (those sections are called "expectation sections"). This is a fundamental step of the procedure because of three reasons.

1. It provides inspectors by an overview of the road, forcing them to understand what expectations drivers have about a specific road stretch. This will help making the next evaluations.
2. It measures the risk related to the difference between expectations and reality, and the visibility of the potentially critical locations.
3. It allows to identify the most relevant (dangerous) potentially critical locations to include into the analysis and thus to reduces the number of potentially critical locations to be analyzed in detail. This saves much time (and thus resources) in the Step 2 of the procedure.

The screening process is based on the evaluation of the difference between reality and possible expectations induced by the road, considering punctual expectations, general expectations, and visibility.

In the **second step** (evaluation process) the riskiest potentially critical locations are identified based on the expectations parameter defined in step 1 and they are grouped in based on their area of influence into segments, namely Human Factors evaluation segments. The Human Factors evaluation tool is than applied to each Human Factors evaluation segment. This process requires a visual detailed inspection of the road. This step is a fundamental part of the procedure because it provides the evaluations of the analyzed road. The visual inspection carried out during this step, can be carried out together with standard RSI procedure, because it doesn't require any specific additional operations. This is another strength of the whole procedure.

To be applicable to segments, the structure and mechanics of the Human Factors evaluation tool have been modified and adapted.

The **third step** allows to organize the results so that they are suitable for a network classification. This means to group many Human Factors evaluation segments into singles network assessment sections. For each network assessment section, a risk code is calculated. The risk code allows to both identify four different levels of risk and to make a ranking of the network assessment section. The Human Factors Evaluation procedure, allows to define specific length for the network assessments sections, based on the road agency 's requirements. However, as highlighted in this research, it has been found that a segmentation of a fixed length of 1 km, could be the best choice.

Finally, the Human Factors Evaluation procedure has been tested to evaluate its effectiveness and reliability, its repeatability, its consistency against different segmentation, and to understand how practical its application is.

The effectiveness and reliability have been tested comparing the outcome from the application of the HFE procedure to six road stretches in Europe for a total of about 62 kms, with the outcome of accident-based analysis on the same stretches. The accident-based analysis was performed accounting for the accident rate. Accidents databases have been analyzed to account only for accidents which can be related to Human Factors. For example, animal collisions, vehicle breakdowns and accidents due to sudden illness, have been excluded.

- The results show that the relationship between Human Factors-related issues and accidents is high. Overall, it has been found a rate of concordance between 56% and 81%. The relationship has also been tested accounting for the ranking derived from the two procedures (Human Factors Evaluation and accident-based), showing good consistency (Kendall'W of 0.774, statistically significant with p-value < 0.05). These results demonstrated that the way the road is perceived by the driver has a great influence (probably the most important) in accident occurrence. Thus, it must be considered in road safety analysis.

A repeatability test has been also carried out thank you to two master's degree students, who chose to implement the Human Factors Evaluation procedure on one of the road stretches already analyzed within this study. The results from the two applications are consistent (the risk levels identified are the same).

The overall results are encouraging to promote the Human Factors Evaluation procedure as a usable procedure to assess the risk level of a road network.

CHAPTER 1 INTRODUCTION

Chapter list of acronyms

HFE	Human Factors Evaluation
HFET	Human Factors Evaluation Tool
NWRSA	Network-Wide Road safety Assessment

1.2 Another step to enhance road safety

The issue of road safety still has strategic importance in the development and well-being of a country. Road accidents continue to be one of the leading causes of death in the world, despite the numerous efforts made to improve road safety conditions. Approximately 1.35 million people die because of road accidents every year (WHO, 2019). This number roughly corresponds to the number of inhabitants of the city of Milan. Thus, every year a city like Milan disappears.

Accidents are the main performance measure of road safety. The greater the number of accidents, the lower the safety on our roads.

As it is known and evidenced by experience, most road accidents occur in relation to driver behavior. The driver behavior is not always the primary cause of an accident, but his contribution, positive or negative, is always present, as all the actions and maneuvers that occur on the road are commended to driver behavior. However, if the risk of an accident depended solely on the driver, this would be uniformly distributed throughout the network, and the number of accidents in each road section would be only proportional to the traffic. The presence of many points characterized by a high accident rate and others characterized by a low accident rate, net of traffic, leads to one logical consequence: the road, its configuration, and its environment, affect the behavior of the driver and therefore the occurrence of an accident. The reader may argue that the conclusion reached by this reasoning is obvious, but the reasoning itself is not, since it highlights and makes explicit the centrality of human behaviors as a response to the road environment. Accidents, drivers, and road characteristics, including the environment, are related.

Solving problems related to road safety means, at a first glance, identifying and intervening on those points with a high number of accidents. Therefore, the road safety engineer will have to determine a methodology that allows to identify these points, to study them, and to determine the probable causes of future accidents. This allows to plan interventions that can improve the situation. The classic procedure for identifying these points has been for a long time, and still is, to evaluate the number of accidents that occurred along a certain road section. Regardless of the indicators used, the concept underlying by this procedure can be summarized as “the frequency of accidents in the past is an estimate for the risk in the future”. Although practical, this approach has two main problems: the first is that the data relating to accidents can be prone to error, and the second, more important, is that this procedure requires accidents to occur. A mature and modern road safety management system can no longer be based only on reactive methods, that is, capable of intervening only once the accident has occurred. Acting sooner can mean saving lives. It is therefore necessary that technicians and researchers work to implement methodologies that are proactive, i.e., able to assess the safety risk of a road before accidents occur, both in the design phase and on roads currently open to traffic. This must be the main objective to take that additional step necessary to enhance safety on our roads.

Identifying road safety issues is not an easy task. Accidents triggering and influencing factors are numerous, and accidents may derive from various complex situations. Procedures based only on accidents observation, or which consider only some of the road main geometrical features, may not be sufficient. Sometimes, the "simple" use of road data (e.g., geometric, functional, and cross-sectional data) into an equation, which does not consider the specific development and configuration of the analyzed road section, may not be enough. Approaches based on equations defined by means of statistical inferential analysis, are many times a useful and fast instrument to investigate and quantify the level of risk of a road, but often they seem to be unable to explain and to "read" all the possible critical conditions. Road safety inspections based on visual on-field inspections are instead an instrument that allow to evaluate peculiar aspects of the analyzed road section. This is because road safety inspections are carried out by inspectors, who can accurately analyze the stretch and discern which factors may contribute to accident occurrence.

Finally, road safety analysis procedures, should account for aspects related to the man-road interaction. Up to date, much research has been conducted in this field, and it is now known that those aspects are a fundamental part of road safety analysis. We can now speak of Human Factors applied to the road field and to road safety. This means defining which elements of the road and its environment may influence driver perception and consequently affect driver behaviors. This means also determining analysis procedures capable of considering these aspects. The analysis of these aspects provides the answer to the problem mentioned above, namely that accidents are almost always caused by human behaviors and that most of the time, where many accidents occurred, it is the road and its environment that negatively affect these behaviors. To analyze the aspects related to Human Factors means to analyze the aspects that affect the driver's behavior while driving. Therefore, procedures are required that allow to analyze road safety considering Human Factors aspects.

PIARC (World Road Association) has been attentive to the aspects of Human Factors for several years. In 2019, PIARC published the Human Factors Evaluation Tool (HFET) based on visual inspection procedures, capable of assessing and quantifying the impact of these aspects on single road locations (e.g., curves, at-grade intersections, etc.). The HFET was the starting point of this research.

From these premises, considering the need for a proactive analysis procedure based on Human Factors and the possibilities offered by the PIARC HFET, this work focuses on the development of a proactive Network-Wide Road Safety Assessment (NWRSA) procedure, which is structured around the HFET, namely Human Factors Evaluations-based (HFE) procedure. The HFE procedure shall include visual analysis from inspectors. The HFET, in turn, has been studied and adapted to be used for this purpose.

In sum, the HFE procedure shall aim achieving three main goals.

- The procedure shall be based on Human Factors, which means that it must account for driver behavior. To do this, and to provide a quantification of the analyzed aspects, it has been decided to consider the HFET from PIARC as the starting point of the research.
- The procedure shall be useful to assess the network safety level by means of proactive analysis, capable of identifying risky road sections, without the need of accident data.
- The procedure shall be based on road safety inspections (visual inspections), which provide detailed analysis of the road and can identify road deficiencies that are specific of the analyzed road section.

It was also decided to develop a procedure which can be applied to single-carriageway rural highways, both because of the importance of this road type for road safety, both because the three years PhD period didn't allow to expand the procedure development also to other road types (i.e., motorways, rural local roads, urban roads).

1.3 Structure and development of the thesis

One of the main points of this research was to understand if the HFET can be applied to implement a NWRSA procedure.

Consequently, during the first stage of this PhD research, the HFET was applied to two case studies to allow for the evaluation of its use also for a network analysis. The application made it possible to identify the weaknesses and strengths of the tool and therefore to define the starting point for the procedure development.

In the second stage, the procedure has been theoretically developed and calibrated on a rural road stretch. The development of the procedure required a deep study about Human Factors and their influence on road safety. For this reason, a wide background about Human Factors is provided in this thesis. Specifically, the influence of expectations while driving has been investigated. The analysis of expectations has provided a decisive contribution in the development of the procedure, and one of the main effort made in this work was to "translate" the concept of expectations in engineering processes.

In the third stage, the procedure has been applied to other rural roads from Italy, Germany and Slovenia and the results have been discussed and analyzed to test its effectiveness. Further analysis and comparisons have been lastly implemented to also test the repeatability and consistency of the procedure.

The structure of the thesis follows exactly these steps. The thesis consists of a total of nine chapters (including introduction). The introductory part comprises CHAPTER 1 and CHAPTER 2, while a wider background and literature review about the driving task and Human Factors is presented in 0. 0 is wholly related to the HFET, both presenting the background premises and its development and improvements. The methodology considered for the development of the procedure is instead provided in CHAPTER 5, together with the structure of the HFE procedure itself. In CHAPTER 6, the results from the application of the procedure to some case studies are presented, and in CHAPTER 7 these results are discussed. Final conclusions are reported in CHAPTER 8. A detailed description of each chapter is provided in the following.

Moreover, at the beginning of each chapter, excluding CHAPTER 1 and CHAPTER 8, a chapter abstract is provided, which describes the contents and the main findings/significance of the chapter. A list of acronyms is also provided at the beginning of each chapter, which contains all the acronyms used in the chapter.

Chapters summary

CHAPTER 2 provides additional insights about the main aspects related to road safety that have stimulated the realization of this work, and thus which contribute to set the objectives of the HFE procedure. Moreover, it clarifies what are the main approaches to road safety and which approach can be strategic for improving current road safety standards, with a deeper insight on RSIs, as a procedure to overcome some limitations linked to other currently used procedures.

0 provides all the conceptual and theoretical bases, along with the main literature review concerning Human Factors. In this chapter it will be clarified what are Human Factors principles and how they can be applied to road design. A detailed background is also provided about driving models, risk perception, and psychological aspects related to driving. In the chapter the concepts of expectation as an essential part of the analysis will be explicit. Expectations are the basis of the HFE procedure logical approach.

In 0 the HFET from PIARC is analyzed. A background about its development is provided, and its structure and contents are described. Moreover, weaknesses and strengths emerged from its application to two test roads are discussed, and the amendments and improvements presented. In this chapter, it will be considered the aspects related to the applicability and consistency of the HFET itself, and not to how including it in the whole HFE procedure.

CHAPTER 5 deals entirely with the procedure, the core of this thesis work. In this chapter the assumptions made, and the methodology followed to improve the procedure, will be provided and all the considerations made will be explained in detail. The chapter also presents the weaknesses and strengths of the HFET considering its application to a network, both in term of reliability and possible real implementations (e.g., understanding the application time of the HFET). This set the basis to define HFE procedure's requirements. The result of the research work presented in this chapter will be the procedure itself.

CHAPTER 6 presents the application of the procedure to some case studies. The case studies are composed by six road stretches of two-lane two-way rural roads: two from Italy, three from Germany and one from Slovenia. In this chapter the description of the road stretches will be provided, along with the description of the available road's databases (accidents, traffic, geometrical features). The results of the application of the procedures to those stretches will finally be presented.

In CHAPTER 7, the discussion concerning the results is presented. The numerical outcome from the procedure will be analyzed and compared with the outcomes from accident analysis to test its effectiveness. Moreover, a comparison is presented between the results obtained on the same stretch from the application of the HFE procedure by different inspectors. The comparison allows to make a first repeatability test. The consistency of the procedure has also been tested against different segmentations. Together with the numerical evaluation of the results, the discussion of the application of the procedure itself is presented, highlighting its strengths and weaknesses.

Finally, CHAPTER 8 comprises the conclusions of the work. In this chapter a summary of the objectives achieved is provided, considering the step implemented and the outcomes from the analysis of the results. Possible suggestions for further improvements of the HFE procedure are here presented.

CHAPTER 2 DEALING WITH ROAD SAFETY

Chapter abstract

This chapter describes the approach to the problem used in this work, highlighting the importance of a wider approach to road safety. This approach must be based on experts' knowledge, and must comprises different disciplines, among all, engineering, and psychology. The chapter highlights the importance of network-wide road safety assessments (NWRSAs), and how it is intended in the updated EU Directive on road safety. Accident prediction models (APMs) and road safety inspections (RSIs) are also discussed, highlighting their strengths and weaknesses, defining the reason of the choice of considering the RSI as a most practical instrument to carry out NWRSAs.

Chapter list of acronyms

APM	Accident Prediction Model
ARAN	Automatic Road Analyzer
CMF	Crash Modification Factors
EB	Empirical Bayes
HFE	Human Factors Evaluation
HSM	Highway Safety Manual
LOSS	Level of Service Safety
NSS	Network Safety Screening
NWRSA	Network-wide Road safety Assessment
RSA	Road Safety Audit
RSI	Road Safety Inspection
RTM	Regression to the Mean
SAPO	Safety Potential
SPF	Safety Performance Function

2.1 A scientific approach to road safety

Accidents are the outcome of some concurring factors, and thus they are the possible consequences of some causes[1]. Unfortunately, the complexity of the factors influencing the accident occurrence, makes identifying causes very difficult, even more, because accident causes are mainly identified observing the result and not the cause itself. For this reason, a quality scientific approach to road safety must start with accidents data observation, but it

[1] "Causes" may not appear a correct term, because it may imply that something is to blame. "Influencing factors" or "contributing factors" are more suitable terms. However, in this work, the term "causes" will be also used, including in this term all the contributing factors, because they contribute and concur to the accident causation. Moreover, to intervene on the accident's cause, means to intervene on the contributing factors.

must than relate with knowledge. Road safety experts must consider all their knowledge to try to understand accidents. This leads to theory formulations that need to be tested. This is the base of a scientific approach and the way to add a little brick to the building of science.

Unfortunately, defining theories and test them, it is not an easy task talking about road and accidents: it is not easy to prove the goodness of a theory or even the effectiveness of some countermeasures, because implementing real measures in the real world is expensive, and if the safety theories are not true, they can translate into accidents. Driving simulators come in our help to overcome this issue, nevertheless, driving inside a driving simulator is not the same as driving on roads. Drivers behavior, which is the leading cause of accidents, can be highly influenced by the simulator itself (Bruck et al., 2020) (Espie et al., 2005). Despite those difficulties, all efforts should be made to enhance this approach, relying more on critical evaluations and reasoning about accidents causation, than on accidents as data extrapolated from the context. Additional information is also provided by the naturalistic driving data. With this data it is possible to relate some near crash conditions, to accidents triggering and contributing factors (Guo et al., 2010) (SWOV, 2012) (Jia et al., 2021) (Singh and Kathuria, 2021). Such types of analysis are proactive analysis and are extremely useful to improving the knowledge on accidents causation (van Schagen and Sagberg, 2012). Their main limitation is that the analysis of such data requires many efforts, which are hardly addressed by a human. Likely, always more often, machine learning processes are implemented and used to analyze those data. However, sophisticated algorithms which allow to consider all the risk factors of a road, are not present up to date.

Whatever the case, the knowledges applied by road analysts (engineers, psychologist, or simply technicians) to identify and solve road safety issues, are crucial.

Concerning the current situation, since the end of the last century, mathematical and statistical approaches have grown across all fields, from physics, to medicines, to economy, to sports, to social science, and so on, providing an amazing instrument to analyze observed data. Statistical analysis, inferential statistics, and regression models, perfectly fit the concept of empiric science and empiric research. Empiric research means, in its extreme level, to define all the possible relationships between different variable, only looking at data. A more theoretical-oriented approach is historically linked to the concept of rationalism. Well, while approaching to road safety, both these two approaches must be considered. A methodology based only on statistical inference, may provide good calibration, and in some context may provide extremely higher goodness of fit coefficients, but it can lack of one of the most important parts that is the knowledge behind the results, and the analysis of the specific situation.

The field of road safety is not suitable for a rationalistic approach, because it is exceedingly difficult to define and to test a theory, because of the complexity of accident causation. Nevertheless, if the road safety system wants to improve its effectiveness, the theoretical part is crucial in developing road safety analysis procedure. Theories must develop from observations and must be finally proven with observations, but must pass through a cognitive analysis, an evaluation that goes a little far above the statistical regression alone. This is what this work, with all the consequent possible limitations, have tried to do. Providing a procedure that derives from the knowledge about road safety, and then applying the procedure to some roads to evaluate the results.

2.2 Engineering and psychology

The analysis of road safety, or rather the aspects and features of the road that influence road safety, is not a trivial process. To understand what factors can cause an accident, it is necessary to analyze the road carefully, and primarily understand which factors must be consider understanding the how the driving task is carried out. Human factors are among those factors. The represent how human beings can read, interpret, and react to the road and its stimuli. To fully understand this topic, it is necessary to cross over into subjects that, at least at first glance, seem not to have much to do with engineering. One of these subjects is psychology. And although the classical approach prefers to place psychology in a "literary" subject, psychology is in effect a scientific subject, which has its roots in medicine and physics. It is essential that as engineers use concepts and rules from physics, they must also consider rules and concepts from psychology. Figure 2.1 illustrates the well-known conceptual scheme of the most influencing factors for road safety: driver, road, and vehicle. Moreover, the figure also presents the specialist which must deal with those factors. Talking about Human Factors in road design means to evaluate the relationship between the road factors and the driver factors, thus a strictly collaboration between engineers and psychologist is mandatory.

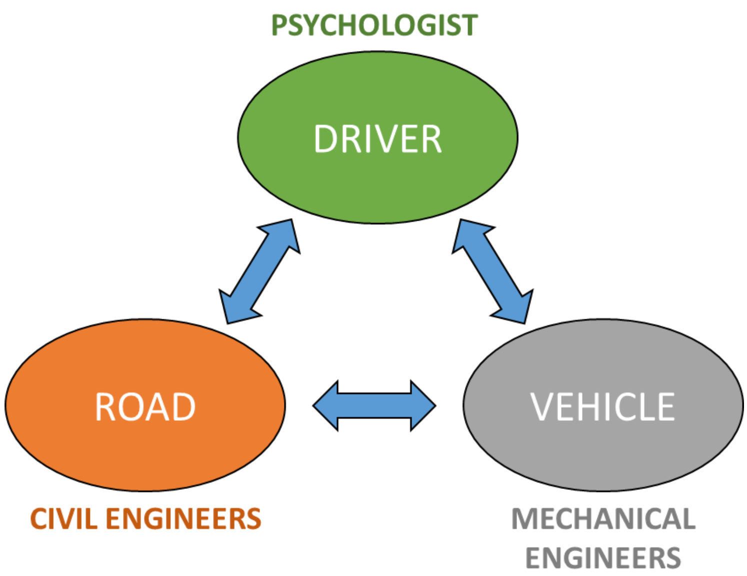

Figure 2.1 – Main factors influencing road safety

Some researchers in the field of human factors have proved their importance under many safety and functional aspects. The many years that have passed since the invention of the car, the advances in psychology, the many data available from all over the world, allow us today to clearly say that there are reasons behind driver's behavior. These reasons are most often automatic and involuntary and are derived from the driver's road perception. Within these reasons, expectation plays a fundamental role. Expectations are linked to the experience of the driver and are a powerful instrument used by human beings to overcome some of their physical limitations (e.g., the inability to read in a few seconds all the information deriving from the surrounding environment). Therefore, expectations will be a central concept in this work and a fundamental concept for the improvement of the procedure.

Addressing the issue of road safety from a human factors point of view means placing the driver at the center of the system, and building the road around him, in an ergonomic way, considering a road that adapts to his needs, and not a driver who adapts to the road. Or rather, the second option must be considered because of the first: the driver adapts to the road, but within certain limits and these limits are considered when the road is designed, and they derived from the human capabilities to interact with the road.

2.3 Overview of current road safety analysis procedures

2.3.1 The need of a well-defined procedure to analyze road network safety

The process to analyze the level of safety of the road network, is the so-called Network Safety Screening (NSS), which has the same meaning as the Network-wide Road Safety Assessment (NWRSA). For the purpose of this work, the term used will be NWRSA, which is the same term used by the updated European Directive (European Parliament and the Council, 2019). The NWRSA process assumes different names within different Road Agencies (road agencies), however the objective of the process is always the same: it is "the process of identifying sites for further investigation and potential treatment" (Srinivasan et al., 2016), or "to identify sections of the network that should be targeted by more detailed road safety inspections and to prioritize investment according to its potential to deliver network-wide safety improvements" (European Parliament and the Council, 2019). The identification of the riskiest sections of a road and the classification of all the sections belonging to the road network, allows to prioritize the interventions, choosing the site which has the highest impact on road safety. Nowadays, NWRSA procedures mainly rely on accidents data, both considering "standards" indices such as the accidents frequency, the accidents density, the accidents rate (PIARC, 2013), the safety potential (SAPO) (Kathmann et al., 2016) (Ministero delle Infrastrutture e dei Trasporti, 2012), and the Level of Service of Safety (LOSS) (Kononov et al., 2019) and also considering more advanced procedures, like the use of Accident Prediction Models (APMs) and Empirical-Bayes procedures (AASHTO, 2010).

Approaches based on accidents data are recommended if data are available and reliable, because accidents may provide extremely useful information about road deficiencies. However, specific conditions of a site, which include all the factors influencing an accident occurrence, can be really identified only by means of visual safety inspection. Furthermore, accident data may also present some issues that influence the reliability of the analysis: accidents need to occur (must wait for them, with the consequences of possible injuries and deaths), accidents are still a stochastic variable that are influenced by the regression to the mean phenomenon (RTM) and a non-linear relationship is present between traffic and accidents (Srinivasan et al., 2016), and finally accident data are not always available (e.g. there is a high lack of data in Low- and Medium-Income Countries). To avoid some of the issues related to accident data, Accident Prediction Models (APMs) has been adopted, with Empirical Bayes (EB) adjustments (see 2.3.2). APMs are a powerful instrument to evaluate the level of safety of a road and thus of a network. Nevertheless, they must rely on a high number of data, that are not always available, both to define and calibrate a specific model. Lastly, considering the state of the art of these procedures, they lack aspects related to the man-road interactions.

Those limitations highlight the need to implement some new approaches, which may allow to analyze the safety level of a road network, without the requirements of a wide accident database. An answer to this demand has been provided by the development of approaches based on road surveys and inspections, which must evaluate the road safety without considering the number of accidents. This type of approaches are proactive approaches because they are based on the road in-built safety analysis (an approach based on accidents is called "reactive approach", because it can only be implemented after accidents occurrence). Proactive approaches should be the focus of road agencies to avoid as much as possible any risk of accidents before they occurred. After an accident has occurred, it is impossible to come back.

One of the most used proactive approach procedures, is provided by the Road Safety Inspections (RSIs). At first, RSIs were mainly used as an instrument to carry out specific analysis on sites identified as "high risk sections" from an NWRSA. However, nowadays RSIs are widely used in a systematic and periodic process to screening the network. The results of an inspection provide a risk analysis, which can be used to classify different road sections.

2.3.1.1 *The updated Directive 2008/96 EC*

The 23rd of October 2019 the European Parliament issued the Directive (EU) 2019/1936 (European Parliament and the Council, 2019), which contains updates and amendments to the Directive 2008/96 EC (European Parliament, 2008). The new directive contains many amendments about managing process, subjects, matters and scope of the directive, but also about the safety process and analysis that should be adopted.

At a more macroscopic level, the first thing that can be noticed is a different approach to road safety, definable, if possible, as even more mature than the one of the original Directive 2008. In the last 10 years, also thanks to the application of road safety analysis procedures systematized by the Directive 2008, such as Road Safety Inspections (RSI) and Road Safety Audits (RSA), it was realized, both at a global and, above all, at European level, that to improve road safety even more, it was necessary to take an extra step. It is not easy to ask road agencies and member states for such a step, but this choice demonstrates the maturity of the European safety management system. This new step consists in the assumption that proactive approaches should be the priority in road safety analysis. As already discussed, proactive approach allows to identify road safety risks before accidents occurrence. For these reasons, such a type of approach must be the final objective of road administrations that want to improve a complete road safety management system. In addition, another input given by the directive update seems to indicate that the human component, in the analysis procedure, is a fundamental component. The term "human component" wants to highlight not the driver, but the central role of the inspector. Therefore, even more strongly than in the original version of the 2008 Directive, the centrality of visual inspection procedures is emphasized.

The last innovative point of interest for this research, which is identified by the updated 2008 Directive, is the attention to the perceptual aspects of the road, which must be considered in safety analysis. The concept of self-explaining and self-enforcing roads is an indispensable necessity for the safety of our roads, which must be considered (Article 4, paragraph 6) (European Parliament and the Council, 2019). The basic notion of a self-explaining road, which originated in Netherland, is a "traffic environment which elicits safe behavior simply by its design" (Theeuwes and Godthelp, 1995). By this concept, the driver should clearly understand the road he is driving, its elements and its features, changing his driving behavior according to the road elements. Self-explaining roads concept could appear utopistic, nevertheless is something to which designer should tend to finally make roads on human scale. This concept can be easy integrated in the concept of the Safe System and the Vision Zero approach (Tingvall and Haworth, 1999).

Wrapping up, the two most relevant innovations introduced by the directive concerning network analyzes, are:

- Need for a network analysis based on visual inspections and therefore a higher detail of analysis (i.e., NWRSA) (accidents can still be used, but only as a secondary option, Article 5, paragraph 2);
- Need for an analysis based also on aspects related to the perception of the road, as it is necessary to evaluate not only the possible severity of the impact, but also the risk of an accident, and this is inevitably linked to the factors that can trigger accidents, which are mostly related to man-road interaction.

These two points fit exactly the topics of this research. The HFE procedure accounted for these new requirements from the Directive, proposing itself as a procedure that can be used by EU member states precisely to respond to these needs.

2.3.2 Accident Prediction Models with Empirical Bayes (EB) adjustments

APMs account for the systematic influence of road physical and functional characteristics on accident occurrence and are developed analyzing the historical accident trends occurring on similar road infrastructures by means of statistical procedures. These models allow to relate the number of crashes expected on a site to its specific geometric and environmental characteristics (Yannis et al., 2016). At present, APMs have been extensively used in the road infrastructure field for the estimation of the number of accidents to be expected on road segments and junctions (Greibe, 2003) (Cafiso et al., 2010) (Moraldi et al., 2020), as well as to determine the expected safety impacts of design changes (La Torre et al., 2019) (Šenk et al., 2012). Within the large number of APMs developed during the last years, the Highway Safety Manual (HSM) (AASHTO, 2010) (AASHTO, 2014) and the PRACT Project (La Torre et al., 2016) approaches offer a consistent method for making reliable crash frequency predictions based on traffic, main road geometrical features (both planimetric, altimetric and cross-sectional) and other functional and safety aspects such as the presence of lighting or the presence of road safety barrier.

An exhaustive description of APMs is provided by Elvik (Elvik, 2010). The great reliability of those methods come at the price of a high demanding number of available data and reliable models: sometimes a simple calibration procedure as the one proposed by HSM is not sufficient and specific safety performance function (SPF) are required if the base conditions considerably differ from the standard conditions (La Torre et al., 2019). This is proved by further research such the ones from Gross et al. (Gross et al., 2009) and Bonneson et al. (Bonneson and Pratt, 2009), which highlights different results in road safety effects of the same countermeasure applied in different regions. This places some limits on their use. Furthermore, the explanatory capacity of accident phenomenology even of the best calibrated available APMs can’t directly account from many human-related aspects to date. This should be the objective of further experiments, even if the task is not easy. As a matter of fact, accidents may happen due to causes that differ from the geometrical and physical features considered by APMs. Accidents occur due to the interaction between vehicle, road, and drivers. This limitation is partially overcome using Empirical-Bayes methods. Empirical Bayes methodologies allow to consider both the predicted accidents from the model, and the observed accidents from the reality. The use of this process has a double benefit: the reduction of the aleatory bias of the observed accidents (e.g., regression to the mean) and the inclusion of aspects not considered in the prediction model, which anyway influence the number of observed accidents.

Crash Modification Factors (CMFs)

To the concepts of APMs is generally associated al so the concept of Crash Modification Factors (CMF) (AASHTO, 2010). A CMF is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site (FHWA). Wide research has been conducted concerning the definition of CMF. The wide available databases provide some interesting and reliable results that help to understand which can be the influence of a specific factor on road safety. On the other hand, sometimes many of the findings from that research can be applied only to some very specific situation. Consequently, the most used CMF reference, that is the CMF Clearinghouse, provides a description of the conditions considered in the developing of the CMF. Moreover, CMF Clearinghouse provides also a “star quality level” for each CMF presented. The star rating is based on a scale (1 to 5), where a 5 indicates the highest or most reliable rating. The review process to determine the star rating judges the accuracy and precision as well as the general applicability of the study results. Reviewers considered various factors for each study (depending on the study type used to develop the CMFs) — study design, sample size, statistical methodology, statistical significance, etc. — and judged each CMF according to its performance in the various factors (including multiple subcategories within each factor). There are 7493 CMFs in the CMF clearinghouse and about 6% of those CMFs are classified with 5 stars[2]. These data allow to make two important considerations: first, the factors influencing road safety are thousands, even if we consider only road-related factors (including road environment); second it is not easy to define a reliable CMF applicable in many different conditions.

To conclude, after dozens of years of research, APMs based on inferential statistic have proven to be of a great use but have also shown some limitations based on the difficulties to define clear relationship between a road feature and the expected number of accident (i.e., to determine causal relationship between the two variables) and mainly because of the large amount of data required to implement reliable APMs and to correctly apply them. Moreover, it is often impossible to account for all the variables influencing accident occurrence. A nice and powerful metaphor about the significance of statistical inference in road safety, and the difficulties in making statistical inference, is provided by the springs example by Hauer (Hauer, 2015, pages 92-93). For a detailed review of statistical approach on APM the work from Abdulhafedh is also suggested (Abdulhafedh, 2017).

2.3.3 Road Safety Inspections (RSIs)

PIARC define RSI as "a systematic, on-site review, conducted by road safety expert(s), on an existing road or section of road to identify hazardous conditions, faults and deficiencies that may lead to serious accidents" (PIARC, 2012a). Moreover, "the primary purpose of an RSI is to identify issues relating to road safety; it is not a check of compliance with design standards. The Road Safety Inspection shall only consider those matters that have an adverse bearing on road safety under all operating conditions." (Transport Infrastructure Ireland, 2017). Similar definitions can be found all over the world. The Directive 2008, with its update of 2019 (European Parliament and the Council, 2019), introduces a double concept of RSI:

- "targeted road safety inspection", which means a targeted investigation to identify hazardous conditions, defects and problems that increase the risk of accidents and injuries, based on a site visit of an existing road or section of road, and
- "periodic road safety inspection", which means an ordinary periodical verification of the characteristics and defects that require maintenance work for reasons of safety.

The first definition represents the concept of RSI introduced also in the first version of the Directive 2008, that is a consequence of the network safety assessment and ranking. After the identification of the most critical road sections resulting from the network safety assessment,

[2] Up to August 2021

additional detailed analysis will be carried out with the RSI. Now, a question arises: why RSIs, which are proactive procedures, should be used only as a consequence of the network safety assessment? Would they become a re-active procedure? The answer is that it depends on how the network assessment is carried out. If it is based on road accidents, RSIs become, in some way, a reactive procedure. The concept of "targeted road safety inspection", means a very detailed analysis of the road, which helps to identify the main safety issues, but also to understand the possible safety countermeasures. In this sense, it provides a link between the analysis stage and the intervention/project stage. Such an RSI can only be applied to some sites identified by the NWRSA. The level of details and the link to the project stage, reduce the possibilities to use these RSIs (targeted RSIs) as an instrument to implement an NWRSA and to define network safety levels.

However, during the last years, understanding the potential of their application to improve road safety, some road agencies decided to try to include RSIs in the NWRSA process. An example of this kind of "hybrid" procedure is provided by Italian authority, which introduced the concept of "periodic road safety inspections" also in the *Guidelines for road infrastructure safety management* (Ministero delle Infrastrutture e dei Trasporti, 2012). This RSI should provide another safety analysis of the network, and together with the results from the accidents analysis, it will concur to define the risk level of every segment of the network. Unfortunately, even if the proposal was enlightened, there weren't sufficient instrument to quantify, and thus to compare, the network safety level by means of road safety inspections and this results in a difficult application of the procedure during the NWRSA process. Another example of "hybrid" procedure is provided by Ireland authority, which integrated standard network safety analysis based on accidents, and risk classification based on RSIs (Transport Infrastructure Ireland, 2017), where RSIs mainly have the task to identify the risk in terms of severity. Another RSI procedure, which has widely spread all over the world during the last decade, is the iRAP Star Rating procedure ("iRAP Methodology fact sheets - iRAP," n.d.) (Ambros et al., 2017). The procedure relies on visual inspections that can be carried out both manually by inspectors or automatically by equipped vehicles. The procedure requires that the main road characteristics are considered, both geometrical and functional. The influence of these aspects is considered and a risk score is obtained that is based on the exposure, the probability of an accident and the severity of the accident for different type of roads and facylities. This score is translated in the so-called Star Rating, which allows to implement a classification of the sections of the road network.

Another interesting proactive approach to a NWRSA procedure, was proposed by Cafiso et al. (Cafiso et al., 2007). This approach relies on RSI and provide a safety index suitable for the ranking of the analyzed sections. Furthermore, Cafiso et al. also investigated the results of the procedure by the use of high speed automated system (ARAN 9000 vehicle) and investigation by the inspector with low cost instrument (Cafiso et al., 2017). The results show that the high-performance monitoring systems are particularly useful for the evaluation of risk factors related to cross section and geometric alignment (e.g., horizontal curvature, vertical gradient). On the opposite, for roadside hazard, in-field inspection can be considered more reliable and practical if supported by appropriate low-cost equipment and tools. Thus, on-site inspections are still providing an adding value, albeit with a higher time expenditure. Moreover, it has been demonstrated that RSI which are carried out following a systematic and structured procedure, produce the same results, even if carried out by different inspectors (Cafiso et al., 2006).

Despite the results and the objectives of the introduction of RSIs in the network assessment process, it highlights the possibility to use RSI as a completely proactive procedure to analyze the network safety level. These considerations suggested that RSIs can be chosen as an instrument to carry out NWRSAs, even more in those countries where expensive equipment and instruments, road data, and accidents data, are not easily available.

2.3.3.1 *The importance of accident data*

As previously stated, accident data can be affected by many inaccuracies and errors. Most of them are due to carelessness during their collection, some other occur because the collection system is not ready to collect all the required information about an accident. Moreover, they may occur because accidents can be the outcome of many concurring factors, and this may grant them a kind of randomness (e.g., it is hard to observe the same number on accidents in the same point of the road every year). Finally, accidents always means that something bad is happened, and a reliable "safe system" must try to improve road safety, without waiting for accident occurrence.

Nevertheless, accidents data are crucial for road safety. Accurate accidents data, together with accident’s analysis, are mandatory to clearly understand accidents causation in the field of research, and when the number of accidents is high (after having validated the data), it is clear that a problem is present in the segment, despite all other possible results from different analysis.

Accident data represent the only actual safety measure to be considered at least as reference and validation parameter when alternative approaches and surrogate measure of safety are investigated, as in this thesis.

2.3.3.2 *The challenge of Low- and Middle- income countries*

Road accidents are one of the leading causes of death all over the world, but it struck even more in low- and middle- income countries. 93% of the world's fatalities on the roads occur in low- and middle-income countries, even though these countries have approximately 60% of the world's vehicles (WHO, 2019). These data highlight that major efforts must be made in these countries to improve their safety management system. The causes of this backwardness in the safety management system are many (Odonkor et al., 2020) (Heydari et al., 2019). The reduced availability of resources is certainly one of the most relevant aspects. Having limited resources may limit the design phase, and even more the maintenance and the safety analysis. But the most relevant aspect is perhaps relating to the organization of the system, which often must face a significant increase in vehicles and an increase in technological innovations, without having enough time to adapt and plan its development correctly (Khanal and Sarkar, 2014). This often leads to the lack of a systematic approach and the impossibility of having access to many of those data that are the basis for many of the current safety analysis. Those data are relating to both accidents and the characteristics of the road. It is therefore evident that analysis procedures that do not require a large amount of data, but only the work of trained practitioners, can be an indispensable resource for increasing road safety in these countries. For this reason, a NWRSA procedure based on RSI can be very helpful to analyze road safety in those countries.

CHAPTER 3 HUMAN FACTORS AND ROAD SAFETY

Chapter abstract

This chapter analyze in detail why considering Human Factors in road safety is a crucial task and how it is possible to evaluate the influence of road characteristics on driver behavior. In this chapter the theoretical concepts are presented upon which the procedure is based. The central role of space perception and expectations will be illustrated together with the risk theory derived from literature review. Three main aspects will be considered to analyze the road safety level under a Human Factors point of view: factors influencing general expectations, factors influencing punctual expectations, and the time provided to read the situation. To demonstrate this statement is required to introduce the concept of accident's chain and the concept of risk, both real risk and perceived risk. In addition, few insights are provided about the way the environment is perceived by road users, and which are the most relevant aspects that could mislead drivers while driving.

The chapter will finally present the PIARC approach to Human Factors. It has been chosen out of all other Human Factors guidelines because it divides Human Factors aspects into three main categories, which fit the concepts of general expectations, factors influencing punctual expectations, and the time provided to read the situation. Moreover, it offers a comprehensive evaluation tool which can be used to analyze the triggers of accidents, and which has a proven prediction quality to predict accident spots (Birth and Pflaumbaum, 2006) (Birth et al., 2015).

Chapter list of acronyms

CMF	**Crash Modification Factors**
DSD	Decision Sight Distance
GEX	General Expectation
HFE	Human Factors Evaluation
HFET	Human Factors Evaluation Tool
HSM	Highway Safety Manual
NWRSA	Network-wide Road safety Assessment
PCL	Potentially Critical Location
PEX	Punctual Expectation
SSD	Stopping Sight Distance
VIS	Visibility

3.1 Defining the factors influencing road safety

The first thing to know to deal with road safety is to clearly understand the complexity of road accidents causation. It is not a matter of looking in detail to which causes may have led to a single accident, it is instead the conceptual and logical approach that must be taken to analyze road safety. Without a clear general frame about the chain of events related to an accident occurrence, accident triggering factors, and accidents concurring factors that lead to an accident, it is impossible to clearly identify the risk factors and thus to make a reliable safety analysis of a road.

3.1.1 Road accidents

"Crashes are rare and random events." This is how the American Highway Safety Manual (AASHTO, 2010) introduce the nature of accidents. Interesting is also the definition by the RoSPA: "A road accident is a rare, random, multi-factor event preceded by a situation in which one or more road users have failed to cope with their environment" (Royal Society for the Prevention of Accidents (Great Britain) and TMS Consultancy, 1995). These definitions of the accident's nature are today well accepted all over the world. The first adjective, "rare", means that road users involved in accidents are an extremely low part of the total volume of users which are acting every day in the transport system. The second adjective wants instead to underlines that accidents occurrence is not only due to specific causes, but also to chance. This stochastic and random attribute of accidents occurrence is due to the complexity of the circumstances that often influence accident occurrence, which are hard to consider all together (multi-factor event). Sometime the leading cause of an accident is easy distinguishable, but some other time there is not any leading cause, but only many minor causes, deriving from specific aleatory circumstances. Accidents are only the tip of the iceberg because they occur as the 'worst case' result of unsafe operational conditions in the road traffic system. As stated by Elvik et al., "*Some of the factors that influence the stochastic process leading to accidents are known, other will never be known*" (Elvik et al., 2009).

A good road safety practitioner must avoid classifying hard-to-explain accident as a random occurrence. The stochastic nature of accidents cannot be completely denied (as it is the translation of their complexity), but all efforts must be made to understand the causes of accidents, and all the possible knowledge about factors influencing an accident occurrence, must be considered. This means to include the analysis of driver behavior and its response to the road system. As a matter of fact, today the term "crash" is sometimes preferred to the term "accident". In fact, the second implies a part of randomness, and this is not accepted mainly by those who must deal with the law (advocates and judges). However, in this work, the term "accident" will be used, because of the necessity to stress on the apparent randomness of an accident, because of its complex nature.

The definition of road accidents by RoSPA, presented before, underlines that road accidents derive from a "multi-factor event preceded by a situation in which one or more road users have failed to cope with their environment". These simple words are exactly the key to comprehend the nature of road accidents. As already stated, accidents are multi-factor events, but they result from a situation where the driver failed to cope with the road and its environment, which also implicitly means that the road and its environment engage the driver with some difficult situations and failed to communicate to the driver the right information. These concepts it is very important because it underlines that the first input to a possible accident, comes from the road and its environment, and that to correctly work, the road systems must consider continuous cooperation between drivers, the road, and the road environment.

After having provided the definition of road accident and have underlined those causes of accidents are multi-factor and strictly related to the road and its environment, it is necessary to try to understand in more detail how an accident originates and what are the theoretical factors, which act by increasing or decreasing the risk of an accident.

3.1.2 Main categories of contributing factors to road accidents

Accidents are multi-factor; this means that there are many factors that contribute to their causation. Considering all this factors, it is possible to identify three main categories of contributing factors. These contributing factors are:

- human factors (drivers' behavior, capabilities, and limitations)
- road factors (including its surrounding and environment)
- vehicles factors (vehicle relationship with the driver and with the road)

Before creating ambiguity, it must be clarified how the term human factors is used and intended. In this thesis it will be used the generic term "human factors" to indicate all those factors related to the human beings, thus including for example effects of drugs, alcohol, or the use of telephone while driving. This definition is widely used in literature. On the other hand, among all those factors, there are some human-related factors that are strictly linked to the human capabilities under "standard" conditions, and not under modified condition (e.g., effects of alcohol, psychological conditions that lead the driver to break the rule, diseases that reduce driving performance, etc.). The standards conditions can be considered as Human Factors, and this term will be used with initial upper cases. Moreover, those Human Factors focus on the relationship between the driver and the road. Those specific Human Factors are defined by PIARC as "those psychological and physiological threshold limit values which are verified as contributing to operational mistakes in machine and vehicle handling. In the case of road safety, the Human Factors concept considers road characteristics that influence a driver's right or wrong driving actions" (PIARC, 2016). Moreover, the term driver behavior must also be emphasized as the set of behaviors and actions the driver made while driving. Not all these actions derive from the road perception, like not all human factors aspects can derive from human beings' standard conditions. For example, an extremely aggressive driving behavior cannot be wholly a consequence of a wrong road perception, because other factors are present which influence driver behavior. This aspect will be deepened later in this chapter. However, to correctly read this work, it must be clear that Human Factors influence the road perception, which in turn influence driver behavior. But driver behavior it is not only related to the road perception, but also to other factors (age, formation, contingent situation, vehicle handling, etc.).

Coming back to the general analysis of accident causations, the influence of those three main categories of factors can be summarized with the Venn diagram of Figure 3.1 by Treat et al. (Treat et al., 1979). The calculated percentage refers to United States of America data of several years ago, but other studies show that the values are still the same over the years (Rumar, 1986) (National Highway Traffic Safety Administration, 2008) (Mansfield et al., 2008).

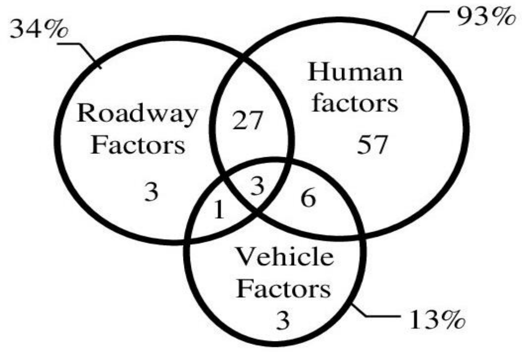

Figure 3.1 – Contributing factors to vehicles accidents (Treat et al., 1979).

It is interesting to go deeply in the meaning of the two first groups, which are the ones this thesis is focused on, looking in details to what have been considered under human and roadway factors. The specific data from Treat et al. research are showed in Figure 3.2, Figure 3.4, and Figure 3.5. Figure 3.2 shows the Major Human Direct Causes of accidents, which are the category to which each specific cause belongs. The higher number of accidents is due to the Recognition Errors (intended to include both the recognition and comprehension problems), but the research also demonstrated a higher percentage of Decision Errors and Performance Errors. All these three groups represent some types of errors that are linked to the road perception and so represent the result of the iteration between the road and the driver. Critical Non-Performances Errors (e.g., driver falling asleep or blacking out) are partially related to the road, because the configuration of a road may influence the driver workload and thus the possibilities of dozing, and Non-Accident (e.g., suicide) are completely road-independent.

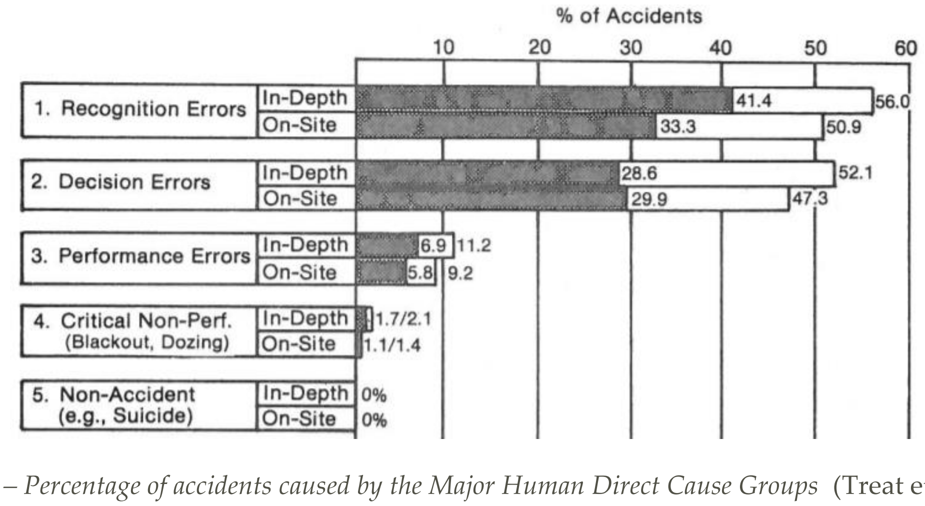

Figure 3.2 – Percentage of accidents caused by the Major Human Direct Cause Groups (Treat et al., 1979).

Similar results are provided by more recent research from the NHTSA (National Highway Traffic Safety Administration, 2008), which are shown in Figure 3.3. Considering the disaggregated results of the NHTSA study, it is possible to identify which critical reasons, as defined in the document, can be included under the Human Factors category (a subgroup of the general human factors).

Table 9(a). Critical Reasons for Critical Pre-Crash Event Attributed to Drivers

Critical Reason for Critical Pre-Crash Event		Number of Crashes		Weighted Percentage
		Unweighted	Weighted	
Recognition error	Inadequate surveillance	1,080	414,626	20.3%
	Internal distraction	482	218,548	10.7%
	External distraction	229	77,496	3.8%
	Inattention (i.e., daydreaming, etc.)	194	65,712	3.2%
	Other/unknown recognition error	109	51,926	2.5%
	Subtotal	2,094	828,308	40.6%
Decision error	Too fast for conditions	348	171,604	8.4%
	Too fast for curve	181	100,713	4.9%
	False assumption of other's action	260	92,583	4.5%
	Illegal maneuver	232	78,112	3.8%
	Misjudgment of gap or other's speed	212	65,221	3.2%
	Following too closely	85	30,452	1.5%
	Aggressive driving behavior	99	31,026	1.5%
	Other/unknown decision error	335	125,805	6.2%
	Subtotal	1,752	695,516	34.1%
Performance error	Overcompensation	211	100,090	4.9%
	Poor directional control	249	95,165	4.7%
	Other/unknown performance error	30	7,751	0.4%
	Panic/freezing	20	7,137	0.3%
	Subtotal	510	210,143	10.3%
Non-performance error	Sleep, actually asleep	160	65,141	3.2%
	Heart attack or other physical impairment	133	48,822	2.4%
	Other/unknown critical nonperformance	76	31,881	1.6%
	Subtotal	369	145,844	7.1%
Other/unknown driver error		371	162,132	7.9%
Total		5,096	2,041,943	100%

Estimates may not add up to totals due to independent rounding.
Data source: NMVCCS (July 3, 2005 – December 31, 2007), NHTSA, compiled as of April 30, 2008

Figure 3.3 – Critical reasons for critical pre-crash event attributed to drivers (National Highway Traffic Safety Administration, 2008).

The following critical reasons are included or have a high chance of being included in the Human Factors category:

- Inattention (i.e., daydreaming, etc.)
- Too fast for conditions
- Too fast for curve

The following critical reasons have a medium to high chance of being included in the Human Factors category:

- Inadequate surveillance
- Internal distraction
- External distraction
- False assumption of other’s action

- Misjudgment of gap or other’s speed
- Overcompensation
- Panic/freezing
- Sleep, actually asleep

The following critical reasons are not included or have a very low chance of being included in the Human Factors category:

- Illegal maneuver
- Following too closely
- Aggressive driving behavior
- Poor directional control
- Hearth attack or other physical impairment

Considering this partition, based only on the identified critical reason (each single accident should be analyzed alone to clearly identify its causes), it is possible to have an estimation about the influence of Human Factors on road safety. About 16.5% of the critical reason identified form the NHTSA research are included or have a high chance of being included in the Human Factors category; 51.0% have a medium to high chance of being included in the Human Factors category; and 13.9% are not included or have a very low chance of being included in the Human Factors category. Thus, a total of about 67.5% of accidents have a good chance of being caused by Human Factors (considering that about 16.1% are unknown errors which have not been classified).

Nevertheless, all those statistical analyzes can only provide an estimation of the possible causes of accidents as demonstrated by the data in Figure 3.4, which shows the Specific Human Direct Causes from Treat et al. (Treat et al., 1979). It appears clear that all the causes are assigned to human driver because it is the one who has the final decision on what to do. However, often the errors are produced by wrong stimuli from the road. Considering the Improper Lookout error as an example. It can be assumed that the driver failed to see an oncoming vehicle before entering the main road from a minor road. Are we sure that it is only a driver failure to see the oncoming vehicle? Will the road provide enough visibility of the upcoming vehicles? Will the road provide enough visibility of the entering vehicle from the main road? And finally, will the road “inform” the driver from the main road of the presence of the intersection so that it will keep higher alertness and will possibly slow? All these possibilities must always be considered before stating the cause of an accident.

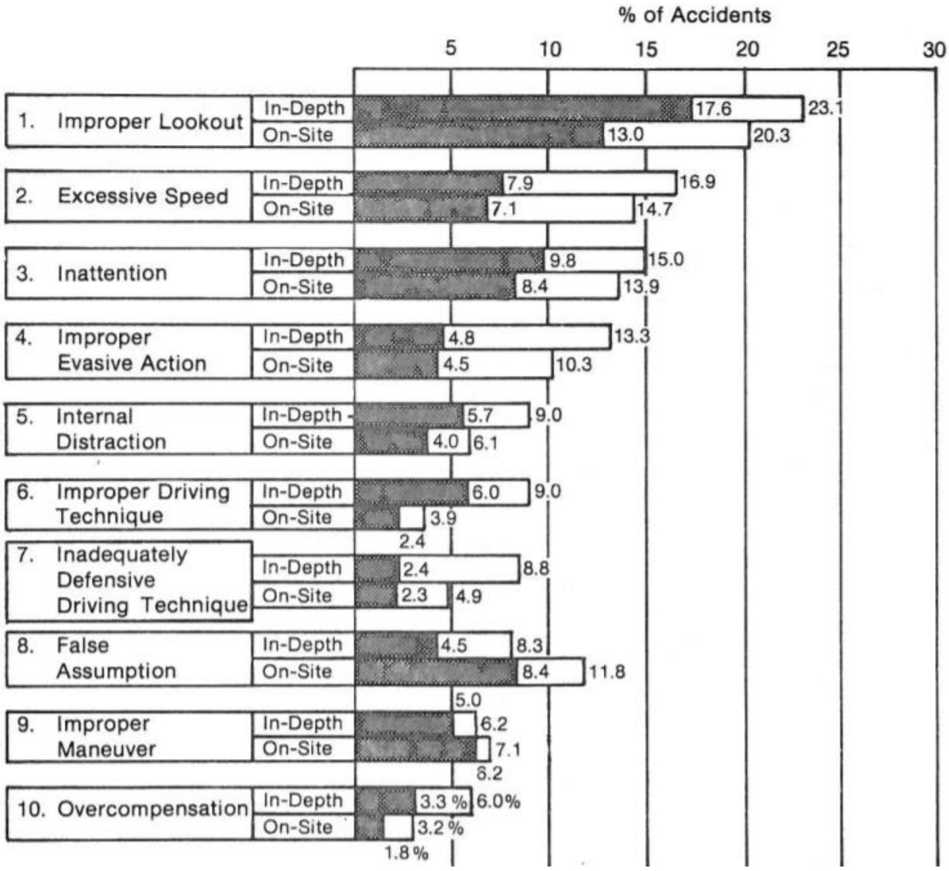

Figure 3.4 - Percentage of accidents caused by the Specific Human Direct Causes (Treat et al., 1979)

Figure 3.5 shows the Specific Environmental Causal Factors (Treat et al., 1979). The two leading Specific Environmental Causal Factors are View Obstructions and Slick Roads. They are both linked to human perception/reaction, even at different degree: the first has a direct influence on driver decision, while the second has a higher influence in the subsequent maneuver development. Also, the other causal factors are, even at different level, related to the capacity of the driver to understand the requirements from the road. However, comparing Specific Human Direct Causes from Figure 3.4 to the Specific Environmental Causes from Figure 3.5, it seems that not all the aspects of the road which can influence the first list, are present in the second list. For example, how about the Excessive Speed? Today it is well-known that there are many factors linked to road layout, cross section and surrounding, which influence the driver choice of speed, that must be considered as road factors. If we want to make a clear frame of the road safety, we must consider those aspects under the right category.

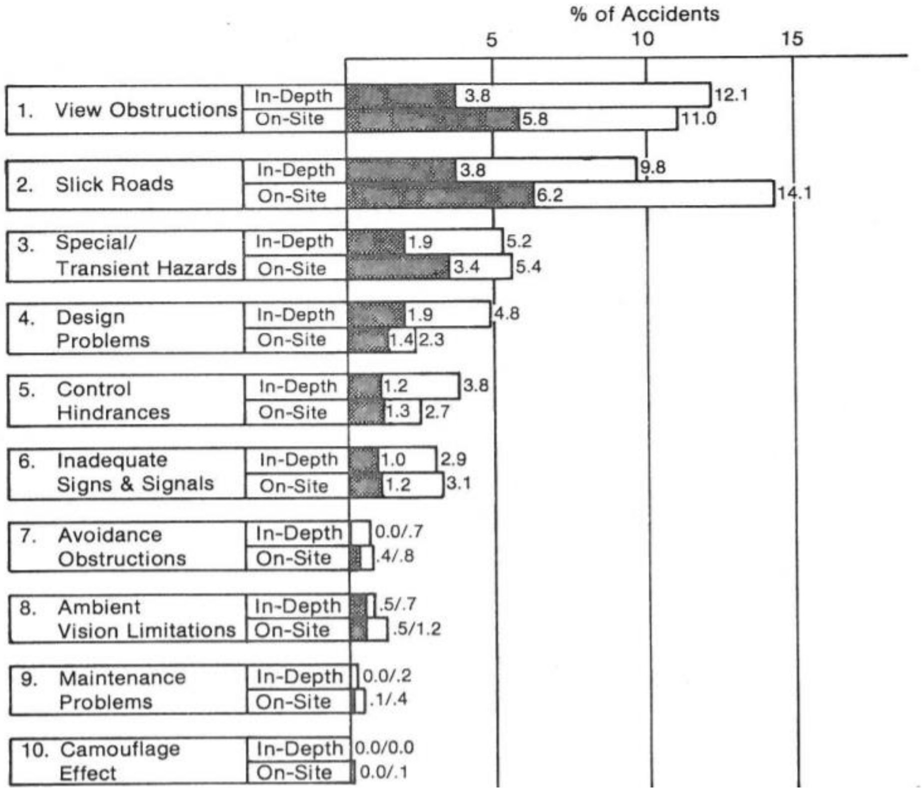

Figure 3.5 - Percentage of accidents caused by the Specific Environmental Causal Factors (Treat et al., 1979).

Accident nature is so that accidents are generally generated by a high number of factors that, partially because of road (or human, or vehicle) deficiencies, partially because of specific aleatory event, manifest together, representing an overwhelming insuperable obstacle for the driver.

Some of the factors related to the road have a direct influence on driver perception, comprehension of the road and, consequently, driver behavior. Those causes derived mainly from:

- expectancy violation
- ambiguous, misplaced, or deficient information (from signs and from the road layout itself)
- low demand on drivers (which causes lack of vigilance)
- high demand on drivers (which causes a cognitive load overwhelming)
- poor visibility of prior information (contrast, size, position)
- composition of the road environment (optical density, urban area, or rural area)
- configuration of the field of view (optical illusion, converging/diverging lines)

All this issue must be considered by road engineers, because when errors are committed due to the nature of the task, the demands of the situation, the inability of drivers to handle information, the inadequacy of the information being presented, or the violation of expectancies, it is the responsibility of designers and engineers to reduce the sources of error (Alexander and Lunenfeld, 1986).

3.1.3 Identifying accidents' causes

Accident's analysis is a widely used procedure to identify the main problems of a specific location and to find the most appropriate countermeasure. Of course, to be sure that the right causes of an accident are identified, it is necessary to collect as more information as possible about the accident. Defining which factors influence the occurrence of an accident, requires some deeper analysis and evaluations. It must be remembered that while talking about "causes", the author intends those elements that produce the effects. Causes are those factors which in some way contribute to the occurrence of an accident (which is the final effect). The concept of cause in road safety is not always easy to be applied and it also not always accepted. Some authors for example has rejected the use of the concept of cause in explaining accidents (Haight, 1980). Moreover, "causes" is also a simplified attribute of the post-crash police reporting. Causes collected in police reports (often presumed/alleged and made by witnesses' statements or police summary reconstruction) are many times confused with the consequences. Some examples of this last statement are accidents caused by excessive speed (or not appropriate speed), loss of vehicle control, don't give way, passing with red light… but there are many other. All these causes are not the real causes. For example, speed is the consequence of many other factors. Sometimes, considering this condition as the cause, the natural consequence is that the driver is to blame. Of course, sometimes it is true, but often drivers' mistakes are due to the road characteristics and this last wrong driver's maneuver is a consequence of bad inputs from the road. Once this is clear, it is possible to use the term "causes" as all those factors that contribute to accident occurrence.

A wide literature exists about how to conduct accident analysis and a good example is provided by PIARC, who summarizes the main procedures of accident analysis (PIARC, 2013). Many studies, like those presented in 3.1.2, provide some statistical results that in turn provide estimations of the influence of a factor on road safety. Estimations from massive data analysis provide some useful information about a trend but cannot assure a perfect causal relationship between the road factor and the accident under all specific situations (their reliability is often connected to the way there are obtained). This is even more clear while analyzing specific aspects related to road safety. One example concerning speed is provided in the Research Report AP-R449-14 from Austroads, which stated that "one difficulty associated with research on road design elements (or characteristics) and speed is that a 'cross-sectional' methodology is often adopted. That is, speeds on roads with different characteristics are compared to assess the effect of a single road characteristic (for instance, lane width). However, it is very unlikely that the roads compared will be exactly the same in all respects, apart from this single factor. Often roads will differ on several different characteristics (e.g., lane width, shoulder width, distance to roadside objects, etc.). It is therefore very difficult to isolate the effect of single characteristics on speed" (Austroads, 2014).

The effect of a countermeasure observed on a specific road stretch can be different if applied to another road stretch with different characteristics. A solution may be provided by accurate before-after analysis, but they also present some specific weaknesses (Institute of

Transportation Engineers and Transportation Safety Council, 2009). Thus, defining an absolute exact relationship between a factor and an accident is a hard task with relative significance because the influence of a factor is often related to other factors. For this reason, as already stated, accident analysis and the identification of accidents causes, is not a trivial task and the analysis of large amounts of data, must go parallel to deeply theoretical analysis.

3.1.3.1 Accident's event chain

Accidents are generated by different factors concurring together, but if we look in details in the accident evolution, we see that they not always contribute at the same time and with the same strength. Accidents occur because of a series of bad circumstances and failures of the "safety layers" provided by the road. A particularly useful conceptual scheme is the so called "Swiss cheese scheme", firstly introduced by Reason (Reason, 2000) to describe the possible vulnerabilities of a safety system. The scheme has been modified and it is provided in Figure 3.6.

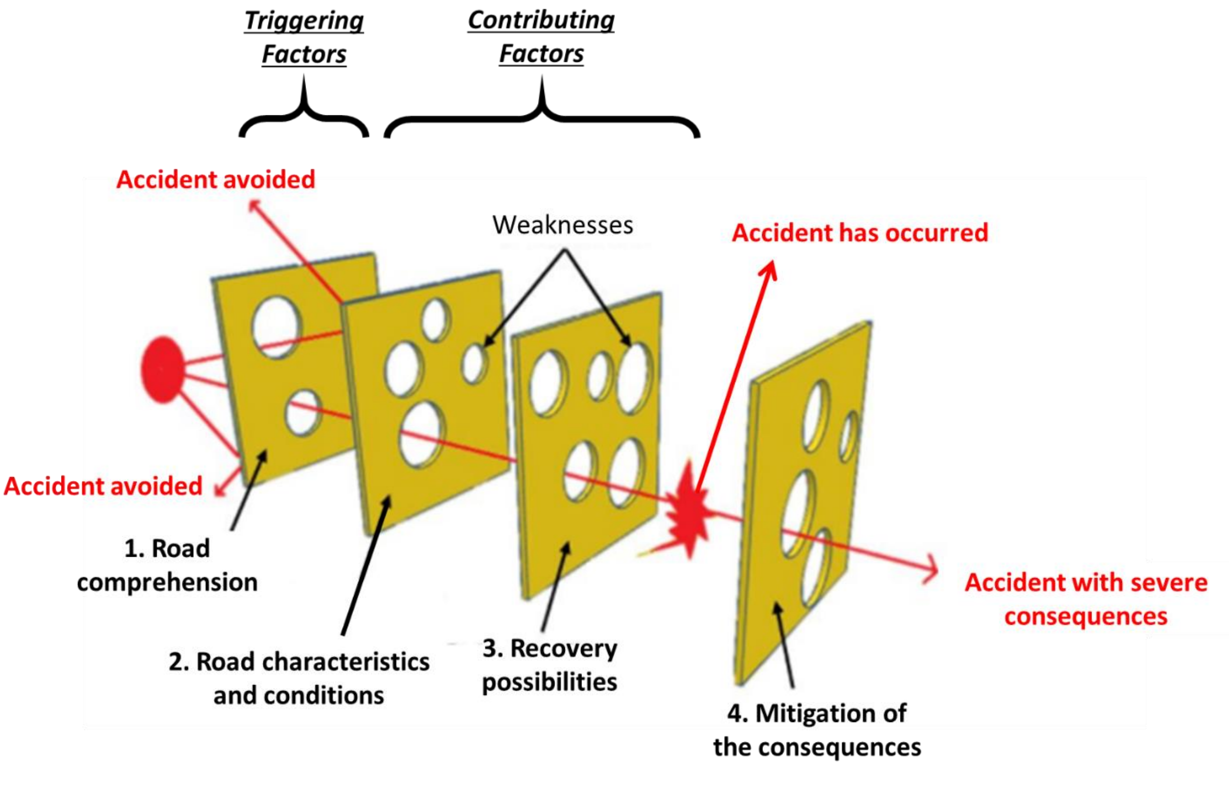

Figure 3.6 – Accident's event chain and safety layers, modified from (Reason, 2000).

In this figure, each slice of cheese, represent a possible safety layer of the road system. Each layer provides a barrier to the accident occurrence, but unfortunately this barrier has some holes. The holes are the weaknesses of the system. If the holes of those barriers are all aligned together it is possible to move through all the barriers. This represents those bad conditions where many concurring factors occur together and lead to an accident. The event chain which leads to an accident can be structured into three main parts, representing the failures of three safety layer: the operating error, the driving error, and the missed recovery.

These failures derive from the weaknesses of the safety layers respectively of road comprehension, road characteristics and conditions, and the recovery possibilities. A fourth layer must be considered which represents the intervention on the outcome of an accident, that is the mitigation of the consequences. This last layer is extremely important because it can change the outcome of an accident from a simple property damage to a severe injury. However, it must be noticed that this layer does not influence the accident occurrence.

Even if it is difficult to group all the possible features influencing an accident occurrence, these three layers may provide a useful conceptual scheme.

The first layer about road comprehension, represents all those factors which contribute to the road perception. It includes the expectations, the visibility, the clarity of the road layout and configuration, and all other factors which are related to the perception of the road from the driver point of view. A wrong perception of the road is the triggering factor of the event chain that may lead to an accident. A wrong perception of the road is considered an operating error. All those triggering factors belong to Human Factors.

The second layer concerns road characteristics and conditions, which means to account for road physical conditions, such as road surface, to account for weather and traffic conditions, and to account for vehicles and driver capacities. After an operating error has occurred, the driver may correct the error. Based on how long it takes to the driver to understand his error and to decide how to correct it, the correcting maneuver can be easy to be carried out or not. If the correcting maneuver will not take place, then a driving error occurred, and the accident will likely happen. Human Factors are still participating also to this layer. This is because of the driving performance which is generally based on the close-loop model. The close-loop model implies that the driver continuously check is driving behaviors based on the road characteristics, adapting, and modifying their driving according to what they perceive (this concept will be better described in 3.1.4).

The third layer represent the possibility to recover, that is the last chance to avoid a collision or a run-off the road. Factors belonging to this layer are quite the same of the previous one except that Human Factors are very limited. Those factors concern the last part of the maneuver, such as abrupt braking and steering, and all other maneuvers that will be made when it is clear that an accident is likely to happen. If also the recovering maneuvers fail, the accident occurs.

The fourth layer represents the mitigation of the consequences of an accident and, together with some aspects of the preceding layer, it is the base of the concepts of the forgiving roads and forgiving roadsides. This means that accidents may occur, but the road system must assure that the outcome are the less severe as possible. A typical example is a safety barrier preventing the driver to hit a tree or run-off from a bridge.

A similar logic structure has been already introduced by Bald et al. (Bald et al., 2008), which is presented in Figure 3.7. The scheme shows the development of the events and possible situations that will lead to an accident, highlighting which are the “active safety” factors and the “passive safety” factors. The first are all those factors contributing to the occurrence of an accident, while the seconds are all those factors which influence the outcome of an accident.

Both this last scheme and the previous "Swiss cheese scheme" help to identify four different steps of the event chain that must be considered. The factors participating to all the four aspects are not necessarily different. All the road elements may contribute to more than one of the four layers of the first scheme.

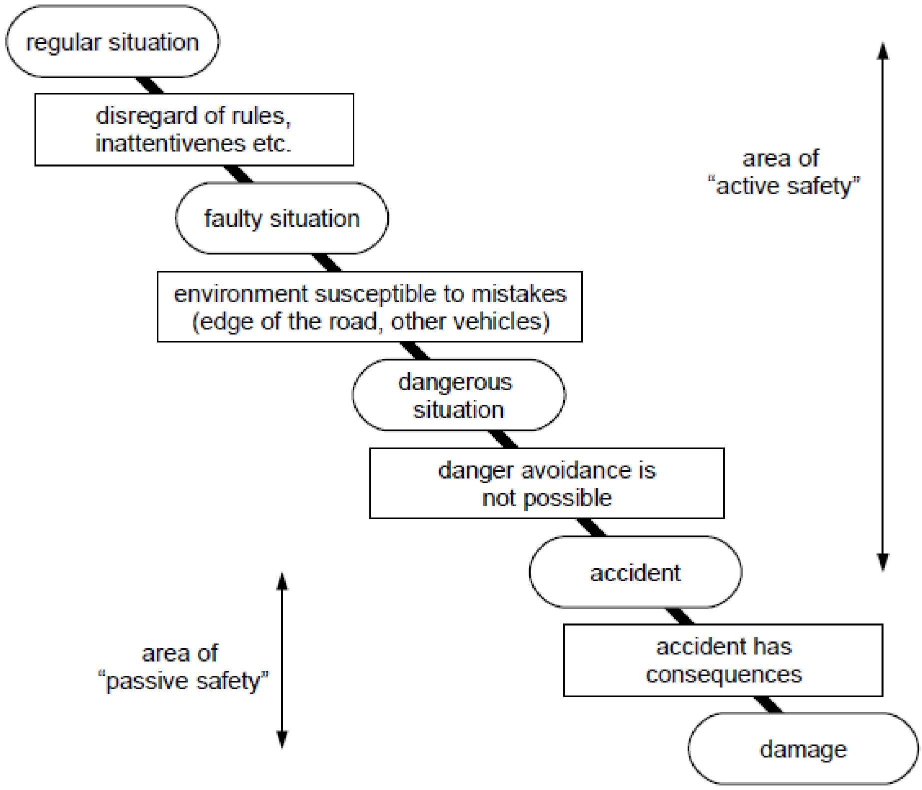

Figure 3.7 – Events chain for accidents and damage occurrence (Bald et al., 2008), *from* (Durth and Bald, 1988)

3.1.3.2 *Triggering factors and contributing factors*

Considering the factors influencing the accident occurrence, it is possible to define at least two different types of relevant factors:

- Triggering factors
- Contributing factors

Triggering factors are the factor that involve the first error, which start the event chain that finally can lead to an accident. The triggering factors are those factors that represent the stimuli of the driver, and so the information from outside. Triggering factors can be repeated considering the continuous close-loop of the driving task (see 3.1.4). Moreover, triggering factors are not only the factors that influence the driver some milliseconds before the first wrong maneuver/decision but may have some prior influences. For this reason, expectations about the road, are part of this category[3]. The presence of triggering factors and the possible error due to the influence of those factors, does not assure the accident occurrence. To have the crash, there must be some contributing factors. Contributing factors have a high influence on crash achievement, both positive and negative. Triggering factors are mainly related to the first layer of the Swiss Cheese Scheme, that is *road comprehension*, but they may also occur in the second layer, that is *road characteristics and conditions*. Contributing factors are instead related mainly to the second and third layer, that is *recovery possibilities*. Furthermore, factors can be both triggering and contributing for the same event and can assume negative and positive influence within the same event. This implies that implementing a specific countermeasure may improve some safety aspects and reduce some other. This is because the road modification can also modify the road perception from the driver point of view (see also the concept of risk perception in 3.1.5 and behavioral adaptation in 3.1.6). Moreover, the effect of the improvement, in terms of quantity, may varies based on the context where it is used. A clear example can be made considering a run-off-road accident due to a low radius curve travelled at an unsafe excessive speed. The main factors which trigger the operating error, passing through the first safety layer, are: a long straight before the curve, previous curves with greater radius, difficult estimation of the low-radius curve because of a poor visibility of the inner curve, and a wide carriageway which influences driver choice of speed. For all these reasons, the driver approaches the curve with a too-high speed, and the event chain that could lead to an accident is than triggered. Nevertheless, in most cases this will not lead to a crash, and here is where contributing factors influence the results. Possible contributing factors of this specific example can be a high friction course, which helps the driver to fast reduce the speed of the car and to balance the dynamic force in the curve, and the wide carriageway, both with wide lanes and shoulders, which give more opportunities also for a wider trajectory and to recover wrong trajectories. In this case we have two different main contributing factors which play different role both as contributing factor and as triggering factors:

- Road friction plays a role only as contributing factor, with a positive contribution which helps to reduce the probabilities of an accident occurrence.
- Carriageway width plays a negative role as a triggering factor, but it plays a positive role as a contributing factor (in this specific example).

Finally, the same factor, may have a different weight as triggering factor and as contributing factor. This contribute to demonstrate how hard is to quantify the possibility of an accident occurrence. This may also explain the different influences of lane and shoulder width on safety, as presented in 3.1.3.3.

Human Factors applied to road safety help mainly to identify the triggering factors. This concept fits perfectly to the identification of operational errors and driving errors defined by

[3] As discussed in 3.2, three type of expectations can be considered: long-term expectations, short-term expectations, which together form the general expectations, and punctual expectations.

PIARC (PIARC, 2016). Figure 3.8 shows the logic scheme proposed by Birth et al. (Birth et al., 2004) and subsequently considered by PIARC to define the event chain which could lead to an accident. The concepts of triggering and contributing factors, and severity factors, have been added to the scheme. Triggering factors can be considered those factors which cause the operational mistakes, while contributing factors influence the occurrence of the driving mistake. Severity factors influence the outcome of an accident.

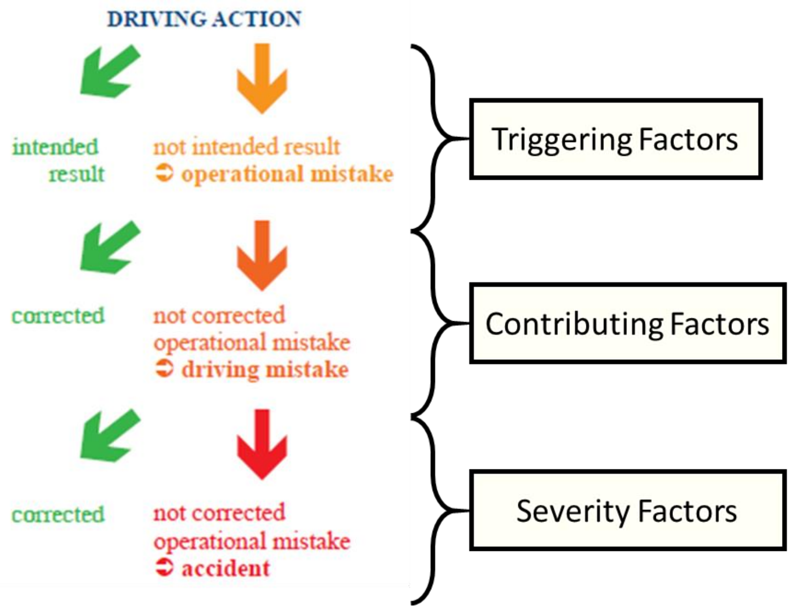

Figure 3.8 – The context of operational mistake, driving mistake, accidents, and their related factors, modified from (PIARC, 2016), *already in* (Birth et al., 2004) .

The proposed procedure is based on the analysis of Human Factors, and thus it considers the analysis of triggering factors. Reducing the possible factors that trigger the accident event chain, means to reduce the number of possible accidents.

3.1.3.3 Example of different influence of geometrical features on road safety

Concerning triggering and contributing factors, an interesting research about the different influence of the same factor, has been conducted by the researchers of the FHWA (Boodlal et al., 2015), which analyzes the influence of the lane and shoulder width on speed and on accidents causation. Figure 3.9 and Figure 3.10 show respectively the relationship between lane width and shoulder width with speed and safety, represented by the calculated CMF from HSM (AASHTO, 2010). A CMF, namely Crash Modification Factor, is a factor that account for the reduction in the number of predicted accidents by implementing a specific modification of the road (see 2.3.1.1 for details), in this case it has been evaluated how the factor change if the lane width or the shoulder width are modified. In both the represented graphs, the lane width (first graph) and the shoulder width (second graph) are shown in the x-axis, while the speed in miles per hour is shown on the left y-axis and the CMF value is shown on the right y-axis.

As expected, the operating speed increases as the lane and shoulders width increase. Such results as been widely proven by many researches (Austroads, 2014) (Elliott et al., 2003)

(Martens et al., 1997). Nevertheless, the opinions on the effects on road safety of such countermeasures are divergent. A higher speed would generally mean a higher risk of accidents (DaCoTA, 2013) (Finch et al., 1994) (Nilsson, 1982) (Nilsson, 2004) (Taylor et al., 2000) (Taylor et al., 2002) (Donnell et al., 2018), but it has also been observed that wider shoulder and wider lanes have a general positive influence on accident risk (they reduce the risk of an accident occurrence) as clearly shown in Figure 3.9 and Figure 3.10.

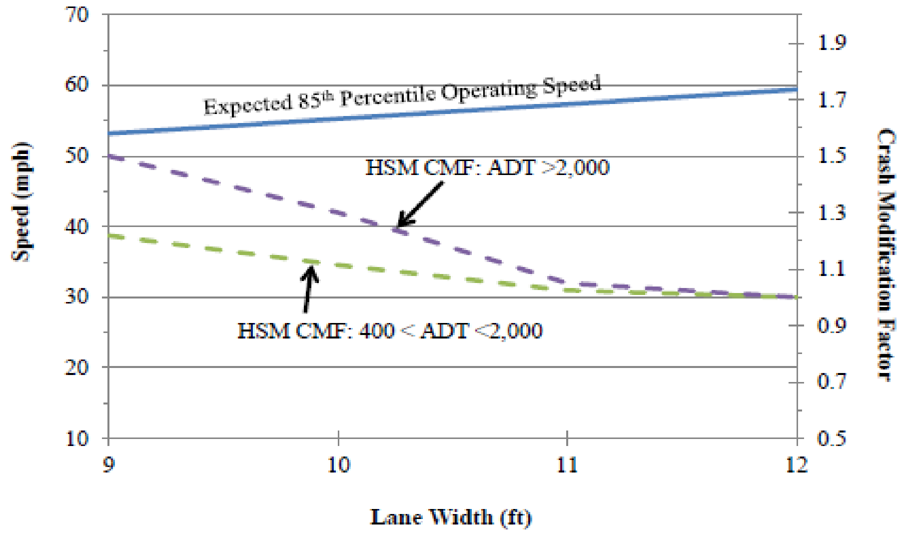

Figure 3.9 - Graph. Relationship between lane width and speed and safety for two-lane rural highways (Boodlal et al., 2015).

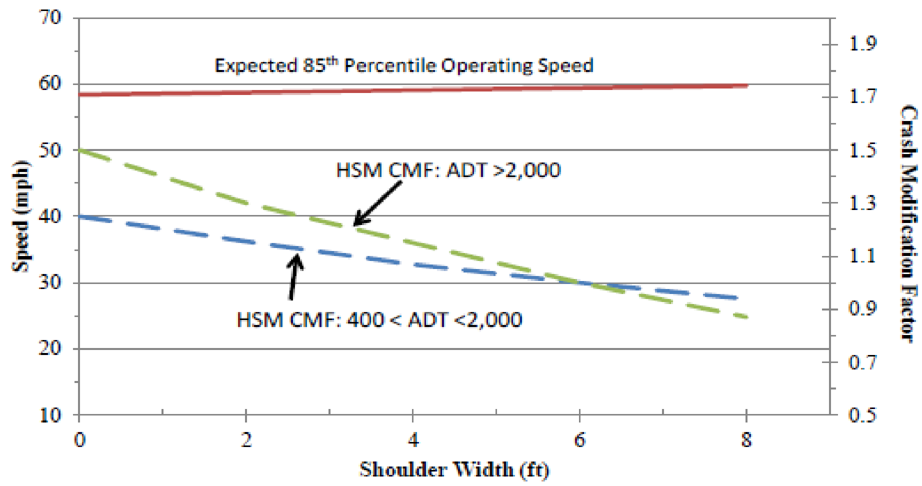

Figure 3.10 - Graph. Relationship between shoulder width and speed and safety for rural, two-lane highways (Boodlal et al., 2015).

This highlights that carriageway width seems to have little negative influence as triggering factor, but a high positive influence as contributing factor. However, different relationship may occur in different specific cases. The FHWA research concludes that the relationship is not so obvious as represented in Figure 3.9 and Figure 3.10. They found that *"The results of the lane-width–shoulder-width safety evaluations show more complex (but intuitive)* *interactions between expected crash frequency, lane width, and shoulder width than what is currently reflected in the Highway Safety Manual CMFs for rural, two-lane roads. For any given pavement width, there are combinations of lane width and shoulder width that result in the lowest expected crash frequency (for all crash types and severities as well as for fatal-plus-injury crashes). For narrower total paved widths, the optimal lane width appears to be 12 ft. […] As total paved widths become larger, there is not necessarily a safety benefit from using a wider lane, and in some cases, using a narrower lane appears to result in lower expected crash frequencies".*

Figure 3.11 shows the trend of the CMF considering the influences of the lane and shoulders width on road safety. The best result is given by a very narrow lane (10 ft) and a very wide shoulder (6 ft), while the worst result is given by narrow lane (1o ft) and medium shoulder (4-5 ft). It surprises to notice that with a lane of 10 ft, a shoulder width of 3 ft slightly reduce the CMF compared to a shoulder of 4-5 ft, while a shoulder of 6 ft, drastically reduced the CMF.

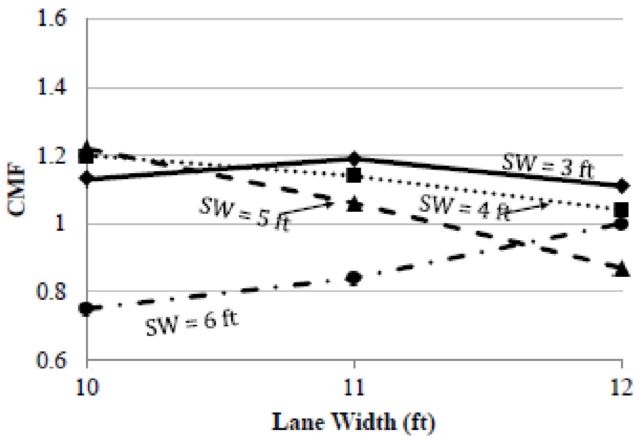

Figure 3.11 - CMFs for combinations of lane and shoulder widths for two-lane rural highways (Gross et al., 2009)

The safety represented by the trend of HSM CMF has the strength of be derived from a high number of data, but on the opposite this high number of data analyzed together may cause the loss of some factors and, in most of cases, the lost data are the one related to the driver and their perception.

Another different result, which otherwise leads to the same conclusion, is the one provided by Pokorny et al. (Pokorny et al., 2020), who analyzed the influence on road safety of lane and shoulder width in Norway, with the application of a case-control method. The outcome of the method which is the safety performance measure is the odds ratio. They calculated the relationship considering five different samples that are: all accidents, severe accidents, slight accidents, winter accidents (occurred between November and March or under icy road conditions), non-winter accidents. The results are shown in Figure 3.12. The graph on the left shows the results concerning the shoulder width, while the graph on the right shows the results concerning the lane width.

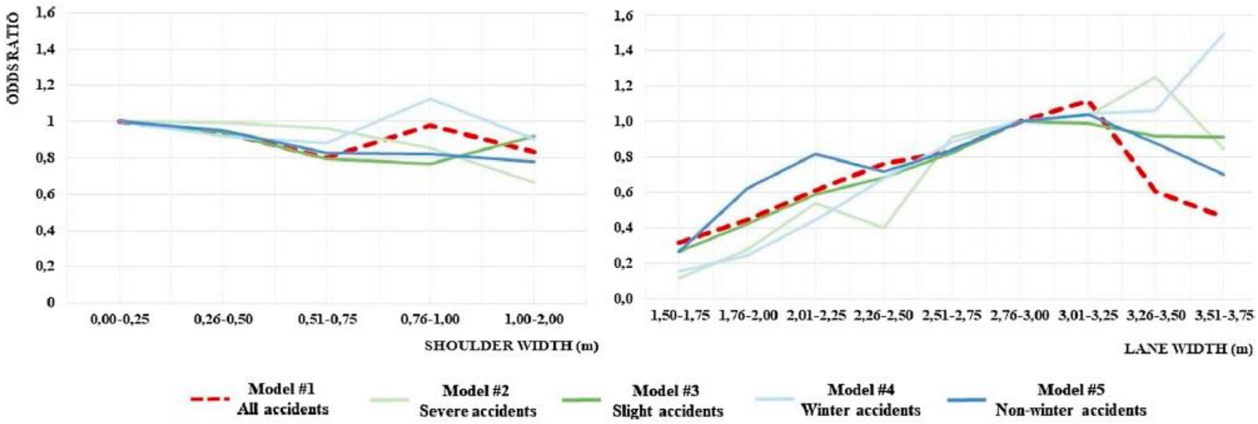

Figure 3.12 - Graphic illustration of the odds ratios for shoulder (left) and lane (right) widths for all models (Pokorny et al., 2020)

Concerning the shoulder width, the highest level of risk was found for the narrowest shoulder category 0.00–0.25 m. The level of risk then decreases to the minimal value for the category 0.51-0.75m. Yet as shoulder width increases to 0.76-1.00m, the risk increases once again, followed by another decrease for the widest category. For lane width, the model indicates the lowest risk being associated with lanes between 1.50-2.00 m. There is an increasing trend of odds ratios with increasing widths up to 3.25 m. For the wider lanes, the risk generally drops.

It must be also highlighted that the presented researches, like most of the research on the same topic, limit the evaluations of lane width to widths less than 4 m. Influences of wider lanes should be also investigated.

All these examples show the different influence of the same road element under different circumstances and as a triggering or contributing factor, and clarify the importance of accurate accident analysis, which must be carried out with adequate instruments and knowledge. Shoulder width may have an influence as triggering factor and a different influence as contributing, and both are influenced by other elements of the road, which are present in that specific analyzed segment. The results show that some other factors, which are nevertheless linked to shoulder and lane width (e.g., speed), have a strong influence on road safety. By means of statistical analysis we can say that a variation in one factor may have a certain influence on road safety, under specific conditions, but many times it is impossible to statistically consider all the variables. For this reason, theoretical approach must always accompany statistical analysis.

3.1.4 The driving tasks

Driving is a complex task, even if sometimes it appears to be so easy. Instead, driving requires attention, it requires at least three senses (sight, hearing, and touch) and it brings the driver to take decision in a reduced time, that highly differ from their standards (people running at a moderate speed reach a speed of about 15 km/h). Furthermore, as some psychological aspects occur, identify the real process of the driving task is a challenging job. For this reason, it is useful to try to use some specific scheme that can help to understand those process. Many general framework schemes can be found in literature. A trusted scheme is the one proposed by Alexander and Lunenfeld (Alexander and Lunenfeld, 1986), which was also considered by AASHTO Highway Safety Manual (AASHTO, 2010). This scheme synthetizes the driving task into three different performance level, as represented in Figure 3.13. These levels, and their associated activities and subtasks, can be described according to scales of complexity and priority. The scale of complexity increases from control through guidance, to navigation; priority decreases in the same direction.

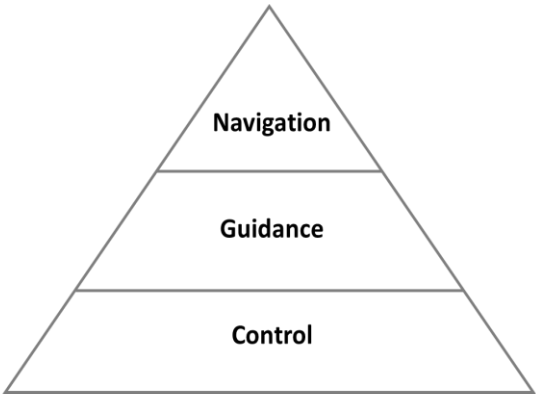

Figure 3.13 – Driving Task Hierarchy, adapted from (Alexander and Lunenfeld, 1986)

According to Alexander and Lunenfeld (Alexander and Lunenfeld, 1986), the three performance levels are described as following.

"Control: Control refers to a driver's interaction with the vehicle. The vehicle is controlled in terms of speed and direction. Passenger vehicle drivers exercise control through three or four mechanisms- steering wheel, accelerator, brake, and gear shift. Information about how well or poorly the driver has controlled the vehicle comes primarily from the vehicle and its displays. Drivers receive continual feedback through vehicle response to various control manipulations.

Guidance: Guidance refers to a driver's maintenance of a safe speed and path. Control subtasks require action by the driver. Guidance requires decisions involving judgment, estimation, and prediction. The driver must evaluate the immediate environment and translate changes into control actions needed to maintain a safe speed and path in the traffic stream. Information at this level comes from the highway-alinement, geometry, hazards, shoulders, etc.; from traffic-speed, relative position, gaps, headway, etc.; and from traffic control devices-regulatory and warning signs, traffic signals, and marking.

Navigation: Navigation refers to the activities involved in planning and executing a trip from origin to destination. Navigation information comes from maps, verbal directions, guide signs, and landmarks."

The three levels form a hierarchy of complexity and priority. The control level is the easier level, and it is overlearned by most drivers. Its "simplicity" is translated in the capacity of driver to perform this task in an automatic way. Brain does not have to think too much to maintain the speed and to adjust the position in the lane: drivers automatically do it even while their attention is somewhere else (listening to the radio, thinking, talking with the passenger). At guidance level information handling is increasingly complex and require more efforts from the driver. Actions, maneuvers and change in the driving program (e.g., a change in speed) needs a conscious activity of the driver, who must take decisions. These decisions require time to be taken and peculiar information to be activated. Navigation level is the most demanding. At this level drivers need more processing time to make decisions and respond to information inputs.

Many other examples of framework schemes can be found in literature. Control loop models and hierarchical models are two of them.

The concept of the close-control loop model was already recognized as early as 1970 and presented in more detail for road design by Durth (Durth, 1972) and Dilling (Dilling, 1973). The same model was subsequently implemented by Bald (Bald, 1987), which compares the speed-choice model, to the function of an heat pump, as shown in Figure 3.14. With the same scheme Bald describes also the risk regulation, with the central role of speed as the parameter which can be most modified by the driver and which has a higher influence on the measurable and perceived risk, as depicted in Figure 3.15 and Figure 3.16.

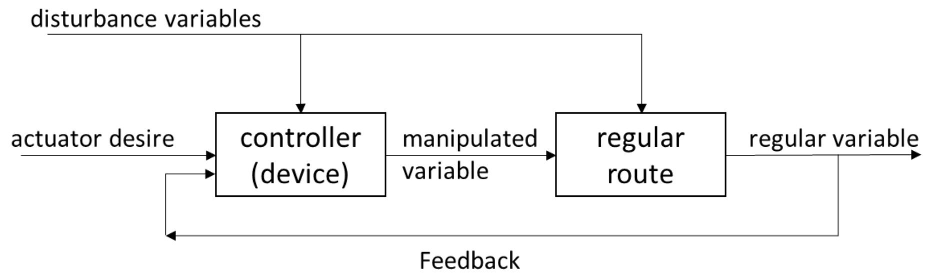

Figure 3.14 – Close-loop model for adjustable systems (e.g., heat pumps), translated from (Bald, 1987)

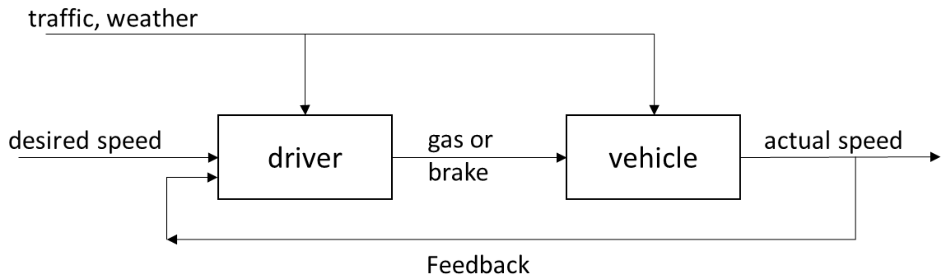

Figure 3.15 – Speed control loop, translated from (Bald, 1987)

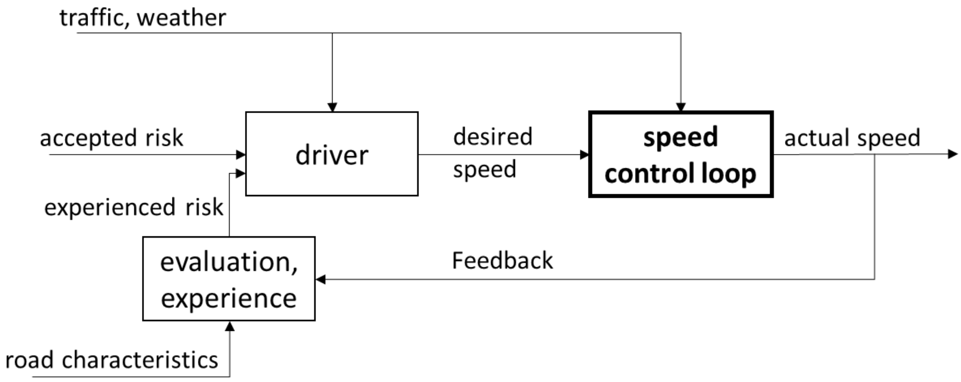

Figure 3.16 – Risk control loop, translated from (Bald, 1987)

The close-loop control model is extremely useful to explain the continuous changes in driving maneuvers and it is suitable to be applied considering the assumed risk model (see 3.1.5) as also introduced by the bottom close-loop model from Figure 3.16.

Some examples of hierarchical models are instead provided by Michon, Donges, and Rasmussen (Michon, 1985), (Donges, 1999), (Rasmussen, 1986). It is interesting to notice that the models are very similar. The model from Alexander and Lunenfeld (Alexander and Lunenfeld, 1986) belongs to this category. A combined scheme which considered all the previously cited models is presented by Weller (Weller, 2010) and here reported in Figure 3.17. The three different levels, even with different names, have the same meanings as those from Alexander and Lunenfeld.

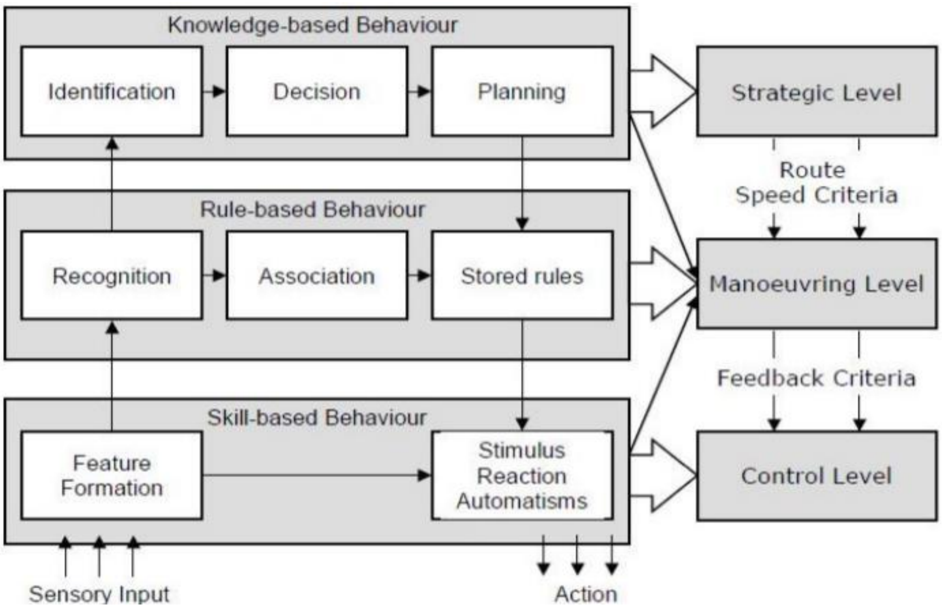

Figure 3.17 – Combination of performance levels according to Rasmussen (Rasmussen, 1986) *and the hierarchical model according to Michon* (Michon, 1985), *modified from Donges* (Donges, 1999), *presented in Weller* (Weller, 2010).

A more detailed model related to this scheme is depicted in Figure 3.18. Here Reason tried to explicit when a change in the driving level is required and which are the reasoning and the causations behind the switch from one level to another (Reason, 1990). It must be noticed that under standard conditions, only the control level is activated. Continuous attentional checks allow to identify when a problem arise. In this case, it is possible to switch from the control level to the guidance level (or rule-based level). This simple step is crucial, because it underlines that information from the road must be seen, perceived, and comprehended.

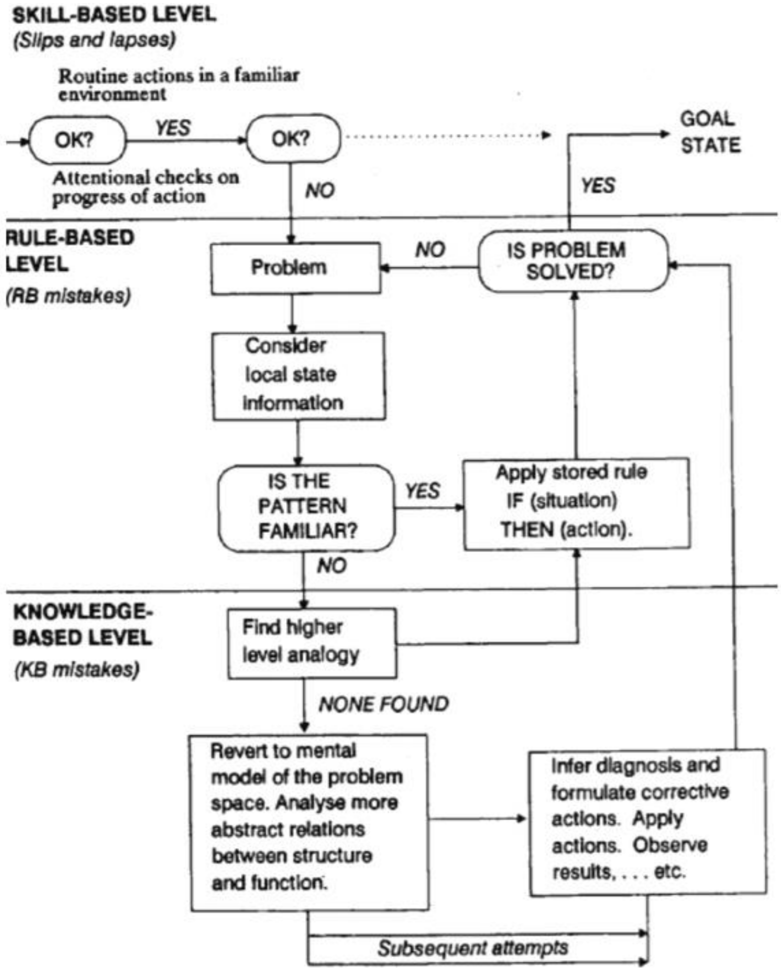

Figure 3.18 – The generic error-modelling system as proposed by Reason (Reason, 1990).

The scheme in Figure 3.18 by Reason open the way to possibilities obtained by link together the hierarchical model, with closed-loop model, because of that continuous "attentional checks". Consequently, a new conceptual scheme may be drafted, which is proposed in Figure 3.19. In this simple scheme, the concept of close-loop model is included in the hierarchical model, and the concept of expectations has been included. As discussed later, expectations concept is crucial in the proposed HFE procedure.

In the following the conceptual scheme proposed in Figure 3.19 will be described. The driving task starts with the guidance level. It can be easily assumed that before engaging first gear and driving away, the driver has already defined its route and thus the navigation process, at least for the initial part of the driving, will be not activated. Also, passing from a 0 speed to a speed different than 0, even with few maneuvers, it is something that require to have an activated guidance level. The process has now started. Based on expectations at a guidance level, the driver makes their maneuvers and adopt a specific behavior. Based on that behavior the driving characteristics are defined. Those characteristics produce some feedbacks to the driver. Those feedback, as all the information perceived by the driver, are not objectively perceived. One of the factors that influence the perception of the feedbacks (i.e., information from the surrounding), are expectations, which have a central role in this conceptual scheme. Based on the perceived feedbacks the driver will automatically switch to one of the three different performance level. The most two common levels are the control levels and the guidance level. If the feeling is that no specific maneuvers must be made because expectations (and thus the consequent adopted behavior), and perceived feedbacks are consistent, thus the driver will continue with the control level.

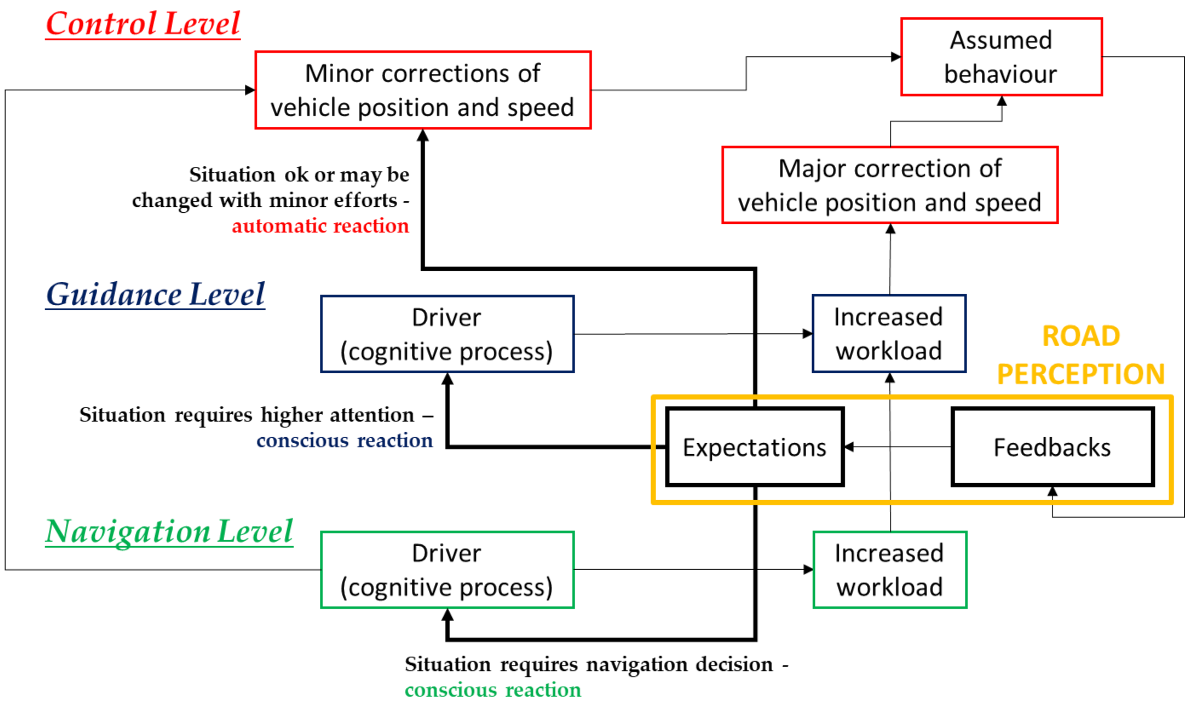

Figure 3.19 – Combination of the performance levels from Alexander and Lunenfeld (Alexander and Lunenfeld, 1986) *and a close control-loop model inferred from the one introduced by Durth* (Durth, 1972).

On the other hand, if expectations and the perceived feedbacks are not consistent, some major change in the driving characteristics is required. The driver switches to the guidance level and adapt is driving in a continuous loop, until the conditions are again stable, and it is possible to go back to the control task. The guidance level requires some increase in the workload, based on the task to solve. The activation of the navigation level is required when decision must be taken about the road to follow (e.g., where to turn). Such a task generally requires the higher cognitive load to the driver.

In this scheme, it is evident that expectations and the correct perception of feedback (i.e., information from the surrounding) are crucial. The perceived situation determine which performance level will be activated to correctly answer to the road demand. Failures in the activation of the guidance level, as well as wrong responds to the road demands, may contribute to accidents occurrence. Expectations determine driver's behaviour, and the more expectations are away from the reality, the more driver's behaviour will be different than a behaviour consistent with the road characteristics.

The importance of expectations leads to explore how the perception process is carried out. Indeed, the correct perception, identification, and comprehension of the stimuli providing by the road, are essential part of driving.

3.1.4.1 Dealing with the incoming information

The driving task does not consist of independent activities performed independently. At any given point in time, drivers are faced with a multitude of information, transmitted from a variety of sources, and received through several sensory channels. They may be required to sift through this information, determine its relative importance, make proper interpretations, decide on courses of action, and take those actions in a limited time. The key to successfully performance the driving task, is efficient information handling. Unfortunately, drivers are human, and the number of information they can manage at the same time is limited. Figure 3.20 provide a conceptual scheme proposed by Durth (Durth, 1972), which shows the quantity of information coming from the road environment and how much of that information can be processed by the brain. It has been estimated that about 10^{11} bit per seconds come from the road and its environment. Within this, about $5*10^7$ are received by the sight system, and about $3*10^6$ are somehow processed by the brain. That is about 10^5 times less than the starting quantity. Moreover, among the processed information, only 16 bit per second result in a conscious perception.

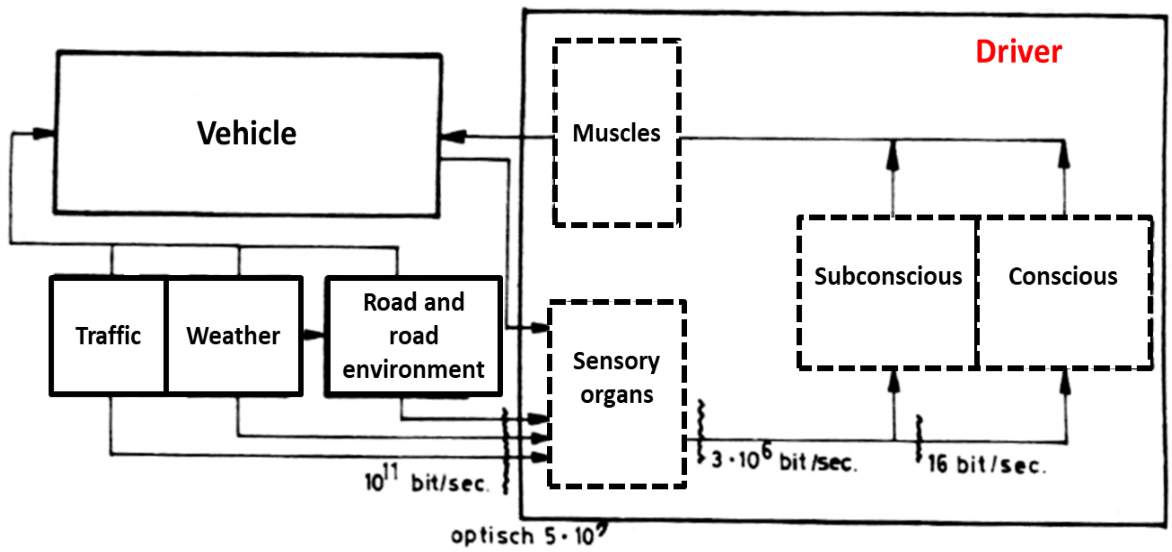

Figure 3.20 – Number of information processed by the drivers, translation from the original scheme from (Durth, 1972).

Thus, it is obvious that drivers can't account for all the source of information located in the road environment. A direct consequence of this considerations could be to wonder how it is possible that drivers are not involved in an accident every day. Indeed, they miss most of the information from the environment. As highlighted by Green (Green, 2017), the reason is because human beings "are designed to navigate the uncertain environment without harm, despite the constraints on our ability to know and to respond to the world. There are many mechanisms to loosen these constrains. The most notable are adaptability and the ability to shift tasks from a resource-consuming conscious mode to an automatic mode that seems to require no conscious awareness." (Green, 2017).

Considerations from Durth, Alexander, and Green, like the ones from many other researchers, confirm a simple logical structure about human nature and driving. Human capacities of processing the information from the world around them are limited and the conscious processing is a high demanding process. Thus, human beings have found some way to deal with this limitation. The solution is to filter the information mainly by means of automatic and unconscious processes, which only under some specific conditions translate into conscious process. This reflects in the driving tasks. The most important and most recurrent driving task is the control task, where most of the information coming from the road environment are processed in an automated way.

The concept of selecting the most relevant information from the road environment, because of the impossibility of processing every information, is crucial. It generally provides huge benefits, but sometimes it may lead drivers into trouble. That is the reason of the importance that the road communicates to the drivers which are the relevant information. Without any misleading information. Otherwise, this "simplified assumption" and filtering of the reality, will result in a wrong interpretation.

When drivers are required to sift through a mass of information, both relevant and extraneous, under time pressures, they need to assign a relative priority to the competing sources, and therefore require a criterion upon which to base their decisions (Alexander and Lunenfeld, 1986). This criterion depends on the driver expectations. Based on their expectations, both about the physical environment (how the road will develop) and about operating development (e.g., how will it be if the driver travels a curve at a certain speed), driver choose a specific behavior. The choice is made making an evaluation that considers all the possible risks. A clear comprehension of the situation, and thus of the possible risks, is even more important at specific points of the road that require a change in the driving behavior. Those locations must be clearly perceived.

To better clarify this, additional considerations must be made about both the concept of risk and the concept of expectations, as well as the Human Factors criteria to analyze both those aspects. This will be addressed in 3.1.5 and 3.2.

3.1.5 The risk perception

"Experience shows that absolute safety is impossible. In every system not all dangers can be avoided completely. Therefore, it is generally accepted to describe or quantify the residual risk. In this case, safety

refers to the level of risk that is socially acceptable in these real-life situations. If the risk level is acceptable, the system is considered as safe" (Bald et al., 2011).

Risk perception is a crucial factor to consider while analyzing road safety. At the cost of being repetitive, it must be underlined that the cases where people volunteer break the road rule, are few, and sometime when they do so, they are sure that they are driving under safe conditions (e.g., exceeding a speed limit). People do not want to put their lives at risk. Nevertheless, it is also undeniable that, from the point of view of an external observer, drivers often take more risks than expected. The simple question which arises, is: why?

To give an answer, it must be searched what is the meaning of risk and what is the risk itself. To clarify this point, it is possible to define two different kinds of risk:

- Real risk, or also measurable risk or objective risk, which is the risk that is objectively present. It derives from a computation of physical values such for example the skid resistance of the road surface in a curve, the speed with which the curve is travelled, the visibility of an intersection, and so on.
- Perceived risk, or also subjective perceived risk, which is the risk estimated by the driver, who can't consider the physical values, nor judge the exact radius of a curve of the road he is travelling.

Moreover, linked to the perceived risk, there is also the overall evaluated risk, which is the total risk that the driver evaluates based both on the perceived risk of the road and on other factors not related to road. The latter often relate to the scopes of the driving (e.g., going to work). Finally, the assumed risk can be defined as the risk taken by the driver as the minimum acceptable risk to achieve their goals (e.g., arriving at work on time) under safety conditions. All these concepts will be better explained in the following.

Real risk

Real risk in the road system can be defined as the definition of thresholds based on quantifiable measures. For example, it is possible to define a maximum speed which allow to travel a curve under safe conditions, depending on the radius of the curve, the transversal slope of the curve, and the friction coefficient of the road surface. Eq. 1 shows the formula to calculate the speed from the Italian design standards (Ministero delle Infrastrutture e dei Trasporti, 2001). The same equation is used all over the world. By means of physical evaluation, if the speed is higher than the value coming from the equation, there are higher possibilities that the friction between the road and the tires get lost and the driver will lose control of the vehicle.

$$V_{max}^2 = g \times R \times (f_t + q_t) \qquad \text{Eq. 1}$$

Where:

V_{max} = maximum speed to travel the curve under (acceptable) safe conditions;

g = gravity acceleration;

R = curve radius;

f_t = transversal friction coefficient that is assumed to be used while traveling the curve;
q_t = transversal slope.

Similarly, it is possible to calculate the probability of a barrier to withstand the impact of a vehicle, to calculate the stopping distance of a vehicle while braking, and calculate the possible kinetic energy released because of a crash. Of course, all these calculations require some assumptions, nevertheless, they can be calculated following some specific equations. However, all these equations relate to functional parameters (such as speed), which are related on the driver behavior in turn. For this reason, while defining the risk of a road, the perception of the risk from the driver point of view is crucial, because it influences all those parameters that go into those equations to calculate the real risk.

Perceived risk

The previous paragraph briefly illustrates as real risk is something that can be measured objectively, even with a degree of uncertainty. Nevertheless, if a person is asked about a risk of doing something without applying complex equations, the answer that he will give, it will be a subjective answer. People, who are driving, don't have any equations to use, furthermore they also have a short time to think about the situation and they are doing something else while thinking (i.e., driving). For this reason, the risk judgment of a driver is clearly subjective and highly prone to error (Kokubun et al., 2005) (Ram and Chand, 2016). Luckily, human beings have found a way to reduce they inability of judgment, that is experience. Experience not only reduce the possibility of an error, but most of the time assure a correct evaluation of the situation. However, the situation can be not completely clear, thus it can be misjudged. A new situation never faced before may arise, or simply, due to some wrong experience, the driver judges a specific situation with a perceived risk that is different from the real one. Regardless of what was the path that led to a certain evaluation of the risk, the consequence is that the driver will adjust his driving behavior based on the risk he is perceiving and not on the real risk of the road. If this adjustment process fails, a driving error occurred. The concept of real and perceived risk has been firstly introduced by Klebelsberg, who talked about objective and subjective risks (Klebelsberg, 1982).

It must be noted that the risk perception and the following risk-taking behavior can also be related to circumstances which are not strictly related to the road. For example, when Sweden changed to driving on the right, it resulted in high reduction of road deaths in the first year, even if it could be expected the opposite. That was because the accepted risk from the population was the same, but the perceived risk was higher and thus the risk-taking behavior reduce (Wikipedia, n.d.) (Flock, 2012). This higher-scale influence on drivers' behavior can be linked to the concept of risk homeostasis strongly supported by Wilde (Wilde, n.d.) and discussed in 3.1.6.

Assumed risk

Assumed risk or also target risk, can be defined as the risk chosen by drivers. Assumed risk is strictly related to the perceived risk, but it is influenced also by factors which do not belong to the roads. As a matter of fact, if the driver is late for an important job interview, they will probably decide to take higher risk while driving, because this is balanced by the consequences of arriving late. For this reason, another type of risk should be considered: the risk of not achieving the goal. This is one of the many factors that give to accidents the quality of "random events". The sum of the perceived risk and the risk of not achieving the goal (e.g., risk of not arriving at work on time), is the overall evaluated risk. "Overall" identifies that this risk account for different type of risk, while "evaluated" means that the risk derived from the driver subjective judging.

A useful graph which can help to understand the relationship between real risk, perceived risk and the overall evaluate risk is provided in Figure 3.21. This graph is a modified version from the graph of Durth and Bald (Durth and Bald, 1988), who firstly propose such risk representation. The graph shows that real risk and perceived risk can be different (in the presented case the perceived risk is higher than the real risk).

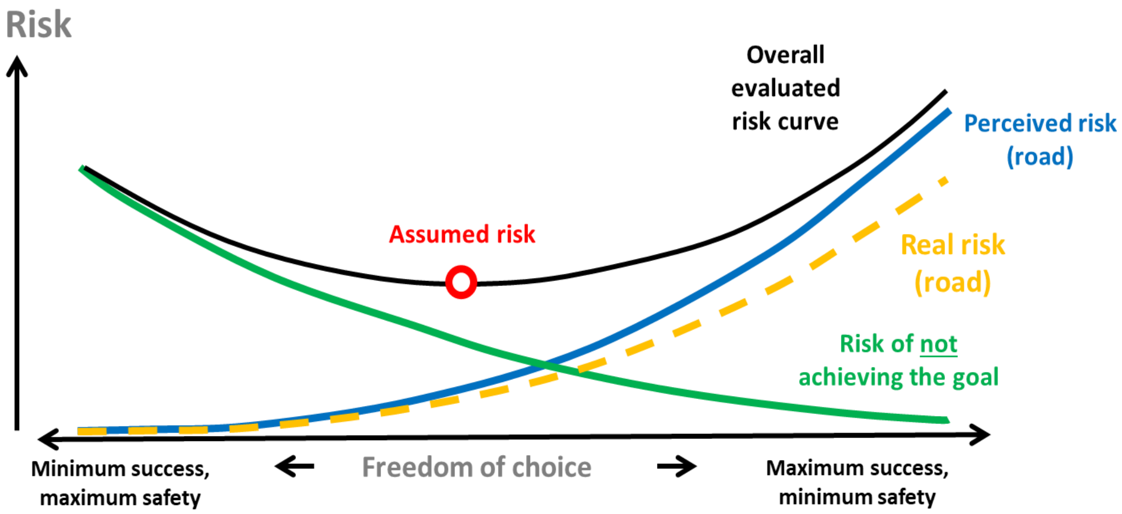

Figure 3.21 – Relationship between perceived, real, and assumed risk, modified from Durth and Bald (Durth and Bald, 1988) *– A.*

While driving, drivers decide the risk they will assume based on two main parameters: the perceived risk, which is strictly related to the perception of the road, and the risk of not accomplished the goal, which is the reason why the driver decided to take the car. The sum of these two components produces the overall evaluated risk curve. The assumed risk is the minimum of the overall evaluated risk. The increase in success in achieving the goal increases the perceived and the real risk (e.g., increase speed to arrive at work on time). On the other hand, reducing the perceived and real risks, lead to lesser chance to achieve the goal.

To maximize the benefits of the travel, drivers adapt their behavior to minimize the risk they have evaluated. This choice determines also the real risk related to road safety. This concept is clarified in Figure 3.22, where it has been assumed a specific condition, that is that the perceived risk coincide with the real risk. The influence of the risk of not achieving the goal is still present. The assumed risk is calculated as the minimum of the overall evaluated risk function. Based on the value of the minimum risk, it is possible to define the real risk, represented as a red point on the curve of the real risk.

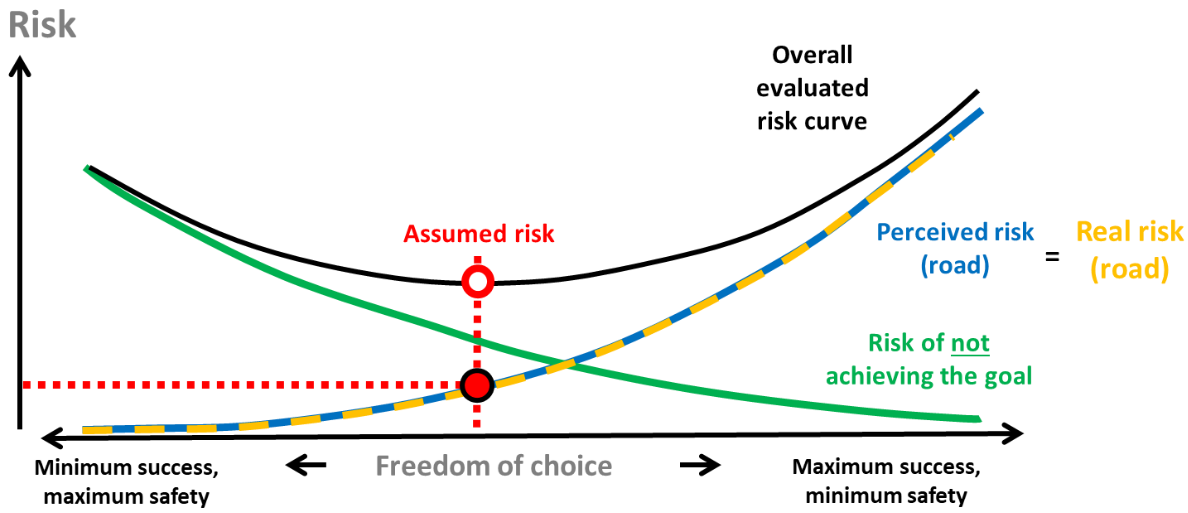

Figure 3.22 - Relationship between perceived, real, and assumed risk, modified from Durth and Bald (Durth and Bald, 1988) *– B.*

Of course, the importance of the goals may be higher, so it can be the perceived risk of the road. This influences the resultant assumed risk, and thus the real risk. Figure 3.23 and Figure 3.24 clarify those concepts. Figure 3.23 shows the situation when the importance of the goal is higher, thus failing to achieve such goal translate into a remarkably high risk for the driver life-project. The assumed risk curve slightly changes and its minimum shift to the right. This means that the driver decides to take a risky behavior (by road safety meanings) to fulfil their task. The real risk increases as represented in the graph by the red point compared to the grey point (which represent the real risk when the importance of not achieving the goal is less).

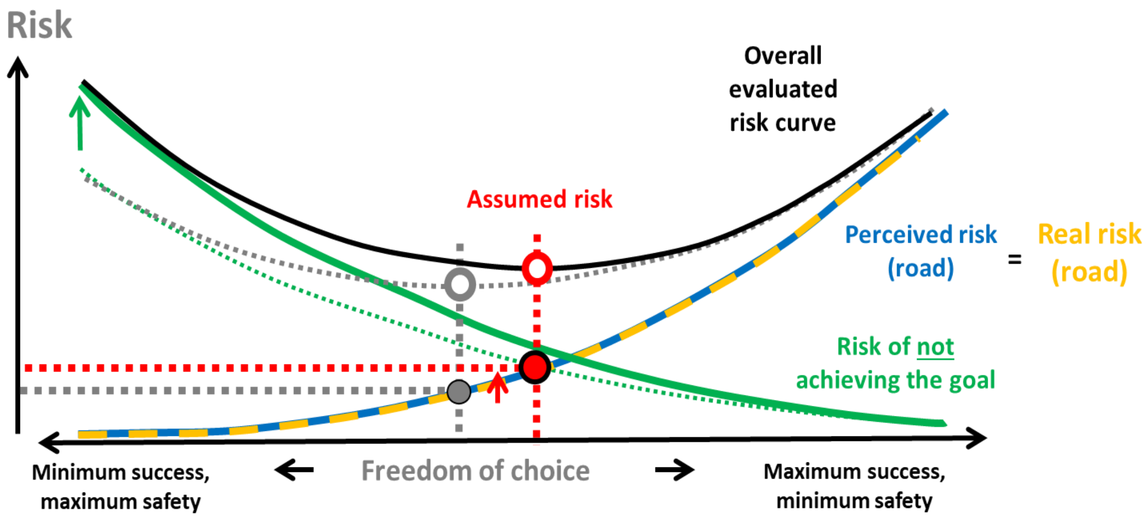

Figure 3.23 – Relationship between perceived, real, and assumed risk, improving the importance of the goal.

On the opposite, in Figure 3.24 is highlighted the influence of a perceived risk higher than the real risk. In this case, the assumed risk minimum shifts to the left, which means that the driver chooses a safer behavior. This translates in a reduction of the objective road risk. On the other hand, if the perceived road risk decreases, the assumed risk will follow the trend of the first example (the minimum shifts to the right), with a consequent increase of the objective road risk.

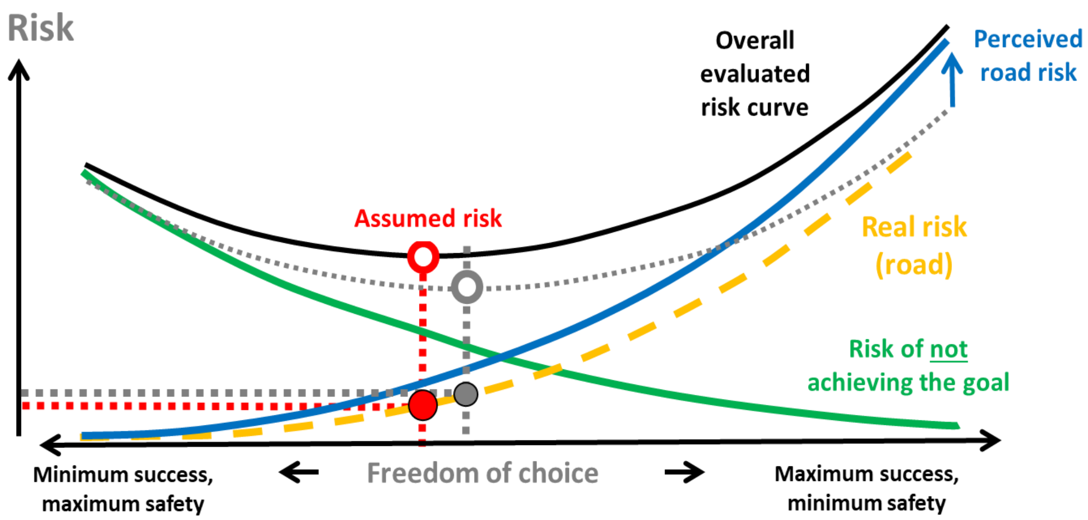

Figure 3.24 – Relationship between perceived, real, and assumed risk, improving the perceived road risk.

Thus, to reduce the real road risk by acting on infrastructure, the focus must be both on the perceived road risk and on the real road risk itself. Because of the importance of the perceived road risk in the occurrence of accidents, the mechanism which regulates the perception of the road must be analyzed and this it can be possible by accounting for expectations.

3.1.6 Behavioral adaptation

Having introduced the concept of real and perceived risk, it is mandatory to explain the concept of behavioral adaptation to have a clear overview of the mechanism behind drivers' behavioral choices. Behavioral adaptation in the road system has been defined by OECD (OECD, 1990) as "those behaviors which may occur following the introduction of changes to the road-vehicle-user system and which were not intended from the initiator of the change; behavioral adaptations occur as road users respond to changes in the road transport system, such that their personal need are achieved as a result; they create a continuum of effects ranging from a positive increase in safety to a decrease in safety". This means that the outcome from the application of a countermeasures may improve safety under some objective parts of the system but may also produce some negative effects to some other parts, because of a change in the driving behavior. The example discussed in 3.1.3.3 demonstrates this concept. A new road with wider shoulder and lanes should improve the road safety of the stretch. However, the driving behavior may change responding to this improvement: the road is perceived as safer (that is true), the perceived risk may be lower, and thus the driver assumes higher risks (e.g., holding a higher speed). This sometimes may result in an overall reduction of safety. Taken to extreme levels, this concept brought someone to say that engineering infrastructure improvements are not effective in reducing total fatalities and injuries (Noland, 2003). Obviously, this is a provocation. Indeed, as illustrated through the previous paragraph, drivers respond based on the assumed risk, which is strictly related to the perceived risk. The perceived risk is based on the road and road environment characteristics. Thus, it is not always true that when implementing an infrastructural improvement, safety decreases, neither increases or still the same. All these possibilities may occur. The more the aspects considered while planning the intervention, the best the outcome will be.

A useful model to schematize behavioral adaptation, which can help in the analysis of the outcomes of possible interventions is from Weller and Schlag, and depicted in Figure 3.25 (Weller and Schlag, 2004).

In this scheme after the objective enhancement of the road, two other aspects should be verified: if the road appears enhanced to the driver, and if the possible adaptation to the new subjective-perceived road, may produce some benefits for the driver. This model fits exactly the theory of assumed risk presented in 3.1.5.

Behavioral adaptations are often associated to adaptations to some specific measures. Two other concepts that are strictly related to behavioral adaptations are risk homeostasis and risk compensation.

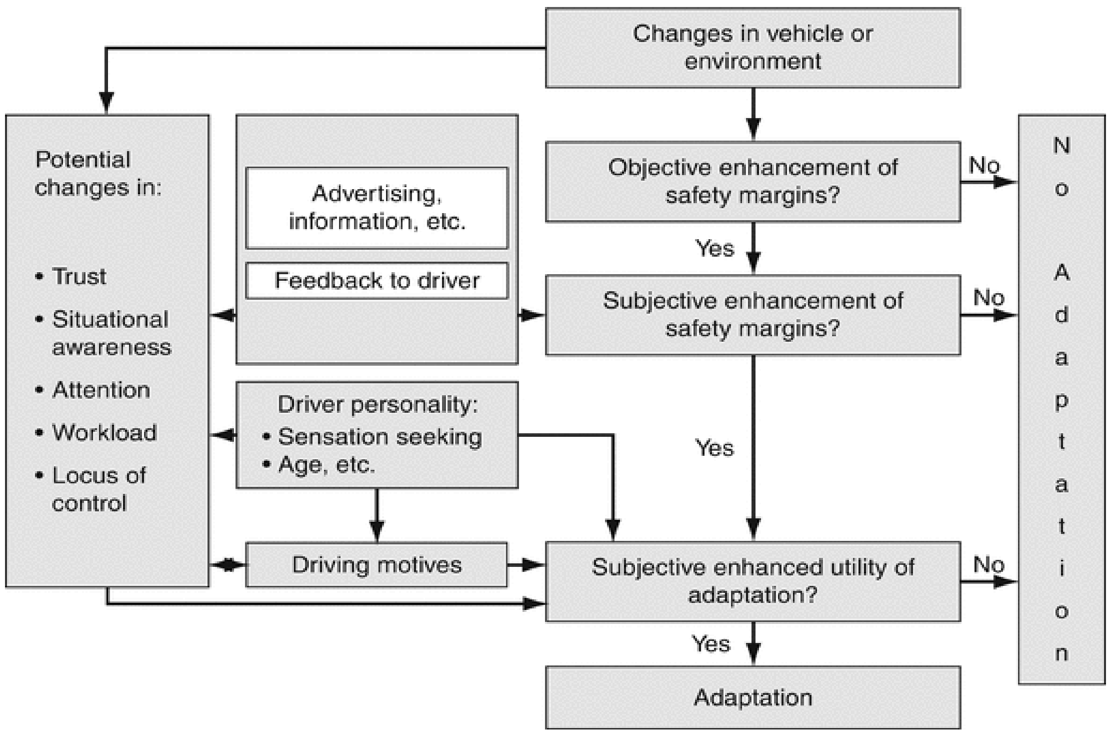

Figure 3.25 – Process model of behavioral adaptation (Weller and Schlag, 2004).

Risk homeostasis and risk compensation

Literally talking, risk homeostasis means the tendency of balancing the risk. In biology, homeostasis is the state of steady internal, physical, and chemical conditions maintained by living systems. By this concept introduced by Wilde in the contest of road safety (Wilde, 1988, 1985, 1982a, 1982b), he extends the significance to the whole road system. It is not only the adaptation to the single countermeasure, but it accounts also for societal influence, and other road safety related aspects which may influence the perception of risk of an accident. More precisely, as also defined by Weller (Weller, 2010) and clarified by Wilde itself (Wilde, n.d.), the theory of risk homeostasis represents the tendency of the driver to adapt their behavior to reach a target risk, not a defined value of risk that is constant over the time. By this meaning also the term "risk compensation" appears appropriate to identify this mechanism. Nevertheless, Wilde clarified that he had made use of both terms in two different period of his work, despite the intended meanings was the same. Eventually, Wilde suggest to name the theory as risk homeostasis (Wilde, n.d.).

The theory of risk homeostasis has found many followers but also many opponents. Despite this, Wilde theory offers some good basis for the developments and tests of behavioral theories. Moreover, the theoretical assumptions proposed in this thesis, fit Wilde's theory, mainly considering that:

- the concept of risk of not achieving the goal and the concept of perceived risk (Figure 3.21), reflect the four factors defined by Wilde which influence driver choices: the expected advantages of risky behaviors, the expected cost of risky behaviors, the expected benefits of safe behaviors, and the cost of safe behaviors (Wilde, 2001, 1994).
- they consider the influence of some external factors, which are not directly related to the road. These factors have been already presented as the goals to achieve. However, following Wilde intuitions, there are also some external factors which influence the perception of risk, because of societal characteristics. Similar considerations were also argued by Ajze and his Theory of Planned Behavior (Ajzen, 1985), where he stated, as cited by van der Horst, that "the motivation of drivers resulting in certain behavior is based upon their intentions that in turn are determined by attitude, subjective norm and perceived behavioral control" (Van der Horst, 2017). Despite their nature, those external factors influence the perceived risk, because they contribute to expectations and expectations influence the perceived risk. This contribution to drivers' expectation is completely automatic even if not completely unconscious[4]. This contribution may be called "awareness of accident risk" because it is the measure with which the driver

[4] Considering the example of Sweden when Swedish government decided to change to driving on the right, it resulted in high reduction of road deaths in the first year, even if it could be expected the opposite. That is because of a general overestimation of the risk. Drivers knew they must drive safer, but they won't think about it continuously while driving.

feels the risk of an accident. The awareness of accident risk curve has the same trend of the perceived risk curve. In addition, the awareness of accident risk is subjective, because it derives from society, from personality, and from experience (likely if someone has been involved in an accident, they will have higher fear).

- the assumed risk concepts can be assimilated to the target risk concepts, because both are the balance of risk perceived risk and risk of not achieving the goal (the most risk/effective behavior).

The substantial difference is that despite the adaptive and homeostatic behavior of drivers, there are still some specific elements which influence driver behavior because of human natures. These elements will even not be nullified by long-term mechanism of adaptation. Road optical illusion, and road optical density, for instance, is supposed to not been influenced by adaptation (positive influence of this elements has been proven, but only with a mid-term analysis) (PIARC, 2019, page 77). Moreover, countermeasures which mainly influence the outcome of an accident (i.e., the severity), are less influenced by adaptive processes. One example above all is to improve the skid resistance. That countermeasure is effective in curve balancing or in decreasing the stopping distance, with positive effects on safety, but it is impossible for the driver to perceive the change.

Finally, even if external factors will influence for sure the risk perception (overall evaluated risk), they can't be the most influencing. If that is the case, accidents will likely be distributed homogeneously along the road networks of similar areas (countries/regions). This is not true: some points of the road present a recurring higher number of accidents. The influence of the single road segments can't be denied. For this reason, it seems confirmed that to improve road safety, it is possible to act on reducing external factors (risk of not achieving the goal, and awareness of accident risk), and even more on reducing road factors (perception of the road[5], and real risk). Road practitioners and administrations must focus on the latter. The logic scheme of the mentioned theory is depicted in Figure 3.26. The scheme completes what introduced in Figure 3.21 and Figure 3.22.

[5] Instead, the perceived risk is composed by both the perception of the road and the awareness of risk.

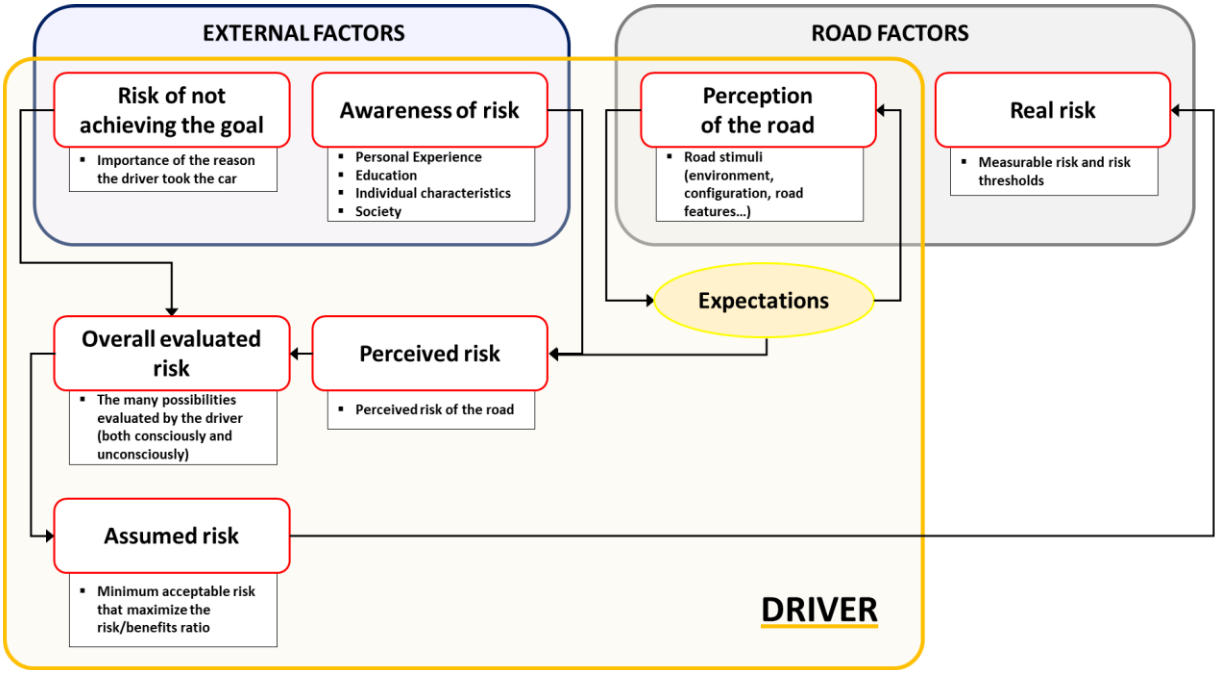

Figure 3.26 – Logic scheme of driver's evaluation of risk

The perception of the road is the outcome of the environment analysis process taken by the driver, as presented in 3.1.4.1. Consequently, expectations can be considered as the factor which influences the driver's perception of the road. This introductory part has been necessary to provide a complete framework of the factors influencing road safety, to underline how central is the driver is the road system, and to define the boundaries of this research, which accounts for the elements of the road and its environment that influence driver behavior. As already noted, the perception of the road is linked to both physical aspects (sensation) and cognitive/psychological aspects, which are mainly constitute by expectations.

3.2 Expectations

Expectations are defined by the Cambridge Dictionary "the feeling of expecting something to happen" (Cambridge Dictionary, n.d.). This definition fits exactly the meaning of concepts which are at the basis of the driving task. To understand this concept the way the human beings face the everyday life should be briefly presented. As well expressed by Green (Green, 2017), there are many aspects which are connected to the concept of expectations. Those aspects can be summarized as:

- drivers (human beings) do not perceive an objective reality;
- drivers tend to focus their attention to what is perceived as more relevant for the specific situation;
- drivers have some innate perceptual organization;
- drivers rely on experience (operant learning concept).

The first statement seems quite impossible, nevertheless the examples that can be provided to prove this statement, are many. One above all is the fact that human beings substantially perceive a 2D world, thus a simple line can be perceived of different lengths based on the surrounding. That is exactly the case of the Ponzo's illusion, depicted in Figure 3.27. The two yellow lines are of the same length and width, but the one on the top appears of bigger dimensions than the one on the bottom. This ambiguity makes clear that the perception of the reality it is not objective. Expectations influence the driver perception of the reality.

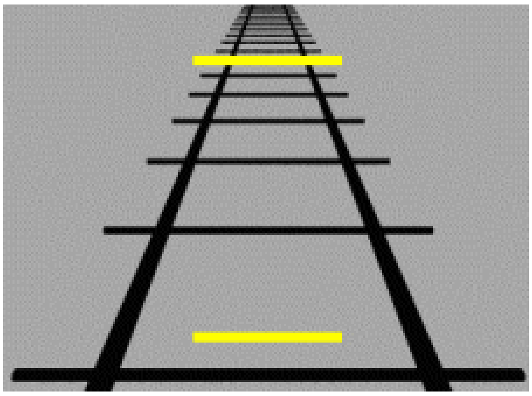

Figure 3.27 – Example of Ponzo's illusion ("Ponzo illusion - Wikipedia," n.d.)

The second statement includes both the conscious and unconscious level, even if the latter is more influenced by instinctive "eye-catcher" (see 3.5.3). The screening of the road environment and the more or less conscious decision to focus the attention only on some part of the world in front of the driver, derives from the human limitations already discussed in 3.1.4. The impossibility to analyze in detail and in the same moment all the information coming from the surrounding, and thus processing all the incoming information, forces the driver to select the information that are considered as most relevant. Approaching a pedestrian crossing, the driver will look to both sides of the zebra crossing, focus the attention on those points, missing what is happening in the other part of the road. Expectations contribute to the definition of what is relevant and what is not, and thus influence where the attention is directed.

The third statement concerns the perceptual mechanisms of humans, which tend to organize the perception of elements by some specific rules. The most common principles are proximity (closer elements are grouped together), similarity (similar elements are grouped together), symmetry (symmetrical elements are coupled together to form a "close" element), and continuation (elements are grouped if creating continuation of the previous group). Those concepts refer to the Gestalt principles that will be discussed in 3.5.4. This is also a kind of expectation, which derives entirely from the human nature. This instinctive expectation may contribute to provide a general image of the reality that slightly differ from the reality, and so contribute to a wrong choice of the most relevant elements to analyze, because of a modified perception.

The last statement explicit that driver expectations are influenced by their experience. Both short-term experience and long-term experience. The first concern the idea that a person has about the specific situation, for example if they must solve a task under specific conditions.

The person will assimilate the environment condition (e.g., light of the room, sounds, objects position, etc.), the task operation (mainly if the task is repetitive), and so on. This situation specific experience, which are short-term experience, are related to the long-term experience. Human beings take the knowledge they have stored in their memories from a lifetime and adapt that information to solve the current task they must do. The new task may in turn provide some new information to store in the memory. The memory represents the long-term experience, which is the one developed during lifetime[6]. Experience influences the association of some expectations to some perceived features. This will be clarified by the concept of schemata and behavioral script presented in 3.2.1. The mechanism which influences the association of a specific configuration of the surrounding to a specific behavior, is also related to the concept of operant learning. Operant learning concept is most frequently associated to B.F. Skinner and the "behaviorist" school of psychology (Jones and Skinner, 1939) (McLeod, 2018), based on Thorndike's Law of Effect (Thorndike, 1927): behavior that is followed by desirable consequences is more likely to occur again, and behavior which is followed by undesirable consequences is less probable. This concept fits with the theory of risk introduced by Wilde and considered in this work. Moreover, this concept is at the base of some relevant road safety aspects. For example, the credibility of speed limits. If a speed limit is not credible, and thus doesn't reflect the standard driving characteristics of the road, the driver may associate that driving at a speed higher than the speed limit it is not so bad. Every time they drive in such a road stretch, they drive at a higher speed and no problem arises. Thus, the positive outcome is present even when driving over the limit[7].

Whatever is the case, expectation about the oncoming situation is influenced by the preceding experience, both short- and long-term experience.

It appears obvious how much these human characteristics (i.e., expectations) influence the driving task. All road elements and location which require a change in the driving program, can result in a hard task to overcome if they are unexpected, because drivers could take the wrong decision or comprehend too late the situations. Th concept of expectations is central in the definition of the HFE procedure.

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[6] The definition of memory and the way information is stored in the memory would require many other pages of explanations that are not presented in this work. For some useful and interesting information about how memory works it is possible to reference to (Chabris and Simons, 2010) and (Green, 2017).

[7] This may occur if a speed limit is set because of reduced visibility from the minor road, while the main road geometry allows for higher speed. The driver that is driving on the main road, will probably doesn't perceive the risk of driving faster if they never face a car entering from the minor road. The consequence is that it will continue to drive faster because of the positive outcomes of this manoeuvre. Furthermore, it is likely that the driver keeps the same behaviour also in similar situations.

Based on the four listed characteristics which deal with expectations, it is possible to define two types of expectations: expectations based on driver experience (General Expectations, GEXs), and expectations based on what the driver think to see in front of them in a specific moment (Punctual Expectations, PEXs). The first are linked to the fourth characteristic, the latter to the first three characteristics.

GEXs mainly derived from the experience, both of long-term (experience in the driver life) and of short-term (experience of the last kms travelled). To make the concept of GEXs clear, a simple example of a motorway is provided. Driving in a motorway create some expectations of what the driver can find in front of him and how the road will develop; the main characteristics of a motorway and its environment derived from the driver's life experience, because motorways share some main characteristics (high speeds, no driveways, no at-grade intersections, curves with high radius, double carriageways, etc.). This is the contribute of the long-term experience. This concepts coincide with the concept of self-explaining roads introduced by Theeuwes and Godthelp (Theeuwes and Godthelp, 1995). The short-term GEXs concerns the expectations about the specific road the driver is travelling, which has the base characteristics of the main road category to which it belongs (e.g., motorway), but has also some peculiarities. Considering the previous example, the same motorway pass through a plain terrain and then goes into a mountainous area. In the first part of the road, the motorway has two carriageways of 4 lanes each, few curves with radii over 1000 m, with low differences in the vertical slope. On the opposite, in the mountainous area, the carriageways have two lanes each, there are many points where the vertical slope change considerably and there are lot of curves, having a radius ranging from 400 m to 800 m. The driver is still in a motorway and the main features of the motorway are still present, but the motorway has changed and so, after some kms of driving in the new environment, also the driver expectations have changed: a curve of 500 m will be unexpected in the plain motorway but is something "normal" and expected in the mountainous area of this example. This is the second level of GEXs, a level that consider some specific characteristics of the road stretch, which summed to the basic characteristics of the motorways, give the GEXs of that road stretch. Moreover, drivers expect not only the road to develops in some specific way, but also that other drivers hold a specific behavior, as clearly stated by Theeuwes in his explanation of the concept and effects of self-explaining roads (Theeuwes, 2017).

PEXs are mostly defined from the location characteristics. The structure of the field of view around the location, the visibility of the location, the traffic control devices which help to identify and clarify the location, all influence PEXs. Following the preceding example, a 400 m radius curve may appear of higher radius because of a wrong coordination between horizontal and vertical alignment or appear far away than it really is because of some converging lines in the field of view. PEXs are linked to the configuration of the road and its environment. Thus, the concept of "gestalt" has a crucial role in defining PEXs (see 3.5.4). These specific punctual[8] characteristics of the location (PEX) are influenced by GEX and together with GEX define a specific perceived image of the road in front of the driver.

The process is illustrated with the pyramid in Figure 3.28. This process may be seen as a hierarchical process where information received from sensorial systems are filtered based on the three different level of expectation: long-term GEX, short-term GEX and PEX. The black arrows represent the filtering process: based on the information (expectations) from each level, only the memorized situations which fit with the image of the road are considered, moving to the next level. The outcome is the association of the whole road situation to a specific situation which require a specific behavior. This behavior is the one chosen by the driver. To this point, to understand this concept is mandatory to introduce the schemata and scripts model.

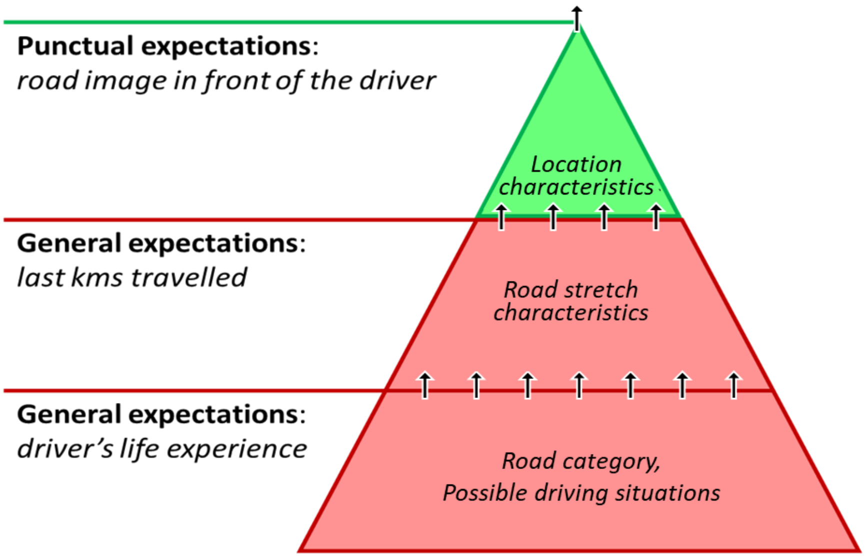

Figure 3.28 – Expectations' pyramid

3.2.1 Schemata and scripts

The general concepts of these two terms are already presented in the glossary, but some additional words must be spent to explain better their significance, especially in the contest of road safety. Schema (pl. schemata) is a term coming from psychology that identifies a general pattern of thoughts or behaviors that arranges acquired information and the relationships among them, limiting them to a predefined type of occurrences. Schemata help to direct our attention and exploratory actions towards the information we regard as important and are required by humans because they are incapable of processing all of the information present in

[8] "Punctual" is here used to specify that these specific conditions are analysed only in the location or immediately before, and thus concern a limited area. Nevertheless, some of the considered elements may have a not punctual development (e.g., line of trees).

the environment in front of them (Kahneman, 2012). Human adaptation finds a way to solve this limitation by the simplification of this cognitive task: not all the information is analyzed, but only the ones relevant to a specific kind of schema, which also concur to define that schema. These will help in the larger number of situations, because schemata are calibrated to the reality, and thus they generally provide a good filter for the real relevant information, but in some other, this filtering of information, could results in the avoidance of the relevant information. Relevant information can be considered as irrelevant because of the schemata priorities (Theeuwes, 2017).

Behavioral scripts, or just scripts, are behavioral procedures or, simply, behaviors, which are consequences of the schemata. Each schema has its own behavioral scripts, that are a series of behavior that are considered appropriate for that specific schema to fulfil the goals and reducing the risk. A clear explanation of the role of schemata and behavioral scripts, is provided by Dumbaugh et al.: "Taken collectively, the cognitive process used to establish traffic behavior is relatively straightforward: individuals cognitively gleam an overall sense of a roadway by relating it to similar types of roadways they have encountered previously, which produces expectations on the potential hazards they can expect to encounter (schemata), as well as the patterns of operating behavior (scripts) that they expect will minimize their exposure to these hazards. This process thus allows individuals to rapidly scan their environments and adjust their operating behavior." (Dumbaugh et al., 2019).

The concept of schemata and scripts are the basis of the self-explaining roads concept (Theeuwes and Godthelp, 1995) (Theeuwes, 2002) (Theeuwes, 2017) (Theeuwes, 2021), and of the studies which were conducted in order to develop a self-explaining road categorization (Riemersma, 2007) (Theeuwes and Menskunde, 1998). Additional insights about the current implementation of this concept in Europe can be found in Matena et al. (Matena et al., 2008).

3.2.2 Situation awareness

Some words must be spent on the concept of situation awareness (or situational awareness). Situation awareness has been defined as, "activated knowledge for specific tasks, at specific times within a system" (Stanton et al., 2006) and also "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1988). Situation awareness explains both how drivers know what is going on, what can be expected to happen, and how quick they can react to specific stimuli. Situation awareness can be eventually defined also as the concept which summarizes the sensations, perceptions and possibly evaluations from the stimuli coming from the road environment, creating expectations about the road, both "present road" and "oncoming road".

Even if it has been necessary to mention this term, in this thesis the concept of situation awareness will not be extensively used, as it is preferred to present the various passages of perception and elaboration of information separately.

3.2.3 Expectations in the driving task

As already seen in 3.1.4 (Figure 3.19), expectations provide a decisive contribution to the driving task. Based on expectations the driver filters the information coming from outside. Feedbacks are part of those information. The pyramid scheme presented in Figure 3.28 represents this filtering process. The definition of a schema is the outcome of the filtering process. Based on the identified schema, the driver chooses how to behave based on a behavioral script. Each expectation defines some scripts and thus some behavior, which define some new feedbacks, which are filtered again by expectations, starting the process again. It is thus possible to include the pyramid scheme of Figure 3.28 into the close-loop model proposed in Figure 3.19, as depicted in Figure 3.29.

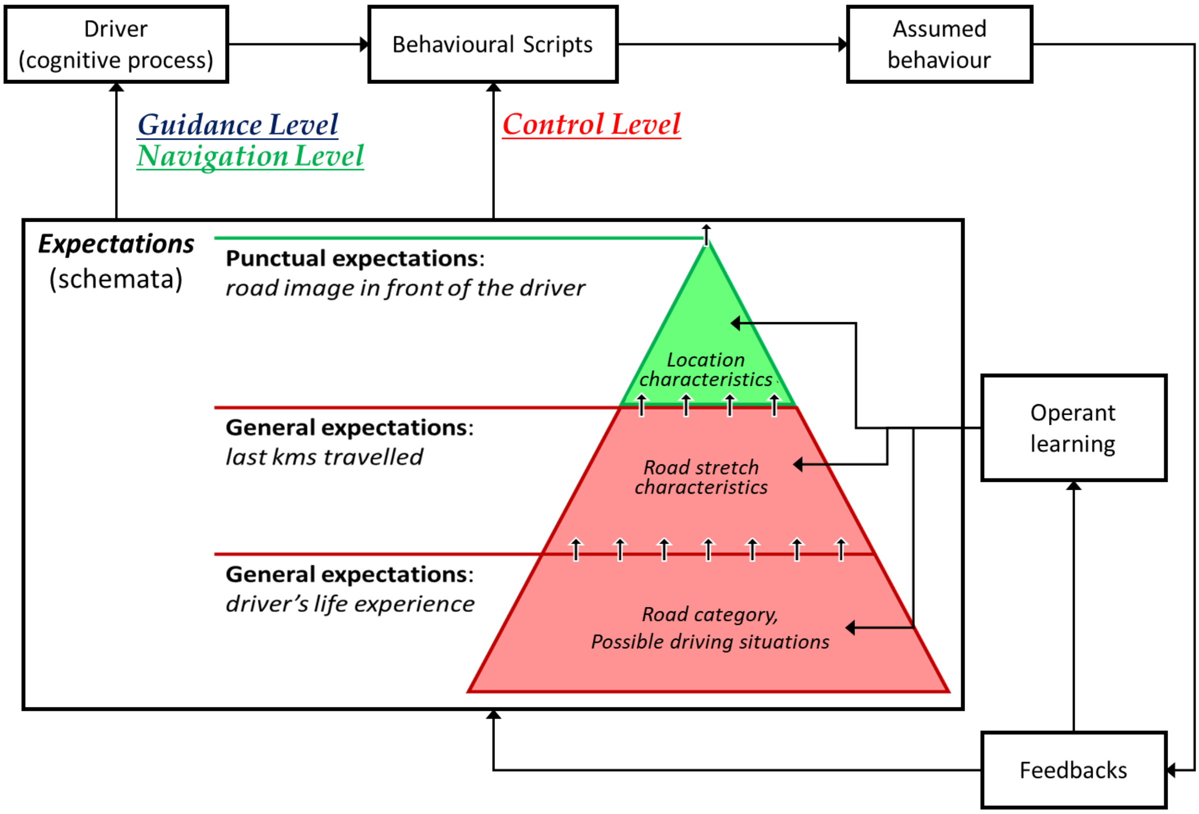

Figure 3.29 – Expectations in the driving task process

What is interesting for road engineers is to understand which are those factors that influence the driver behavior. For this reason, the concept of expectations is crucial while defining a procedure useful to implement a NWRSA that must identify which sections of the road are riskier.

Identifying those road stretches where expectations provided by the road do not comply with the real development of the road should be an objective of the procedure.

Roads must provide the right expectations to drivers. The more the time and clues given to the driver to comprehend unexpected location, the more they will be able to correctly choose the right behavior modifying their expectation to better fit them with the reality. The less the time and the clues provided to the driver, or even the higher the wrong clues provided, the higher the risk of a wrong behavior which could lead to an accident. "*Drivers are smart if they are provided with the right information"* (cit. by Prof. J.S. Bald, University of Darmstadt).

The concept of expectations is a milestone in this work, because the first part of the procedure, which is the great added value of this work, is based completely on this concept.

General expectations and punctual expectations will be used as parameters to define the level of risk of single PCLs.

A factor that may greatly influence the perception of the road, and thus expectations, is workload. Workload plays a fundamental role in successfully managing the driving task.

3.3 Workload

The influence of workload in successfully managing the driving task has been widely investigated by many traffic psychologists. Workload while driving "can be considered as the physical and also mental demand or stress which impacts the driver when negotiating the road information and tasks" (Weller, 2010). Mental stress or demand is defined as "the total of all assessable influences impinging upon a human being from external sources and affecting it mentally" (ISO 10075, 1991). Workload can be of two types: long-term and short-term. While both have influence on the driver behavior, only the short-term workload can be directly linked to the road features and characteristics (Weller, 2010). For this reason, the short-term workload will be discussed in this thesis. Moreover, while talking of short-term workload, it is possible to distinguish in two other different types of workloads: driving-related workload and driving un-related workload. The latter consider the mental demand coming from actions which are not related to the driving task, such as talking, thinking about works, everyday life, and so on. This type of mental demands is often called "distractions". Distractions can't be denied by engineering countermeasures. Therefore, the attention should be directed to the driving-related workload, which depends on road conditions. For example, workload increases on curvy roads and high level of traffic, compared to straight road with low traffic (Wooldridge et al., 2000). Turning requires more workload than traveling straight, although even straight roads with large numbers of salient objects increase workload (Green, 2017; Rahimi, 2016), as long as intersections, especially considering visual search (Hancock et al., 2016). Workload and drivers' stress as a consequence, increase also approaching tunnels entrance (Miller and Boyle, 2019). Figure 3.30 shows a representative scheme of the cited type of workload and how they contribute to the total workload which influences the driving performances.

In this work the driving related workload (which can be described as also road-related workload) will be considered.

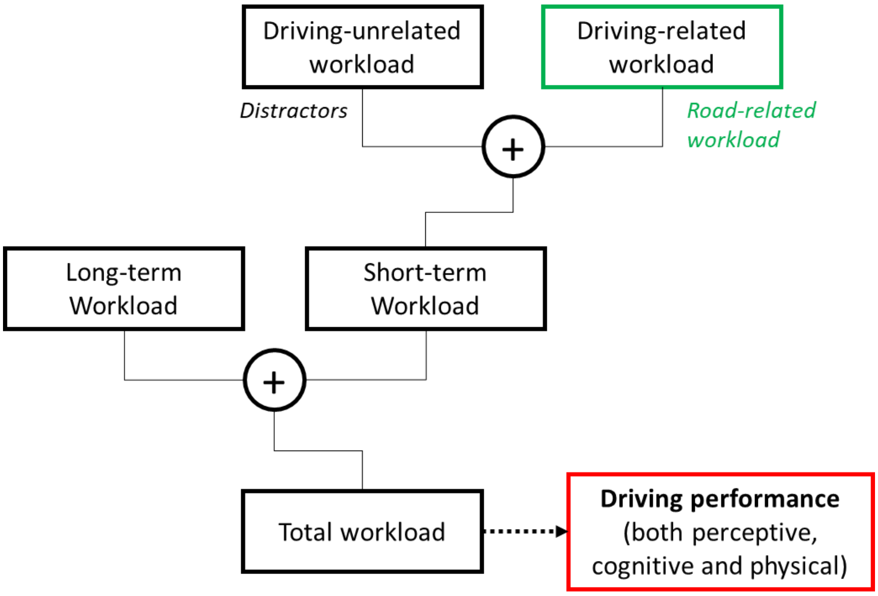

Figure 3.30 – Different workloads and driving performance

3.3.1 Workload and driving performances

One of the most famous relationship between workload and performance, was firstly introduced by Dodson and Yerkes (Yerkes et al., 1908). They found that the level of arousal (stimulation level) influence human performances. The better performances are reached when people are provided with enough stimuli, but not too much. A slightly modified version of the graph introduced by Dodson and Yerkes (Yerkes et al., 1908) is proposed in Figure 3.31. In this graph it is highlighted the mental status of the man making the task. On the left, when the stimuli are few, the person making the task will result bored and tired. On the right, when stimuli are too much, the person will result stressed and restless. The best performances are reached with a medium level of stimuli. In the center of the graph, the person is focused and engaged. This scheme can be entirely applied to the driving task.

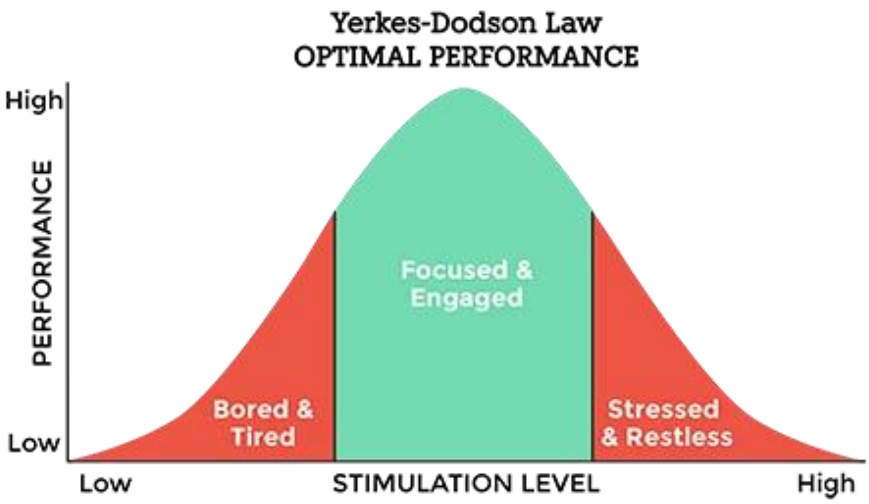

Figure 3.31 – Yerkes and Dodson laws modified by (Bouncyband, n.d.), *from (Yerkes and Dodson, 1908)*

After about one century, De Waard come to similar conclusions by analyzing the findings of different authors concerning this relationship (de Waard and Studiecentrum, 1996). The scheme he proposed is depicted in Figure 3.32.

In his scheme, De Waard proposed six different levels of demand, which has each an influence on workload and thus on performance. Similarly, to Dodson and Yerkes, the performance has a maximum with a medium level of demand. The concept of demand it is not the same as the concept of arousal or stimuli, because it also includes the task mental demand. A better clarification of this two terms can be found in Weller (Weller, 2010). To this thesis, the term “demand” will be used, and its meanings is “quantity of resources required to process information and act”. Moreover, workload can be defined as the ratio between demand (required resources) and available resources. Therefore, a higher demand doesn’t necessarily imply a high workload, neither a low demand necessarily imply a low workload.

Looking at the graph in Figure 3.32, in region A2 performance is optimal, the operator can easily cope with the task requirements and reach a (self-set) adequate level of performance. In the regions A1 and A3 performance remains unaffected but the operator must exert effort to preserve an undisturbed performance level.

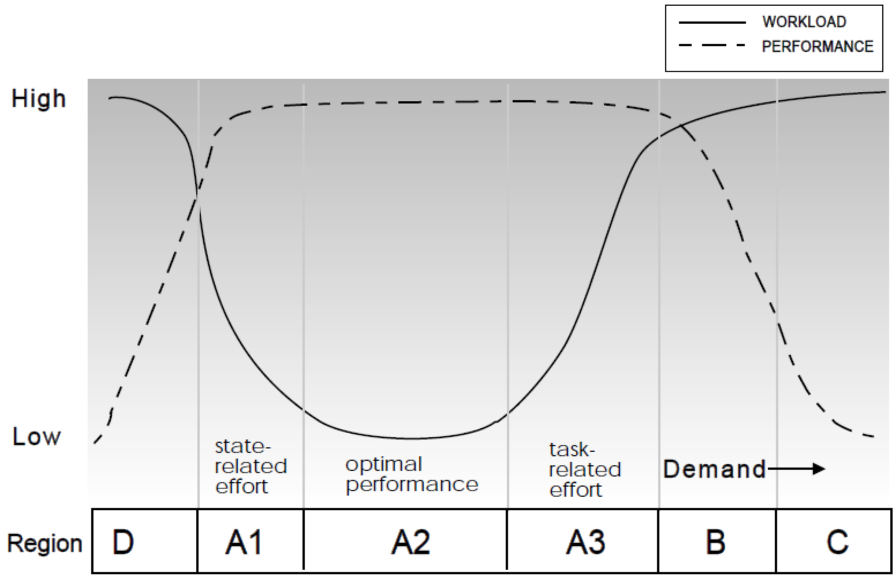

Figure 3.32 – Interrelations between workload and performance on different levels of demand (de Waard and Studiecentrum, 1996)

In region B this is no longer possible and performance declines, while in region C performance is at a minimum level: the operator is overloaded. Considering the workload curve, it seems that it has a wrong trend in the low demand part. However, workload is the ratio between available resources and demand. High workload means that the demand level has reached the resource level. While driving in an environment with low stimuli and low demands, the activated resources are low (level D, the driver is bored). Low available resource imply low alertness and attention and can be defined as mental underload, which can be as detrimental to performance as overload (Branscome and Grynovicki, 2007), because of a reduced ability to react to changing conditions or also to perceive changing conditions. Mental underload is especially likely to occur when the driving environment is predictable (or appear to be). Moving from level D to level A1 of Figure 3.32, resources will increase with the increasing demand until they reach a maximum. If the demand continues to increase, then the workload will rise (level B and C). Even if resources will increase from the state of underload to overload, the activation of higher resources requires time, and if the demand increase is faster than the allocation of new resources, it will result in a high workload and thus low performances. Moreover, it must be underlined that the higher the cognitive load (load that needs cognition), the higher the required resources (Lee et al., 2005). This also explains the different needing of resources for accomplishing the navigation task, compared to the guidance and control tasks (see 3.1.4). it must be also noted that workload does not influence only the ability of the driver to process information (both consciously and unconsciously) but also other driving performances, such as speed. An example can be found in the research from Miller and Boyle, which analyzed drivers behavior approaching and exiting a tunnel (Miller and Boyle, 2019). The workload increases when approaching tunnel entrance, with a consequent reduction in speed, while it decrease in the last part of the tunnel, with an increase in speed.

3.3.2 Alertness

The intended procedure will also consider an aspect directly related to the concept of resource, which is alertness. Alertness defines the level of attention of the driver and thus, indirectly, it influences the activated level of resources. High alertness corresponds to high available resources. High alertness translates in a reduced time required to process information and respond to the environmental stimuli. Because alertness is a consequence of available resources, alertness is linked to the quantities of information coming from the road environment. The more the stimuli, the high the alertness. Nevertheless, too much stimuli may provoke a too high demand, causing an increasing workload that will decrease the performance (even if alerted, the driver can't process all the incoming information) (Yerkes et al., 1908) (Recarte and Nunes, 2003). The influence of alertness in the proposed HFE procedure will be discussed in 5.3.

3.4 A simplified scheme for information processing

To better understand, it can be useful to consider together in a conceptual scheme road information, expectations, and alertness (which directly influence workload). The processes behind these concepts have been already schematize by Durth (Durth, 1972), who based his assumptions on Bringiotti (Bringiotti, 1967). The scheme proposed by Durth is very simple, but it encloses all the concepts presented before (i.e., information, expectations, and alertness), even if not explicitly stated. Therefore, it has been decided to use the scheme from Durth to explain the relationship between these different aspects.

Durth proposed to consider a scheme based on six variables, which are:

H$_{(x)}$: output entropy, that is the information that should be acquired from the road to complete the driving task under safe conditions;

H$_{(y)}$: entrance entropy, that is the information received and processed by the driver;

H$_{x(y)}$: equivocation, that is the information received and processed by the driver that are not relevant for the completion of the driving task under safe conditions;

H$_{y(x)}$: propagation loss, that is the information that should be acquired from the road to complete the driving task under safe conditions, and that have not been received and processed;

H$_{(x, y)}$: total entropy, that is the total amount of information (relevant from the driving task or processed by the driver); and

R: transinformation, that is the information that should be acquired from the road to complete the driving task under safe conditions, and that have been received and processed.

The scheme from Durth is depicted in Figure 3.33. The scheme is the same proposed by Durth except that this one is colored.

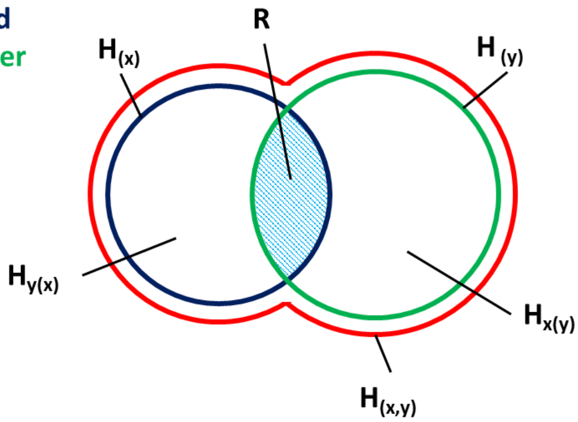

Figure 3.33 – Acquisition of information scheme from Durth (Durth, 1972) *(colors have been added)*

By that scheme, Durth stated that the more the green circle (entrance entropy) overlaps the blue circle (output entropy), the more relevant information from the road are acquired and processed. If all the relevant information is acquired, it can be assumed that the driver will perform their driving task in the correct way (i.e., they will assume the right behavior). The smaller the intersection area (transinformation), the worst the comprehension of the road by the driver, and thus the worst choice of behavior.

Moreover, Durth introduced another important concept, which is the changing radius of the circles by time, that is changing of information that should be acquired and information that the driver is able to process. Complex road situation may require the driver to perceive more information. On the other hand, driver may have reduced capacity of information processing due to their "available resources". As discussed in the workload section (see 3.3), to correctly perform their driving task, drivers require the demand to be less or equal to the available resources. Under standard conditions the green circle totally overlaps the blue circle:

all the relevant information from the road is processed. When few information is required, drivers adapt their available resource to the situation, decreasing them. This means that the green circle is small. However, according to the "simple and easy" road situation, the blue circle is even smaller and totally enclosed in the green one. Referring to Figure 3.34 this is the initial situation (t_0). After some time while driving, the road requires more information to be processed to correctly behave (t_1).

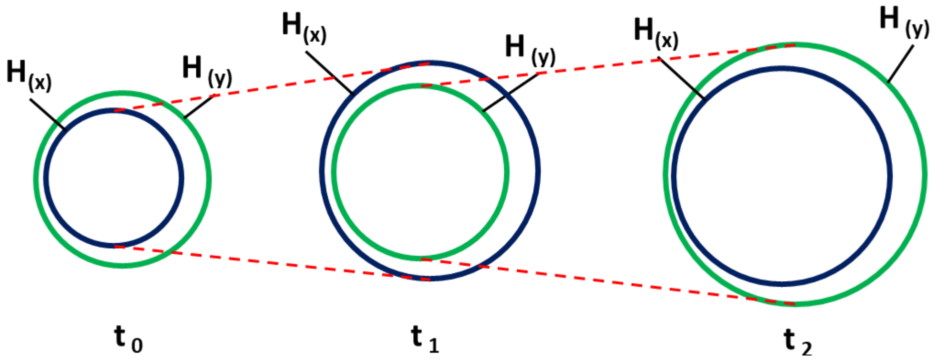

Figure 3.34 – Changing circles' dimensions during time, modified from Durth (Durth, 1972)

At first only the blue circle increases (information that should be acquired from the road to complete the driving task under safe conditions). That is an increased demand. Therefore, the driver adapts to the new situation, making available additional resources that allow them to process all the information coming from the road (t_3). As discussed in 3.3 this process require time and thus an overload of information is possible (in Figure 3.34 at time t_1 an overload is present).

To describe the different situations that may occur in performing the driving task, Durth presented four different situations derived from the interaction of the two circles. These situations are presented in Figure 3.35. A fifth case can also be considered for theory completion, but this case is impossible and thus it has not been presented. The case is that the blue circle and the green circle have no intersections.

Referring to Figure 3.35, the first situation considered by Durth is the ideal case. Here all the necessary information from the road to correctly perform the driving task under safe conditions are provided. In this situation the green circle is greater than the blue one (the driver can process more information than those required) and its center is close to the one of the blue circle (the attention is correctly directed). In the second situation the green circle is bigger than the blue one but is center is far away from the center of the blue circle. In this case inattention occurs, because the attention of the driver is not completely directed to catch the relevant information. Attention is crucial in correctly performing the driving task and it relies most on expectation. Further insights about attention are provided in 3.5.3. The third situation concerns fatigue. In this situation both the attention and the information processing capacity are not consistent with the demand: the blue circle is bigger than the green one and the two center are away one from each other. In the last situation, that is complication, the road requires more information to be processed to correctly behave, but the available resources are not enough (the same as t_1 in Figure 3.34), because the alertness of the driver is not sufficient to clearly respond to the occurring situation. The different position and size of the two circles derives from three aspects: the road information, which influence only the blue circle, the expectations through attention, which influences the position of the green circle, and the alertness, which influences the dimension of the green circle.

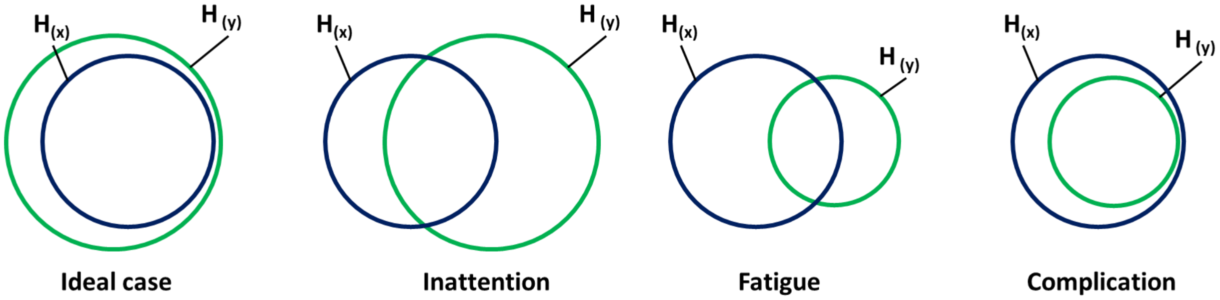

Figure 3.35 – Different driving situations from Durth (Durth, 1972) *(colors have been added)*

Based on this assumption, both expectations and alertness assume a central role in performing the driving task. Furthermore, it can be stated that the position is generally more relevant than the dimension of the circles, and thus expectations have a higher impact on performances than alertness. That is because if the attention is correctly directed, even if not enough information is processed, those processes are strictly related to the one required from the road. On the other hand, even if the available resources are high (big green circle), but the attention is elsewhere, the required information processed are few, and there is much more processed information that are not "relevant" and thus potentially confusing.

Providing the relevant information to the driver, attracting the driver attention to that information both by specific punctual configuration of the road (PEX) or preparing the driver to the relevant information to look for (GEX), and managing the driver level of alertness, are all actions required to improve the understandability of the road and the driver behavior consequently.

Therefore, time and space (and therefore speed), are also decisive in ensuring that the driver adopts an adequate behavior. More available time means greater opportunities to correctly shift attention to relevant information and above all, it means providing the time necessary to increase the number of available resources (thus reducing the workload). The relationship between expectations and time required to the driver to change their behaviour, is deeply discussed in 3.7.

3.5 Road perception and psychological aspects

In the following some main aspects of perception will be presented and summarized. This summary must be included in the thesis to explain some of the aspects to be considered while evaluating road safety by mean of Human Factors. The connections between the stimuli from the real world and driver perceptions are crucial. Because the information needed for driving is over 90% visual (Hills, 1980), an overview of visual perception processes is provided.

3.5.1 The eye

The driving task relates to many senses, but the most used is sight. Sight is the first step of the visual perception. While talking about visual perception, we are talking about what the driver sees (or thinks to see). The eye is where vision begins. Light reflected from objects in the environment enters the eye through the pupil. Cornea and lens take this light and project it onto the retina. The "image" on the retina is the upside-down image of what it has been observed. Moreover, the point where the pupil is focused is projected in the center of the retina. The far the point from the pupil focus, the far the point from the center of the retina. The retina contains the receptors (photoreceptors) for vision. There are two kinds of receptors, rods, and cones, which contain light-sensitive chemicals called visual pigments that react to light in different ways. These two types of receptors are distributed differently upon the retina: cone receptors are packed closely together in the retina's center, while rods are most concentrated about 20° from the fovea. The receptors transform the light into electric signals (neural code) that are sent to the brain. "The cornea and lens at the front of the eye and the receptors and neurons in the retina lining the back of the eye shape what we see by creating the transformations that occur at the beginning of the perceptual process" (Goldstein, 2010), that is the sensation, which will become perception. A simplified scheme of the eye is shown in Figure 3.36.

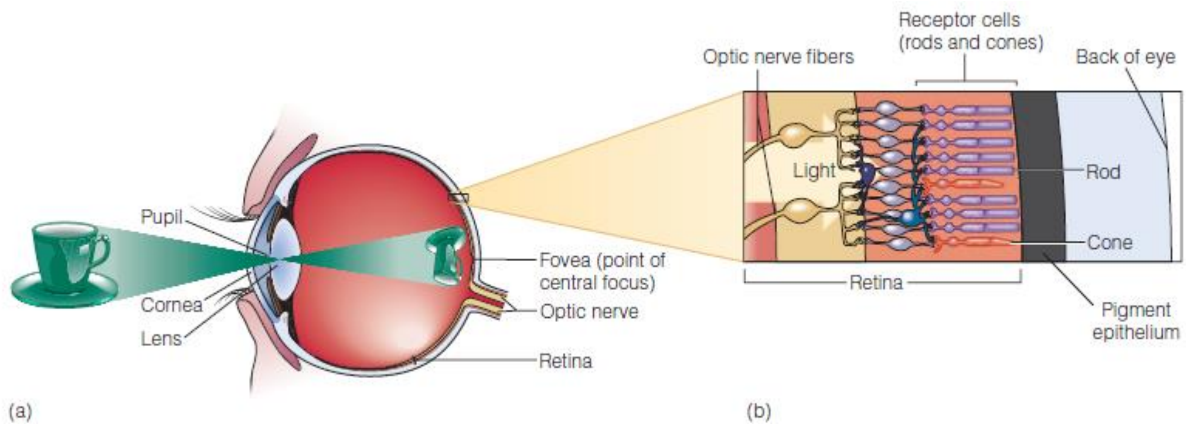

Figure 3.36 - An image of the cup is focused on the retina, which lines the back of the eye. The close-up of the retina on the right shows the receptors and other neurons that make up the retina (Goldstein, 2010)

Cones differ in three different classes based on wavelength their photopigment are better suited to receive: short-wavelength (blue), middle-wavelength (green), and long-wavelength (red). For this reason, cones have also very different sensitivity. On the opposite, rods have only one variety of pigment and they can only perceive short wavelengths. The central fovea has no rods and few short wavelengths cones. This means going away from the fovea the vision of red and green decrease rapidly. The loss of peripheral color vision can cause collisions. One example is that driver can misidentify the color of red signals viewed in the far periphery as being yellow (Sivak et al., 2000). Moreover, the fovea area has the highest visual resolution. As distance from the fovea increases the cone distribution become more irregular, and virtually all visual functions decline. This means the far the point from the fovea, the less the color stimuli reception. The distribution of cones and rods is depicted in Figure 3.37.

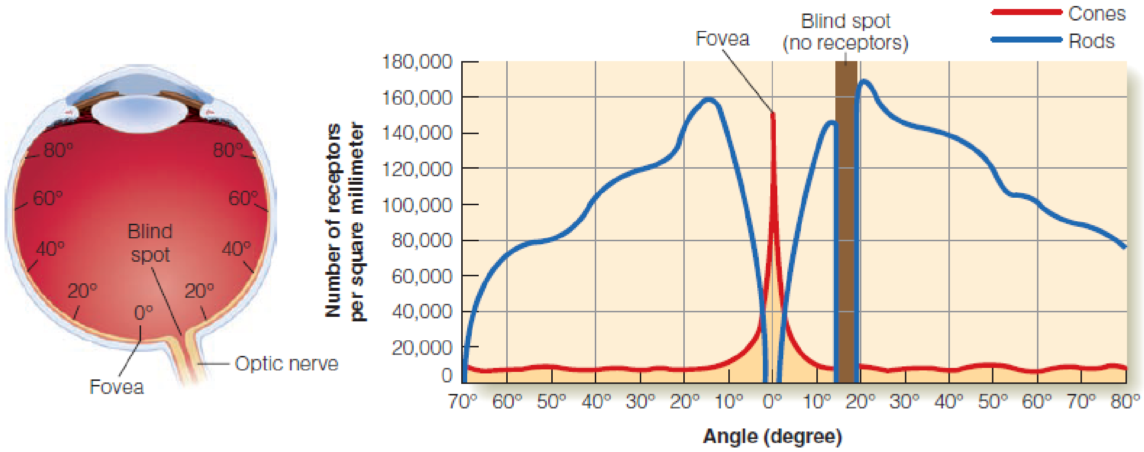

Figure 3.37 - The distribution of rods and cones in the retina. The eye on the left indicates locations in degrees relative to the fovea. The vertical brown bar near 20 degrees indicates the place on the retina where there are no receptors (Goldstein, 2010), *adapted from* (Lindsay and Norman, 1977)

As shown in the same figure, the presence of the optic nerve implies the presence of a blind spot. Generally, we won't notice it. The most important reason that we don't see the blind spot is that some mechanism in the brain fills in the place where the image disappears (Churchlad and Ramachandran, 2012).

The distribution of cones and rods defines the field of view. Human vision is a binocular vision, more precisely, the central part of the field of view is binocular, while the peripheral part is monocular. Figure 3.38 and Figure 3.39 show two schemes of the composition of the field of view, both from top and sideways (Figure 3.38), and frontal (Figure 3.39).

Visual function such as contrast sensitivity, acuity, and motion detection, fall gradually with increasing distance away from the fovea into the periphery. Motion is the only stimulus that can be perceived by the far peripheral field of view, as schematize in Figure 3.40. Nevertheless, slow changes in position in the peripheral field of view are hardly perceived.

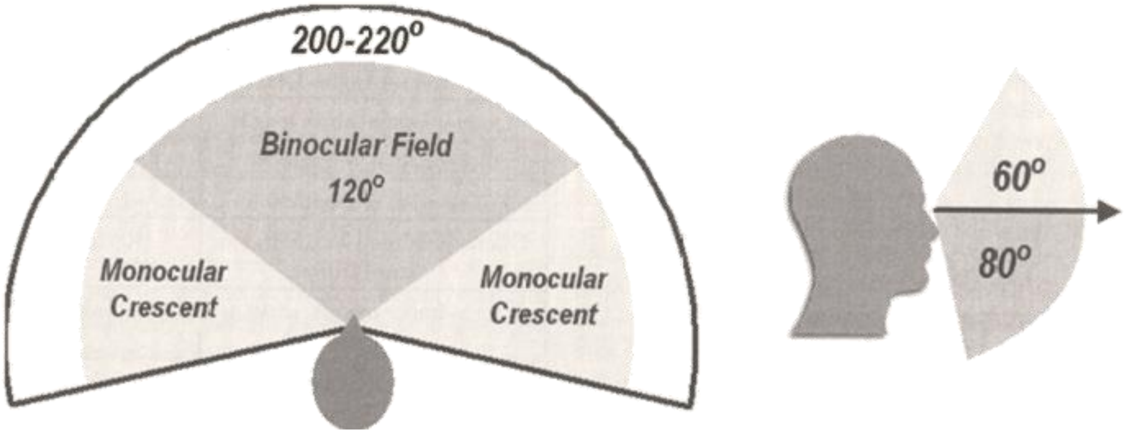

Figure 3.38 – Left: the overlapping 160° monocular eye fields create a binocular field of 120°. Right: the vertical field is 140° (Green, 2017)

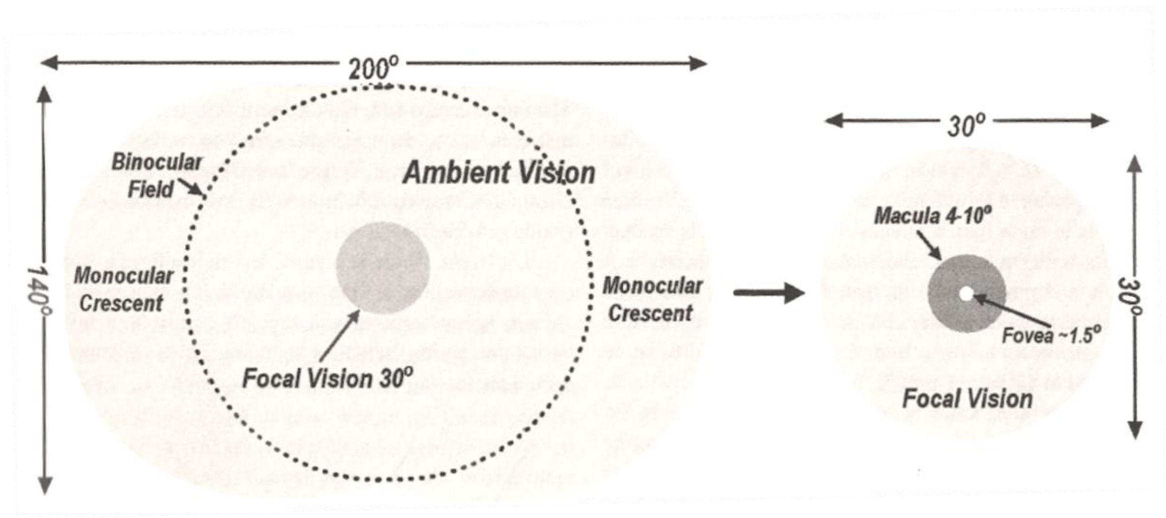

Figure 3.39 – The visual field consists of concentric areas with differing quantitative and qualitative function (Green, 2017)

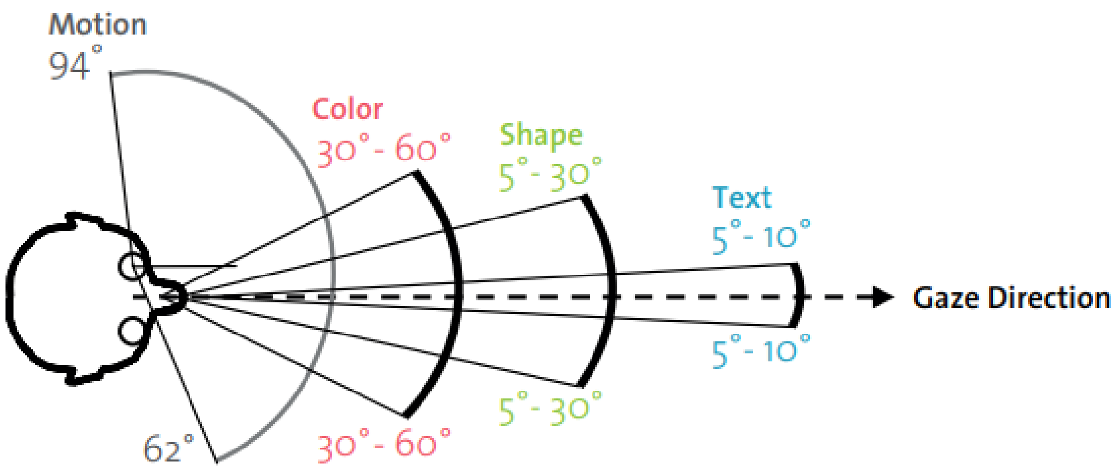

Figure 3.40 – Different perceivable stimuli from different field of view areas (Ishiguro and Rekimoto, 2011)

This reduced capacity of the far areas of the field of view occurs for Green (Green, 2017) for at least four reasons: photoreceptors spacing increases and becomes more irregular, spherical aberration from the optics becomes significant further impairing resolution, the distance is greater from the focus of attention along the sightline, and situational factors, such as traveling at high speed suppress peripheral detection. The last statement has been claimed by many researchers including Lorenz (Lorenz, 1971), however this has been also confuted experimentally by many other (Cohen, 1984) (Schulz, 2013). The conclusion, as argued by Čičković (Čičković, 2014), could be that an unilateral direct relation may not be present, however there should be other factors that influence the speed and that are related to the field of view. Despite this, it can also be argued that while driving at higher speed, the driver must be focused more on the road further development, which becomes its focal point of attention. Thus, the gaze will move less to the road margins, which will remain in the peripheral view. A reduced control of the margins and their fast changing (high speed), determine less information for the brain upon which base the reconstruction of the normally missing information from the peripheral view.

Moreover, humans can suppress not relevant stimuli to performing the current main task. This mechanism always makes them better perform a specific task, reducing the global demand of managing information from the environment (doing so reducing the risk of overload) (Lavie and Cox, 2016) (Cohen, 2009). It can be assumed that the same occur while driving at high speed. While driving at high-speed driver attention is only to the road development and not to the marginal elements.

More recent studies also demonstrate that some objects in the peripheral field of view are more easy-to-detect if they have a particular shape. This has been proved by Costa et al. considering the perception of vertical signs. The study demonstrates that "road signs with angular shapes and prominent vertexes as triangular or cross signs were better identified in peripheral vision than signs with more compact shapes (circular signs)", and that "horizontal and vertical eccentricity negatively impacts the driver's ability to correctly identify and discriminate traffic signs" (Costa et al., 2018).

The area of space from which a viewer can acquire information without eye or head movement was firstly defined by Sanders (Sanders, 1970) as "functional field of view", and it is now called "useful field of view". The useful field of view dimensions depend on many factors, like luminance level, light wavelengths, stimulus salience and the execution of secondary tasks, but it has been proved that it has a major influence in accidents occurrence (Ball et al., 1993) (Allahyari et al., 2007) (Cohen, 2009). The useful field of view deteriorates with age (Ball et al., 1993), when a secondary central task is added (Wood et al., 2006), under monotonous driving conditions (Rogé et al., 2004) and in addition to sleep deprivation (Rogé et al., 2003).

Finally, it must be said that our view is a two-dimensional view. 2D images from our senses are elaborated by the brain which gives us the perception of depth and thus the perception of a 3D space.

So far, eyes don’t provide a correct image of the reality by sensitive receptions. The missing part are completed by our brain.

Those first knowledges give an idea of the importance of understanding potentials and limits of central and peripheral vision, and thus the importance of managing the space behind the carriageway boundaries and suggest the importance of expectation as “schemata”, which help the brain to reconstruct the world around us using few of the information from the environment.

3.5.2 From sensation to perception

“In order to act, the viewer must first decide. To decide, he must first perceive. To perceive, he must first sense. Psychophysics is the science of measuring sensation.” (Green, 2017).

Sensation and perception are two separate but related processes. Sensation is obtained by our sensory receptors, and it is the input from the outside real world. Perception refers to the way sensory information is organized, interpreted, and consciously experienced. In other words, senses are the physiological basis of perception. Perception of the same senses may vary from one person to another because each person’s brain interprets stimuli differently based on that individual’s learning, memory, emotions, and expectations.

In paragraph 3.5.1 some basic knowledges about sensation have been provided. In this paragraph some insights will be given about the consequent process, that is perception. Perception involves both bottom-up and top-down processing. Bottom-up processing refers to the fact that perceptions are built from sensory input. Top-down processes occur because our sensations are influence by our available knowledge, our experiences, and expectations. Expectations are determined by representation of reality in memory. “The representation activated depends on the similarity of the actual situation with the characteristics of the situation stored in the memory” (Weller, 2010).

Expectations are crucial in perception. Two simple demonstrations are the examples provided in the following figure from “Sensation and Perception” (Lumen Learning, n.d.). Figure 3.41 shows a symbol (or a couple of symbols). The symbol is sensed the same by different people (excluding any disability), but it can be perceived in different way: mainly it will be seen as the letter “B” or as the number “13”, or something else.

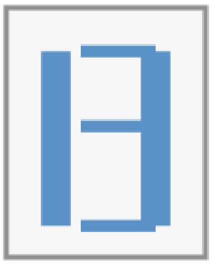

Figure 3.41 – Blue symbols on grey background

An even more interesting example, which proves the high influence of expectations, is the fact that, if the symbol in Figure 3.41 is combined with other symbols, it will then be perceived in an unambiguous and univocal way. Two images are provided in Figure 3.42 and Figure 3.43. In the first figure the letter A and C are used, while in the second figure the number 12 and 14 are used.

Figure 3.42 – A consistent meaning is given to the symbol: a series of letters

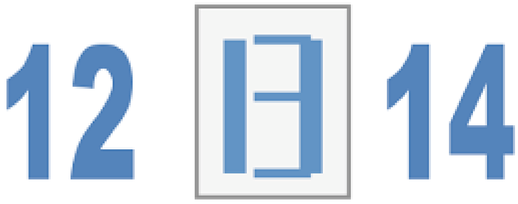

Figure 3.43 – A consistent meaning is given to the symbol: a series of numbers

Now the symbols are univocal: it is a B in Figure 3.42 and a number 13 in Figure 3.43. This demonstrates the way the brain adjusts ambiguous stimuli to fit unambiguous perception consistent with the main perceived framework. Because of other clear information from the environment, expectations arise about what the whole figure should be. The brain compares what it expects with the sensations. If, with some adjustments, the stimuli fit the expected information, thus they become that information.

Moreover, perception can be influenced also by other factors. Some of these factors are sensory adaptation, change blindness, inattentional blindness, and priming.

Sensory adaptation is the reduce capacity of perceiving stimuli that remain relatively constant over prolonged periods of time. This occurs because if a stimulus does not change, our receptors quit responding to it.

Change blindness is a perceptual phenomenon that occurs when a change in a visual stimulus is introduced, but it is not noticed by the observer. "Change blindness is defined as the inability to detect changes made to an object or a scene during a saccade, flicker blink or movie cut...change blindness is especially pronounced when brief blank fields are placed between alternating displays of an original and modified scene" (Caird et al., 2016). Some research findings about change blindness can be found in Levin and Simons (Levin and Simons, 1997), and Silverman and Mack (Silverman and Mack, 2006).

Inattentional blindness means to not perceive evident stimuli because the attention is involved in other tasks. One of the most interesting demonstrations of how important attention is in determining our perception of the environment occurred in a famous study conducted by Daniel Simons and Christopher Chabris (Chabris and Simons, 2010; Simons and Chabris, 1999). In this study, participants watched a video of people dressed in black and white passing basketballs. Participants were asked to count the number of times the team in white passed the ball. During the video, a person dressed in a black gorilla costume walks among the two teams. Nearly half of the people who watched the video didn't notice the gorilla at all, even though he was clearly visible for nine seconds. Because participants were so focused on the number of times the white team was passing the ball, they completely tuned out other visual information. People know they are watching people passing a ball, they won't expect any Gorilla.

Priming generally relies on supraliminal stimuli, which means that the messaging may occur out of awareness, but it is still perceived, unlike subliminal messaging. Supraliminal messages are perceived by the conscious mind. The effect of priming can be also relevant in managing road safety as explained by Koyuncu and Amado (Koyuncu and Amado, 2008). Their research highlights the influence of priming in perceiving road signs. Finally, as Gauthier has noted, visual objects are perceived more quickly and easily if subjects have previously been exposed to them, regardless of whether they remember having seen them before (Gauthier, 2000).

3.5.2.1 Perception of movement from visual cues

The term "optical flow" was formerly introduced by Gibson (Gibson, 1950) as a temporal change in the structure of the optic array, or "the set of light rays that interact with objects in the environment in front of an observer". During locomotion, many visual stimuli reach the eye, and the optical structure undergoes continuous perspective changes. Eventually Gibson defined the phenomenon as optical flow (Gibson et al., 1966). Associated to the term of optical flow, is also the term of retinal flow, which refers to the change in retinal image, which is influenced by eye movements. Both optical flow and retinal flow are represented typically as instantaneous two-dimensional velocity fields in which each vectors corresponds to the optical velocity of an environmental element (Warren and Hannon, 1990). Considering the apparent objects movement while moving ahead (driving ahead) and without any eye movements, the speed of the objects is perceived as the distance between two consecutive positions of the object in each time lapse. For this reason, each object can be characterized by a vector with a direction and an intensity (speed).

Figure 3.44 shows the flow for a car driving across a bridge that has girders to the left and right and above. The arrows and the blur in the photograph indicate the flow.

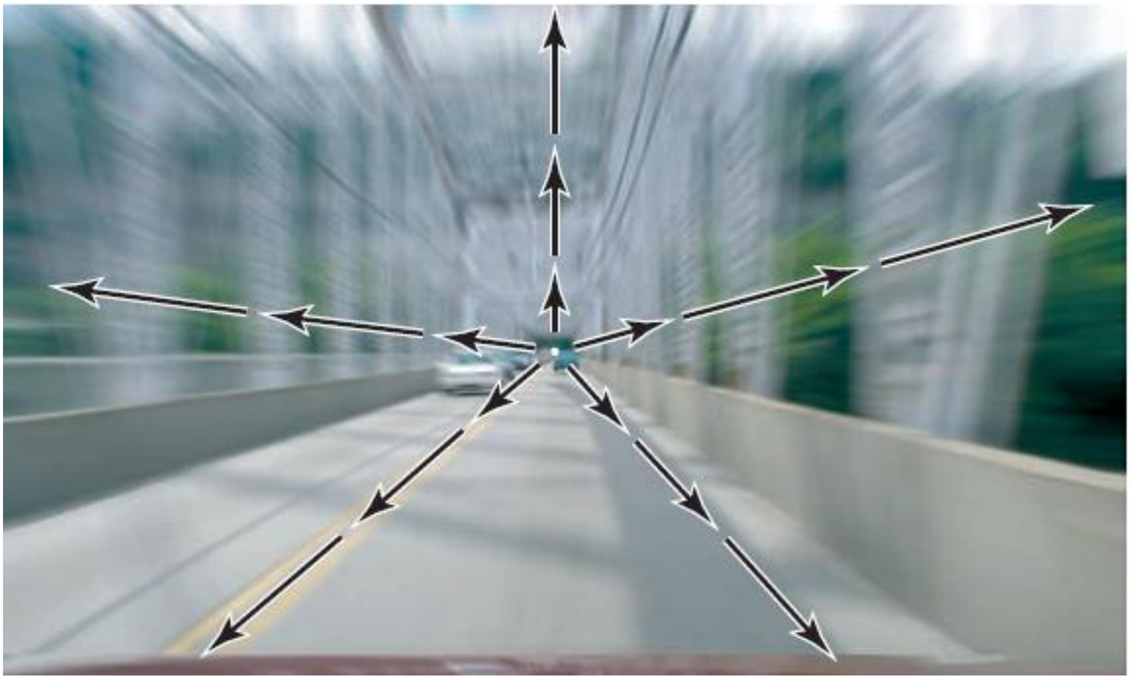

Figure 3.44 - The flow of the environment as seen through the front window of a car speeding across a bridge toward the destination indicated by the white dot (heading) (Goldstein, 2010)

Two main characteristics of the optic flow can must be underlined: the flow is more rapid in the peripheral field of view, and thus objects closer to the observer are faster; and there is no flow at the destination toward which the observer is moving (heading). The only way to perceive a motion toward a target object, if lateral objects are removed from the field of view, is by comparing the size of the target object (if present) in different time interval. However, changing dimensions of far objects are hardly recognized by the eye (this is also the reason why it is particularly difficult for drivers to identify the distance of the preceding car). The different speed of the flow is called the gradient of flow. According to Gibson, the gradient of flow provides information about the observer's speed (Gibson et al., 1966).

From these observations, it is possible to understand the high relevance of the peripheral field of view configuration. Objects in the peripheral field of view are the most "speed-sensitive", that is the sensation of speed can be only drafted by the movements of objects in the lateral field of view (Caramenti et al., 2019). A scenario capable of providing a good amount of visual information is therefore a fundamental element for correct driving.

The retinal flow, which is linked to eye movements, creates an irregular apparent optical flow, because to the original vector, a vector related to the eye rotating movement must be added. Despite the studying of those contributions are very interesting and mathematically computable, several studies have shown how humans are able to recover the heading despite the presence of eye movements (Royden et al., 1992) (Crowell et al., 1998) (Van den Berg, 1996) (Warren and Hannon, 1990). From these experiences it can be assumed that the visual system is equipped with mechanisms that allow the brain to separate the rotation component from the flow field. Thus, the optical flow (flow not influenced by the retinal flow) can be considered the main contributor to the flow perception.

Finally, speed perception by sensations from the peripheral field of view, not only leads driver to be more aware of their speed, but it can also influence the driver speed itself. A large amount of information in the visual periphery may lead to overestimate speed (and thus possibly resulting in speed reduction) (Brandt et al., 1975) (Dichgans and Brandt, 1978) (Salvatore, 1968) and also reduce speed variance (Domenichini et al., 2017). Moreover, in the literature review conducted by Martens et al. it is stated that "a study from Yamanaka and Kobayashi shows that people consider speeds exceeding 2 rad/s in the visual periphery (at about 30 degrees left and right of the fovea) to be very disturbing. Road users usually choose their speed and position on the road in such a way that the angular speed of visual objects in the visual periphery does not exceed this value of 2 rad/s (Horst, Van der and Riemersma, 1984) (Blaauw and Van der Horst, 1982). These results seem to suggest that increasing the density of information in the visual periphery can help decrease driving speed. The lay-out of the environment should be designed in such a way that exceeding the speed limit leads to exceeding this value of 2 rad/s." (Martens et al., 1997). Additional studies have been also conducted by Pretto and Chatziastros which demonstrate the influence on speed of optical flow and contrast in the scene while driving (Pretto and Chatziastros, 2006).

3.5.2.2 Optical illusions

Optical illusions are mainly related to punctual expectations (3.2). Optical illusions occur when the perception of the reality is not the reality. Optical illusions are directly related to Human Factors.

A group of Japanese research made an interesting collection of road optical illusions cases (Computational Illusion Team et al., 2013). They said that "an optical illusion is an illusionary phenomenon where what we see differs from what exists in reality. In the sense that anyone can fall prey to them, optical illusions are universal. By causing errors in judgment, optical illusions can cause accidents. This is particularly true in the case of a moving vehicle. What the driver sees from the perspective of the driver's seat is constantly moving. This means the driver must make instant judgments without enough time to really examine what he is seeing. For this reason, the driver is particularly susceptible to optical illusions. From this, it can be deduced that a close relation exists between optical illusions and traffic accidents. While many accidents are blamed on driver carelessness, it is possible that in a significant number of such cases, driver carelessness has been induced by some form of optical illusion. Considering the seriousness of this possibility, there is an urgent need to identify the relation between optical illusions and traffic accidents and to develop guidelines for effectively reducing or eliminating such optical illusions." (Computational Illusion Team et al., 2013). Thus, an optical illusion is something that will generate wrong expectations to the driver about the road configuration and are related to the local configuration of the road at a specific location. PEXs derive also from optical illusion. Some major road optical illusions are summarized below (Computational Illusion Team et al., 2013) (PIARC, 2016) (Campbell et al., 2012):

- **Optical illusion related to sloping road**: when driving through a series of slopes, the perception of the second slope is influenced by the first slope. The main problem may occur when a descending slope is perceived as a not-descending slope. This may influence the choice of speed.
- **Optical illusion related to tunnel exit**: "from the perspective of a driver, nearby scenes (such as the walls of a tunnel) flash by at high speed. Because the eye adjusts to this speed, and because more distant scenes appear to be moving more slowly after exiting the tunnel, the driver underestimates his own speed" (Computational Illusion Team et al., 2013).
- **Optical illusion of curvature**: curvature can be misjudged if the curve is on a sag or on a crest. Moreover, perception of curvature is also influenced by the outer framing of the curve.
- **Optical illusion related to perspective**: a typical example is due to a double sharp curve of opposite directions with an obstructing object (such as safety barrier) that prevent the markings view. In such a case an oncoming vehicle can be perceived as travelling in the same lane as the driver. The same may occur in a curved crest, as depicted in Figure 3.45.

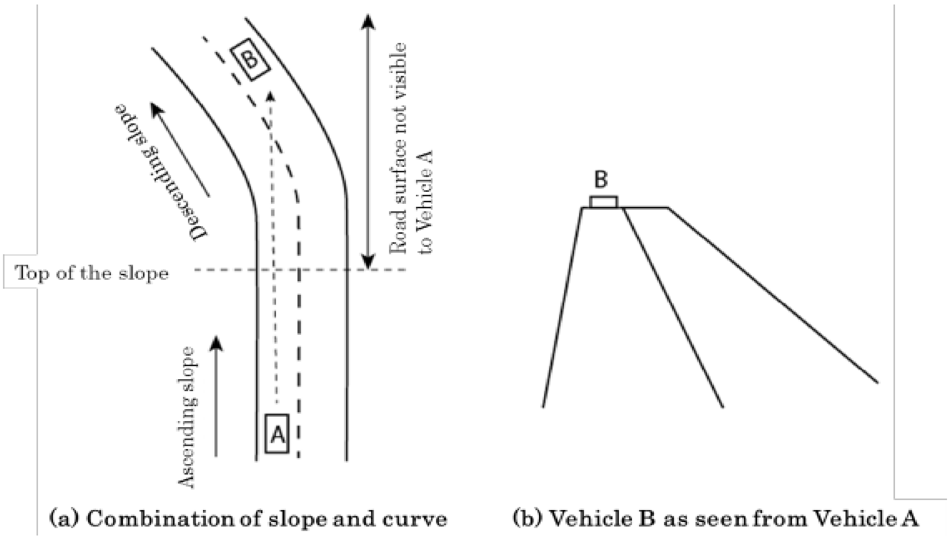

Figure 3.45 – Wrong perception of vehicle position after the crest. The example is from Japan (Computational Illusion Team et al., 2013) *and thus considers the left-driving condition*

- **Optical illusion of distance (and dimension)**: they are greatly due to non-parallel lateral guidance orientation lines (converging or diverging lines), but also to a change in the size of elements composing the lateral guidance orientation line (e.g., a line of tree of decreasing height creates the illusion that the line is longer than the reality). An example from architecture is depicted in the three images of Figure 3.46.

Figure 3.46 – Example of distance and dimensions optical illusion from the Borromini Gallery in Rome. The columns and the geometrical reference of the pavement seem to be of the same dimension, but they are not. This creates the perception of a long tunnel and a big sculpture in the end[9]

- **Optical illusion by signs at night**: at night, far vertical signs are always visible prior to the carriageway because of their reflective characteristics. The configuration of the signs may influence the perception of the road and the driver may be provided with false expectation about the road development.

3.5.3 Attention

Attention can be defined as the human instrument to optimize the use of available resources. Under standard circumstances, attention prevents the overload. Alertness is the state of active attention and can be considered the measure of the degree of possible attention. The main difference between alertness and attention is that alertness can be considered as a general mental condition/state, while attention is generally directed to something. Attention is the focus of automatic and mainly cognitive process to a specific target because processing all the information coming from the environment is not possible and thus some information must be selected as more useful. The crucial point is then what information is considered as more useful. The answer in undoubtedly linked to the goal, and to which is expected will help to reach the goal. Thus, again, expectations will influence attention. This paragraph will present the main characteristics of attention, highlighting the influence of expectation in directing driver attention, and how important is to consider objects capacity of catching drivers' attention.

[9] Images are taken from https://www.edilportale.com/news/2019/03/architettura/architetture-dell-illusione.-la-falsa-prospettiva-del-borromini-a-palazzo-spada_69109_3.html, https://www.youtube.com/watch?v=K6nC1eveo2c, and http://diceche.blogspot.com/2011/10/dice-che-palazzo-spada-le-prospettive.html.

Guided attention and caught attention

The term "guided attention" and "caught attention" have been choses in this thesis as more representative of their significance, which is strictly like to and derive from those defined by Cole and Hughes (Cole and Hughes, 2016) and Trick et al. (Trick et al., 2007). Cole and Hughes identified two tasks: attention conspicuity task and the search conspicuity task. The latter is the task of searching for something that have a chance to be present (e.g., a pedestrian close to a perceived pedestrian crossing). The former is the automatic noticing of an object without any active search for it. In this case "drivers don't search, they just notice" (Cole and Hughes, 1988). Guided attention is thus the attention derived from the search conspicuity task. It is an "oriented" attention; thus, it is "guided". This type of attention can be guided by different level of consciousness or also by unconscious decision. It is not always voluntary. To one extreme, a driver looking for an indication sign or for a parking place uses totally conscious guided attention. This kind of attention mode has been also considered by Trick et al. (Trick et al., 2007), who define it as "deliberate". On the other hand, a guided attention that is totally involuntary is when a driver look at the road margins while approaching a pedestrian crossing, or direct attention to the curb tangent point while approaching a curve (Land and Lee, 1994) (Land, 2006). This attention mode derives from skills and experience but is somehow related to a specific configuration of the approaching environment (e.g., presence of pedestrian crossing and presence of curve). So, also this type of attention mode, defined by Trick et al. (Trick et al., 2007) as "habit" is a guided attention.

Caught attention is divided into two type of attentions too, which reflect the "reflexive" and "exploration" concepts from Trick et al. (Trick et al., 2007). Exploration occurs while driver is moving the gaze around along the road environment without any specific target. This type of attention is the most common while driving. Objects can catch the attention of the driver based mainly on their physical characteristics, then on their usefulness for the driving task. If the object is judged as relevant for the driving the driver's attention will be caught to that object. However, once seen, if the object is judged as not relevant, it may be "discarded", that is the gaze of the driver will hardly be attracted again by it. This type of objects are defining in this thesis as fixation objects, following the definition from PIARC (PIARC, 2019a). Fixation objects must be considered with attention because if they are considered relevant by drivers, they will spend some seconds looking at them (Costa et al., 2019), and so diverging the attention from the other part of the road.

Reflexive mode occurs when attention seems automatically drawn to an object in the visual field. Such objects catch the attention of the driver even if they are not relevant for the driving task. This type of objects are defining in this thesis as eye-catching objects (or eye-catchers), following the definition from PIARC (PIARC, 2019a). Flashing objects has a high chance to be eye-catchers. Commercial Electronic Variable Message Sign (CEVMs) can also be eye-catchers (and also a source of increasing demand, and thus workload) (Molino et al., 2009). However, eye-catching objects can be as such also because of their position, as the single tree in central image of Figure 4.1, or the empty light space in the right image of the same figure.

Combination of colors, size, and positions is determinant to promote a simple object to be eye-catcher. Eye-catchers may have a high influence in directing driver attention as also underlined by Dewar and Olson (Dewar and Olson, 2001). Drivers hardly can ignore those sources of stimuli. Generally, ignoring these stimuli is possible only when other high demanding task are in progress.

Thus, caught attention considers when drivers are not directing their attention, but their attention is captured from outside (exogenous concept).

Figure 3.47 – Examples of eye-catching objects. The picture in the middle shows the original image of the road. The picture in the left has been modified by removing the tree close to the road. The picture on the right has been modified adding an empty space in the forest and removing the tree. Left and middle pictures from Birth (Birth, 2009)*, right pictures modified from the left one*

Table 3.1 shows the four modes of attention defined by Trick et al. (Trick et al., 2007) and presented also by Green (Green, 2017). The deliberation and habit mode belong to the guided attention, while exploration and reflexive belong to the caught attention.

Table 3.1 – The four level of attention, modified from Trick et al. (Trick et al., 2007)

Attention type	Attention mode	Level of consciousness
Guided attention (endogenous)	Deliberation	Controlled
	Habit (skills and experience)	Automatic
Caught attention (exogenous)	Exploration	Controlled
	Reflexive	Automatic

The different modes cited, highlight that there can be some objects that easily attract the attention of the driver. This likely occur in the caught attention, but if the objects capacity of attracting the attention of the driver is particularly strong, this may occur also in the guided attention mode.

One of the main properties of objects to attract driver attention is to be conspicuous. NCHRP Report 600 defines conspicuity as "how easy it is to see and locate a visual target" (Campbell et al., 2012). A conspicuous object has higher change to be identified and can catch the attention of the driver even if not in his line of sight (from the viewer to the focal point). According to Green (Green, 2017) some of the main characteristics that increase conspicuousness are: colors (some color, such as yellow in daylight, has higher conspicuity), flicker and motion (objects that change in time are more conspicuous) (Vignali et al., 2019), symmetry (symmetrical shapes are better at attracting attention in visual search and at directing eye fixation), human shapes (the human form has an innate ability to draw attention), visibility (the higher the achromatic contrast, the size, and the location of the object, the higher its conspicuity), and depth (close objects are more conspicuous).

Despite the differentiations between guided and caught attention, experiences and thus expectations, contribute to all of them. Even in the case of reflexive mode, some objects are eye-catcher because of experience and expectations. In the example of flashing objects, they are eye-catcher because they differ from the homogeneous, not-flashing background. If many flashing lights are filling the scene, probably the eye won't be caught by all of them, because they are expected as "normality". Results consistent with this theory is also provided by Pammer et al. (Pammer et al., 2015). They made a series of three experiments where they introduced some specific stimuli close in the margin of the road. They found that different semantic of the target object leads to different attention to the stimuli. For example, considering the attention on a pedestrian approaching a crossing, it has been found that children have a higher "attention-catching" characteristics than adults. This may be both because of the societal improved attention to children, but also because it is expected that the behavior of a children may be more random than the behavior of an adult.

Familiarity and attention

As reported by Plankermann (Plankermann, 2013), a research from Mourant and Rockwell (Mourant and Rockwell, 1970) investigated the effects of route familiarity on visual scanning patterns of experienced drivers. Familiarity shouldn't be confused with experience. An experienced driver may drive on an unfamiliar road. The results from Mourant and Rockwell shown that driver's visual scanning, and thus the focus of attention, was related to road familiarity. Unfamiliar driver deeply scanned the road, with the gaze moving around to catch all the information from the environment, and mainly focusing on the right side of the road, where information from road signs is available. On the other hand, familiar driver attention is oriented to the end of the road (horizon). Familiarity has also been proven to affect speed (Colonna et al., 2016) (Intini et al., 2018) (Intini et al., 2016). Familiarity is a part of GEXs.

3.5.4 The Gestalt concept and the road environment

An approximate translation of Gestalt is "shapes' psychology or representation". For Gestalt psychology it is not correct to divide the human experience into its elementary components and instead it is necessary to consider the whole as a superordinate phenomenon with respect to the sum of its components: the whole is different from the sum of its parts. Gestalt psychology is the study of how individuals integrate and organize perceptual information into meaningful wholes.

Moreover, what we are and feel, our own behavior, is the result of a complex organization that also guides our thought processes. As expressed by Forbes "The eyes are used to gather an abundance of information about the world that surrounds us. However, the images collected by the eyes are simply a vast collection of colors, shapes, and patterns until the information is interpreted by the brain. In other words, visual information by itself is uninformative. It is only after this information is processed by the brain into visual precepts and coherent images that visual information is meaningful to the observer." (Forbes, 2020). That information come all together, and thus the brain must organize them into known significances. To better explain this concept, it can be useful to describe some of the main principles of Gestalt, which explain the mechanism of perception.

1. **Similarity.** Similar elements are grouped together (and many times are associated with the same function).
2. **Proximity.** Closer elements are grouped together.
3. **Figure-ground.** The figure-ground principle states that people instinctively perceive elements as either being in the foreground or the background. When an element is select as in the foreground, all other elements are background.
4. **Common region.** When elements are located within the same closed region, we perceive them as being grouped together.
5. **Continuity.** Elements that are arranged on a line or curve are perceived to be more related than elements not on the line or curve
6. **Closure.** Elements that are incomplete, but provide cues about a possible complete shape, are automatically completed. Prägnanz concept is related to this principle. Prägnanz has been defined by Gestalt researchers as the ability of sharpen (increase) the perceived main properties of an object.
7. **Focal point.** Whatever stands out visually will capture and hold the viewer's attention first (eye-catching and fixation objects).
8. **Common fate.** Elements which have the same movements are grouped together.

So far, it is clear that the perception of the world around us can be "modified and guided" by different organization of the same space with the same objects. The same is for the road environment. For this reason, the principles of Gestalt have a high influence in PEXs (punctual expectations). In the close-control loop process, of sense, perceive, and look forward of what to expect from the road, the configuration of the road itself must be clear and provide high quality references and structures which help the driver to correctly understand the road requirements.

With regard to the influence of Gestalt principles in the road design, some interesting studies have been conducted by Durth (Durth, 1972) and Lorenz (Lorenz, 1971). Lorenz analyzed many aspects related to the road perception and influence of the road environment as a whole, on the image of the road perceived by the driver. With his work "Trassierung und Gestaltung von Strassen und Autobahnen", where he analyzed aspects related both to curve, grades, depth perception and the influence of marginal elements, Lorenz was one of the first engineer engaging with Human Factors in design (Lorenz, 1971). Some interesting examples of Lorenz considerations are provided in the following (Figure 3.48, Figure 3.49, Figure 3.50,

Figure 3.51, and Figure 3.52). They anticipate the contents of the next chapter because they are part of the concepts of Human Factors for a correct road design considered by this thesis.

Figure 3.48 shows a study about the influence of clothoid element in the perception of curvature approaching a curve. Six images are shown in the figure. The three images in the top represent a direct connection within the tangent and the curve, with no clothoid. The road sketch was made considering three different distances from the curve: 300 m, 200 m, and 100 m. Three other road sketches have been made at the same distances as the preceding but including the clothoid between the tangent and the curve. The perception of the curve is different.

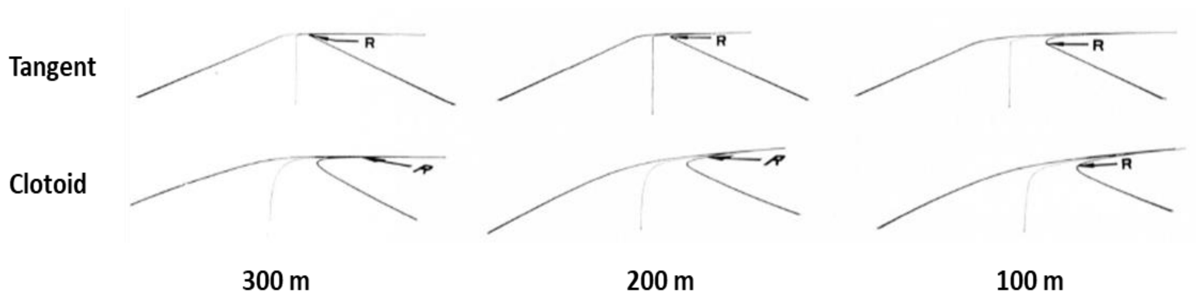

Figure 3.48 – Different perception curve considering the presence of a circle-straight direct connection (top) or to include a clothoid between the two elements (bottom). From Lorenz (Lorenz, 1971)

Figure 3.49, Figure 3.50, Figure 3.51, and Figure 3.52 show instead the influence of road marginal elements on road perception and on expectations, as they provide information about the road (both the travelling one, and the forthcoming). In Figure 3.49 and Figure 3.50, the development of the road behind the crest (a curve) can't be perceived unless the marginal elements are included.

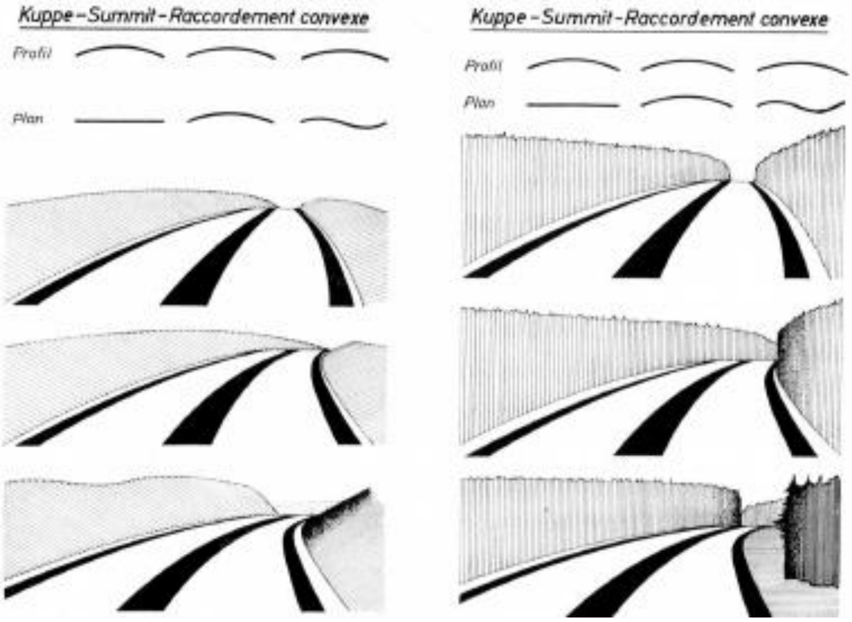

Figure 3.49 – Influence on marginal elements on road perception, curve after a crest, A. From Lorenz (Lorenz, 1971)

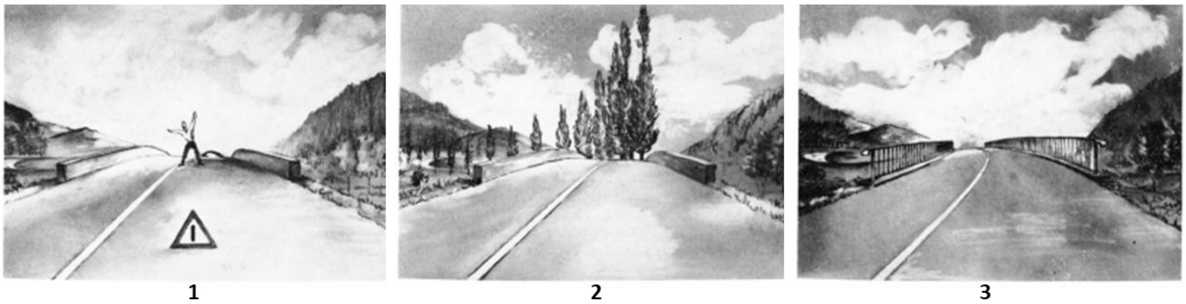

Figure 3.50 – Influence on marginal elements on road perception, curve after a crest, B. From Lorenz (Lorenz, 1971)

Left side picture of Figure 3.51 shows a situation where the road marginal elements provide a negative influence because they suggest that the road is going straight, while the main road goes left. This often occur when the road direction is changed (e.g., bypass) and the course of the old road is still visible. In addition, in this example the marginal elements of the old road are still clearly visible. A possible solution should be to cover the old road development underlying the new one. An example of the possible solution in shown on the right-side picture of Figure 3.51.

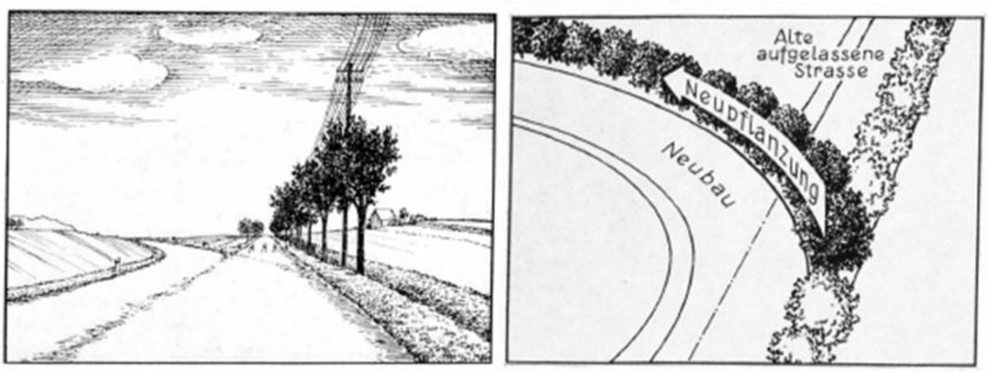

Figure 3.51 – Influence on marginal elements on road perception, misunderstanding of the road main direction. From Lorenz (Lorenz, 1971)

Lastly, Figure 3.52 demonstrates the importance of some type of marginal elements in the perception of slope, which is one of the most influencing optical illusion (Computational Illusion Team et al., 2013).

Figure 3.52 - Influence on marginal elements on road perception, misunderstanding of the slope. From Lorenz (Lorenz, 1971)

The composition of the road scene, and thus the choice of the type of elements to use and their position, may influence also the perception of some critical locations, such as pedestrian crossings, as demonstrated in a recent study by Bichicchi et al. (Bichicchi et al., 2019). Additional interesting examples of the application of the Gestalt concepts to road design are provided by Forbes (Forbes, 2020). These are only some examples that help to understand how managing road perception is crucial to manage road safety. In this context Human Factors are the key to understand how to manage road perception. These criteria are considered in PIARC approach to Human Factors (PIARC, 2016), as discussed in section 3.6.

3.6 PIARC approach to Human Factors

Since the last years of the twentieth century, it has been clear that understanding Human Factors in driving is crucial in understanding road accidents causes. Since then, a lot of research has been carried out on this topic, ranging on different aspects, all of which have as their main prerogative the perception of the road by humans and their consequent driving behavior. To cite few of those researches, there are studies that have focused on bends' curvature perception (Shinar et al., 1980) (Durth et al., 1988) (Zakowska, 1999) (Perco, 2006); on road markings (Babić et al., 2020) and their influence on speed and lateral position (Hussain et al., 2021); on influence of memory and road familiarity (Yanko and Spalek, 2013) (Intini et al., 2018); on influence of road elements on speed and behavior (Ben-Bassat and Shinar, 2011) (Domenichini et al., 2017) (Domenichini et al., 2018); on human workload and decision making (Recarte and Nunes, 2003); on the influence of road configuration and self-explaining roads

(Weller et al., 2008) (Theeuwes and Diks, 1995) (Theeuwes, 2001) (Theeuwes, 2002). These are only few of the research carried out. Some interesting literature reviews of the influence of Human Factors in road safety are provided by Martens et al. (Martens et al., 1997), Plankermann (Plankermann, 2013), and Čičković (Čičković, 2014).

The driver's influence on road safety has been considered since the first car has been driven on a road, but only in the new millennium the topic was dealt considering Human Factors as a whole.

Two relevant collections of Human Factors rules, effects and influences on road safety and design are those proposed by PIARC (PIARC, 2016) and by NCHRP (Campbell et al., 2012). Both these documents provide a strong impulse to the global theorization of Human Factors. The latter presents detailed information on how to manage specific conditions based on Human Factors research (e.g., information searching, speed management, decision sight distance, markings, and signs, navigating a curve, and so on). The report from NCHRP focuses more on practical applications, preferring a numerical approach than a theoretical approach when possible. As a matter of fact, the report provides different sheets dealing with specific aspects. Each sheet is provided with a bar scale rating reporting how much the specific guideline relates on expert judgment or on empirical data. The document is very useful and demonstrates the huge amount of required efforts to put together all the different research carried out in the field of Human Factors, to let those concepts available for all road practitioners. The former collection cited is instead the one from PIARC. PIARC has stressed on the importance of Human Factors in road safety and design since many years. Even the former edition of the Road Safety Manual spoken expressly about Human Factors (PIARC, 2003). From that point on, PIARC produced many documents dealing with this topic (PIARC, 2012b) (PIARC, 2016) (PIARC, 2019b) (PIARC, 2019a) (PIARC, 2019c). The approach from PIARC demonstrates to be more theoretical. However, in the last period many PIARC reports focused on providing demonstration of the effects of Human Factors aspects on road, not by laboratory research, but by presenting some case studies of applied countermeasures (PIARC, 2019b) (PIARC, 2019a) (PIARC, 2019c). Moreover, in 2019 PIARC published a comprehensive evaluation tool to analyze road infrastructures by means of Human Factors. This tool is called Human Factors Evaluation Tool (HFET) and it is the core of the proposed HFE procedure. The tool allows to analyze the triggers of accidents, and it has a proven prediction quality to predict accident spots (Birth and Pflaumbaum, 2006)(Birth et al., 2015). The tool and the way it has been used are presented in 0.

The approach from PIARC took much from traffic psychology and it has been found to be suitable to explains all the concepts presented in the previous paragraphs. Differently from the NHCRP approach, which analyzes separately each road elements (e.g., curves and intersections) discussing the different aspects of that specific element, PIARC approach moves from the global characteristics that influence driving behavior, such as the composition of the field of view, and the driving logic, to the analysis of specific element. Moreover, the organization of the topic into three different rules, fits the expectations-centered theory (see

3.7). Finally, the PIARC approach has been chosen because it has been collected and validated in several international technical committees of PIARC in the time from 2002 up to 2019 from international Human Factors experts.

3.6.1 The three rules of Human Factors from PIARC

PIARC decided to divide all the Human Factors aspects into three main groups, which are called Human Factors rules (PIARC, 2016): the first rule that is the 6 seconds rule, the second rule that is the field of view rule, and the third rule that is the logic rule. All these rules account for different aspects related to Human Factors, nevertheless often road characteristics are relevant to more than one aspect. For this reason, the rules provide general definitions. The rules are briefly presented in the following.

3.6.1.1 First Rule of Human Factors: the 6 seconds' rule

The first rule concern visibility. A potentially critical location (PCL, see 5.1.2) must be first visible to drivers to let they respond and behave correctly. Visibility is first of all the need of a clear line of sight between the observer and the observed, but it is not limited to this. Visibility must account for all those aspects about sensation that has been discusses in 3.5. Before an object is perceived, it must be sensed. An object can be better sense based on its characteristics, such as shape, color, and position. This won't assure that it will be correctly perceive, but without sensation there can't be a correct perception. Therefore, a direct line of sight is often not sufficient to assure the visibility of a specific PCL. Moreover, as illustrates in 3.1.4, driving is a close-control loop. The driver scans continuously the road and adapt their expectations to what they perceive (and what they perceive is influenced by their expectations). For this reason, more time the same information is provided to the driver, more possible is that this information is correctly perceived (the continuous perception gradually changes the expectation about that PCL). Drivers need time to correctly perceive a PCL. For this reason, considering a simple Stopping Sight Distance (SSD) to design a road, for example approaching an intersection, it is not sufficient. Instead, a Decision Sight Distance (DSD) must be considered, that is extremely higher than the SSD. This translates in the PIARC rule of 6 seconds, which means that it can be considered that to correctly perceive the PCL, it must be continuously visible 6 seconds ahead of the breaking section. More precisely, PIARC propose to divide the space preceding the PCL into three parts: the maneuver section (braking section), where the physical maneuver occurs, the response section (2-3 seconds), where the driver understand the PCL they are facing, decide how to deal with it, and starts the physical maneuver, and the anticipation section (2-3 seconds), where the driver scan the environment, adjusting their expectations and trying to identifying the PCL as it really is. In addition, for some specific conditions, an advanced warning section (3-4 seconds) should also be included, to prepare driver with signing and warnings. Figure 3.53 shows a sketch of the sections.

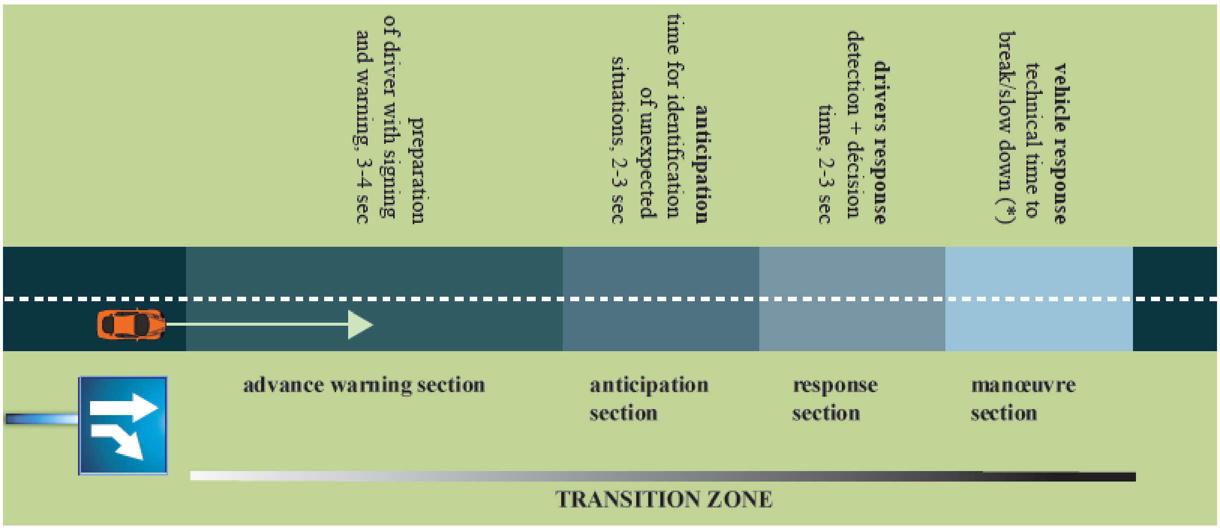

Figure 3.53 – Sketch of the 6 seconds rule, from PIARC (PIARC, 2012b)

The following figures shows some examples of bad visibility of some PCLs. Figure 3.54 shows three different locations that are not clear to the driver, even if no obstacle obstructs their visibility. The first one is an intersection where the main road goes straight forward, and the minor road on the left, seems to be the main road. The central picture is taken 125 m ahead an intersection, but the intersection is not perceivable, even if it is in front of the driver. The last picture shows a pedestrian crossing 50 m ahead and a bus stop 70 m ahead in a rural environment. These two elements are unexpected for such environment, thus it is harder for the driver to understand them and, furthermore, they are not clearly visible because of the geometrical and vertical alignment, for the light, the position of the two elements and the general composition of the visual framework.

Figure 3.54 – Examples of invisible or not clear PCLs: left - intersection where the main road goes straight (Birth, 2004), *center – intersection not visible 125 m ahead* (Birth, 2004), *right – pedestrian crossing not visible 50 m ahead (photo by Andrea Paliotto)*

Figure 3.55 shows instead a sequence of consecutive pictures taken starting about 70 ahead of a driveway. The following are taken with a step of about 14 m (1 second with a speed around 50 km/h).

Figure 3.55 – Sequence of photos approaching an "invisible" intersection, starting 70 m ahead of the intersection. The last photo is about 25 m before the intersection (photo by Andrea Paliotto)

The sequence clearly shows the moment of a car entering the main road from a driveway on the right. The car is visible on the third picture only if you know where to search, otherwise the driver will find a car crossing the road in front of him with about 35-25 m available to brake. Furthermore, a bus stop is present 10 meters ahead of the driveways and a pedestrian crossing is present 5 meter after the driveway. The problem is not only the limited visibility, but also that looking 70 m ahead of the driveway, the road shows no clues or instruction that can help the driver to understand what is placed behind the curve. He can't foresee that some risky location that require a change in his behavior is hiding there, then it will be surprised. It must be noticed that even if an SSD is present at a specific location, a sudden breaking action can always be a risky maneuver for the driver and the other vehicles around.

Finally, it must be noted that the perception is influenced by what it is sensed, but also by the PEX and GEX. Thus, the provided examples contain Human Factors deficiencies under different aspects, as generally occurs in dangerous situations.

3.6.1.2 Second Rule of Human Factors: the field of view rule

The second rule deals with the composition of the field view. Many aspects of the Gestalt approach to perception are considered in this rule. The road must assure a correct perception of itself and of its environment. Optical illusions must be avoided, so as disturbing elements (e.g., eye-catcher with negative influence), marginal elements must be clear and help to contrast road monotony, and road elements composition must help in the control task (speed and position management). This are some of the aspects addressing by the second rule. The second rule concerns all those site-related aspect that can influence the perception of the road and of a PCL and that derives from the current image of the road (last 6-10 seconds), i.e., what locally influence the perception of the current situation and influence driver behavior.

Figure 3.56 and Figure 3.57 provide two clear examples of the possible influence of the field of view. The first image of Figure 3.56 shows a road that it is not symmetrically centered in the space between the trees. Based on its previous experience on other road, where the space is generally symmetrically organized, a driver could take the two lines of tree as a reference, causing a subconscious shift in the lane, moving itself in the position that he should have had if the road was centered within the trees. Furthermore, the monotony and the far long view to the horizon, induce drivers to speed up, searching for additional stimuli.

Figure 3.56 –Optical orientation to the horizon: distant focus and monotony decreased workload and cause subconscious acceleration. Furthermore, the road is not in the center of the space between the trees, and this can cause an unconscious shifting in the lane, from Birth (Birth, 2009)

Figure 3.57 shows three images of the same curve. The first is an image from satellite, while the second and the third are sequential photos approaching the curve from North-East. The curve has been recently modified to increase its radius but the organization of the new field of view is extremely poor. The mayor field of view negative factors are the following.

Approaching the curve, the line of olive trees on the left interrupts, leaving an empty space in the outer margin of the curve, making its outer frame less distinguishable. The only reference, not clearly visible from distance, are the safety barrier and the chevrons, which unfortunately are not parallel to the road axis, giving the impression that a larger radius is present. There is no visibility of the inner curve and thus the only reference for the driver to estimate the curvature is the outside safety barrier and the outside lane markings, which are not parallel.

Figure 3.57 – Example of a critical curve, left - north oriented satellite view, right - photo approaching the curve from East. The curve is visible from distance but not understandable. The field of view shows many problems: the barrier line follows a different trajectory from the road axis, white markings along the shoulder create bad focus point and modify the perception of the road curvature (Andrea Paliotto, photos from Google Maps)

Within the curve, the white bars on the outside shoulder create some ambiguous shapes that attract the attention of the driver and modify the picture of the road.

All these features can cause a wrong reading of the curve and a wrong driving plan approaching the curve.

3.6.1.3 *Third Rule of Human Factors: the logic rule*

A road must have a logic sequence. Unconsciously the drivers adapt their driving to the road that they are experiencing, but this is done in some dozens of seconds or also some minutes (Green, 2017). The experience that the driver has about the road they have travelled builds their expectation about the future development of the road. If those expectation are violated, the drivers generally required time to adapt to a new behavior. If the passage from a required behavior (e.g., driving in rural environment) to another required behavior (e.g., driving in an urban environment) is sudden and doesn't give the driver enough time to adapt, the driver could proceed with the old behavior that is unsafe under the new conditions, or even make some sudden risky maneuvers. Moreover, drivers' expectations about road development and road users' behavior are related to the road category the travelled road is identified with. Road categorization, as discussed in the self-explaining roads theory, has an higher influence of expectations and behavior (Theeuwes, 2017). Moreover, consistency of the road geometrical elements also belongs to the third rule, so as the aspects related to the navigation level concern to the third rule, such for example managing the information provided by road signs, which have a relevant influence in workload.

A couple of examples are showed in Figure 3.58 and Figure 3.59. In the first figure, two couple of sketches are depicted, which represent a town entrance. The first couple shows a town entrance that it is only signalized by the vertical sign, with no change in the road environment and alignment. The second couple shows instead a town entrance where other countermeasures have been taken to improve the perception of the change of the road function. In the latter case the driver will understand better that a change is happening and will comply with the required behavior of the new road function.

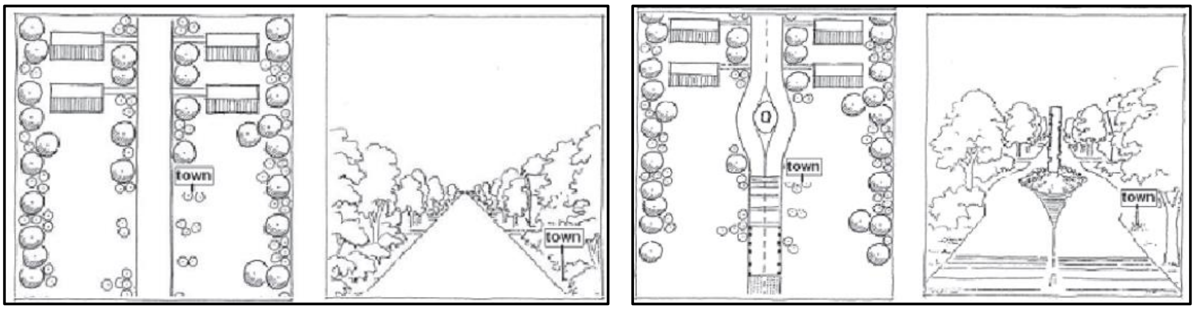

Figure 3.58 – Examples of change in road function with (right) and without (left) change in design and optical characteristics (Birth et al., 2004)

In Figure 3.59 two main problems are clearly showed: bad positioning of vertical signs and overload of information. These two conditions require the driver to study with attention all the signs, giving less attention to the road and causing also a possible missing of information or misleading information.

Figure 3.59 – Bad positioning and overload of information provided by vertical signs

3.7 Expectations-based theory and the three rules of Human Factors

As briefly explained in 3.6.1, the three rules of Human Factors identify three main topics.

- *First Rule*: the time available to the driver to correctly understand the situation (mainly the possibilities to sense the situation).
- *Second Rule*: the configuration of the local road environment, that is the configuration of the elements the driver is facing in a specific location, which generate PEXs.
- *Third Rule*: the expectations derived from the life experience and last kms experience, that is to mentally classify the road under a specific category with specific expected characteristics, that is GEX.

Expectations, both PEXs and GEXs are thus perfectly represented respectively by the second rule principles and the third rule principles. Evaluating the characteristics of a road stretch by analyzing the aspects related to the second and third rules, means to evaluate the possible expectations which can be provided by the road itself. The possibility to evaluate these expectations (PEXs and GEXs) helps to clarify how much the risk is perceived and thus which can be the risk assumed, net of other factors that are not related to the road (see 3.1.5, 3.1.6, and Figure 3.26). Moreover, the first rule provides the instrument to analyze the aspects related to the "number of possibilities provided to the driver to adjust their expectations to reality". The higher the difference of PEXs and GEXs from reality, the higher the risk[10]; the higher the time provided by the road to gradually change expectations, the lower the risk, because expectations provided by GEXs and PEXs, gradually shift to the correct expectations. Figure 3.60 provides a graphical representation of the process of "adapting expectations" and the influence both of bad expectations (i.e., they differ from reality in a way that leads to risky behaviour) and time, approaching a PCL (located at point F). Looking at the graph, it can be assumed that in a first stage (from time = 0 to time A), expectations fit the real risk. In this case the driver can be considered as driving under safe conditions, assuming that other external factors are constant and equal to 0[11]. Then the road changes (e.g., approaching a PCL), but the driver's expectations do not, and thus depart from the reality (from time A to time B). From time B to time C, the situation stabilizes, because the difference between reality and expectations stops to increase. In this section a maximum difference is reached. Moving from the maximum towards the PCL (time F) some relevant and right information are perceived, and expectations start to adapt to reality (because of the close-control loop). The information that helps the driver to start the adaptation process can come from the road itself (visibility of PCL) or sometimes by road signs and markings. For this reason, if an advanced warning section is present (first rule of Human Factors), it will be located here. Time C can be considered as the first point where the PCL is visible. From time C to time D, the driver has already start to correctly adapt their expectations, because more information is provided by the road (the driver is still approaching the PCL). In this period the driver tries to understand what they are facing, thus this period can be identified as the anticipation section. From time D to time E, the driver should have cleared the nature of the PCL they are facing, and they must decide the correct maneuver to hold. This section can be identified as the response section. In this section the information of the road should be clearer and thus the expectations adapt more rapidly (higher slope of the curve). However, it can be possible that expectations are still too far from the reality (as in Figure 3.60). The last part, between time E and time F, is the section immediately before the PCL. Here expectations rapidly adapt to fit the reality. Once

[10] Except in those cases where all the PCL are perceived as riskier than reality.

[11] This strong assumption doesn't fit the reality (see Figure 3.26) but it is necessary to consider the influence on the perceived risk of road factors alone.

arriving in the PCL, the PCL will generally be clear (time F). This last section can be identified as the maneuver section. The higher the difference in point E between the expectations and the reality, the sudden and risky (and possible wrong) the maneuver.

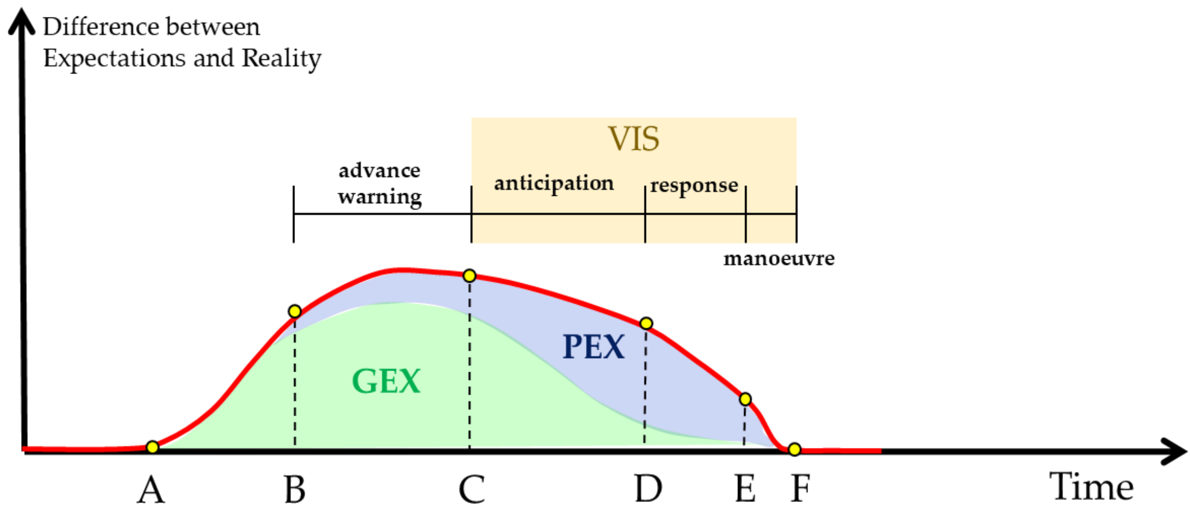

Figure 3.60 – Scheme of the process of expectations adaptation

The graph also provides an ideal scheme of the different contributions of GEXs and PEXs. The closer to the PCL, the higher the influence of PEXs, while the farer from the PCL, the higher the influence of GEXs. That is because GEXs are related to the general characteristics of the road, while the PEXs are related to the local characteristics of the road. Moreover, the term "VIS" is also introduced, which represent the visibility of the PCL.

Figure 3.60 represents an ideal trend of expectations, however the shape of the curve can be very different based both on PEXs, GEXs, and VIS. The formers contribute to the definition of the maximum difference and reduce the capacity of the driver to adapt their expectations to reality (slope of the curve), while the latter provides more possibilities to the driver to adapt and reduces the risk of sudden maneuver, which are always risky. To provide some examples, four different conditions are presented in Figure 3.61. All the conditions are considered high visibility conditions that don't require the advanced warning section. In the graph only the maneuver, response, and anticipation sections are present. All the conditions are considered from time C, that this the point where it can be assumed the PCL is visible. From that point on, PEXs increase rapidly, while GEXs decrease rapidly. For this example, it can be considered that the behavior of the driver is represented by the speed and that it follows the trend of the difference between expectations and reality: the greater the difference, the higher the speed. This simplification may help to understand the four different conditions. Consequently, the higher the slope of a segment, the higher the deceleration, the riskier the maneuver.

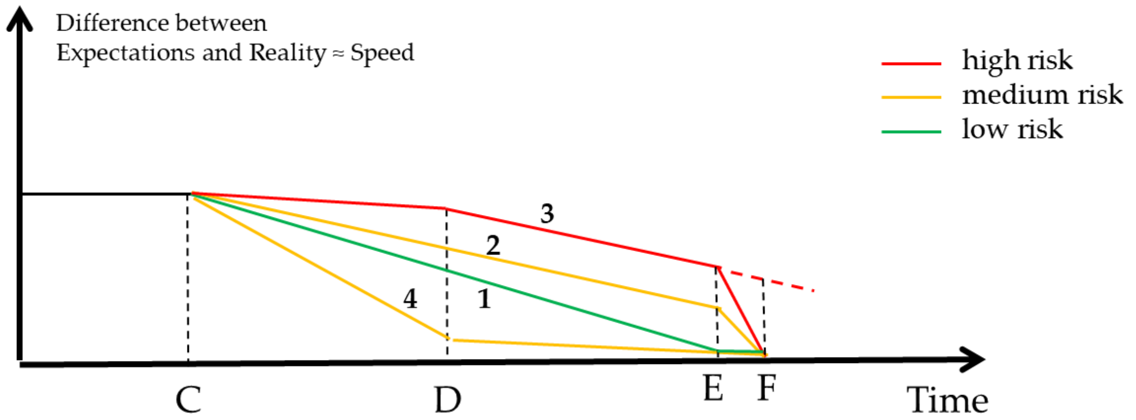

Figure 3.61 – Examples of different conditions for expectations adaptation. To exemplify the influence of expectations adaptation on driver behavior, the speed has been considered. High visibility in considered

The first curve (1) represents a safe condition. The driver sees the oncoming PCL and recognize it to a great extent. In this case the contribution of PEXs is low and expectations gradually change to fit the reality. The driver clearly recognizes the PCL, so no hard maneuver is required. The safe speed is reached before the PCL. Curve number 2 represents a condition where the PCL is less easily recognizable. In this case, PEXs have higher negative influence. The driver changes their expectations, but not enough fast because even if visible, the PCL is not clear, and the environment configuration is not clear too. The PCL is completely comprehended only once the driver is very close. This may cause a harder braking. However, in this condition, the behavior of the driver is very close to a safe behavior. Even if a sudden braking is required, the difference between the actual speed and the safe speed is not too much. The third condition is the riskiest one. In this condition the driver is not able to correctly perceive the PCL because of wrong influences from their expectations. The change in expectations is too slow because the road and its environment are ambiguous and misleading. The driver realizes too late (time E) the real configuration of the PCL and must make a risky maneuver to adapt their speed. It can also be possible that the driver doesn't recognize the PCL at all, judging their behavior as adequate to the road characteristics, and thus travelling through the PCL with a too high speed, not consistent with the road characteristics (dashed line).

The fourth condition shows instead a PCL that suddenly appear to the driver and that is very clear and unexpected considering GEX (the difference between expectations and reality at point C is mainly due to GEXs). The driver is surprised and may make a fast change in its behavior to adapt to the oncoming PCL. The driver will have enough time to make the maneuver in safer condition, but the surprise is so, that they choose to immediately change their behavior. This maneuver is generally not risky, however under some circumstances, a sudden great reduction in speed may lead to some risks.

These four simplified examples are very interesting because they show that, even if GEXs and PEXs both contribute to the difference between expectations and reality, a higher influence in GEX will more often lead to condition 4, while a higher influence in PEXs will often lead to conditions 2 and 3.

In both four conditions it has been considered that the maneuver, response, and anticipation sections are all present. If that is not the case, the risk increases because the driver will likely make a sudden and greater braking, or not adapt at all to a safe behavior. Considering the graph in Figure 3.61, but assuming that the visibility is reduced, the new trend of the conditions 2, 3, and 4 is reported in the graph in Figure 3.62. Curve 1 is not present because there are no low-risk conditions.

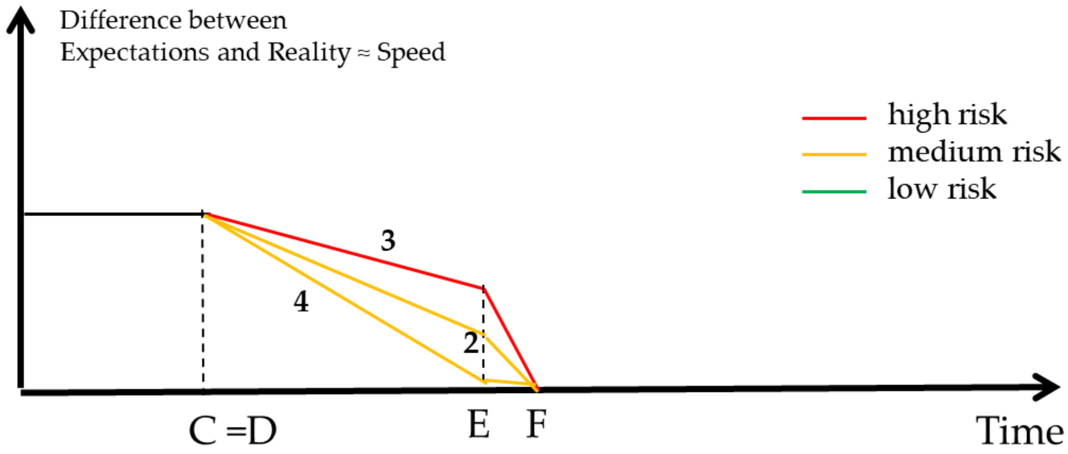

Figure 3.62 - Examples of different conditions for expectations adaptation. To exemplify the influence of expectations adaptation on driver behavior, the speed has been considered. Reduced visibility in considered

In the graph the anticipation section is not present (time C = time D) and thus the time available to the driver to adapt their expectations and their behavior is reduced. If the influence of PEX is not too much (or the difference between expectations and reality at time C is not too much), the driver will make a maneuver that can be considered as at medium risk (curves 2 and 4). If the road is not clear, thus the influence of PEXs is relevant, the driver will likely not understand the PCL and holds a wrong behavior, increasing the risk (curve 3).

Not all the possible conditions have been considered in the graphs, and it should be clear that as the maximum difference between expectations and reality decrease, the slope of each segment will decrease reducing the risk.

From these examples it can be drafted that all the three aspects (VIS, PEXs, and GEXs) influence the risk. Therefore, these three aspects have been chosen as the base concepts to deal with road safety analysis. They will be the core of the HFE procedure. An innovative method to quantify VIS, PEXs, and GEXs has been developed in this research work as discussed in 5.3.

Moreover, the factors influencing VIS, PEXs, and GEXs are considered in the PIARC Human Factors rules and thus, the organization of the Human Factors concepts proposed by PIARC provide the basic instruments to judge the risk of a road stretch considering the expectations-based theory. One of these instrument is the Human Factors Evaluation Tool (HFET).

CHAPTER 4 THE HUMAN FACTORS EVALUATION TOOL

Chapter abstract

In this chapter the Human Factor Evaluation Tool from PIARC is presented and discussed. The Human Factors Evaluation Tool is the core of the Human Factors Evaluation procedure because it allows to analyze road segments and provides a validated quantitative value that represents how safe is the analyzed road segment by means of Human Factors aspects. The original version of the Human Factors Evaluation Tool (HFET) from PIARC has been developed for the analysis of single black spots. Therefore, the procedure of the assessment must be adapted for the complex situation to take into account longer road stretches including several challenging locations. Furthermore, to conduct a Network-wide Road Safety Assessment (NWRSA) the content of every single item must be clear for a reliable assessment. In a field-experimental approach were analyzed two case studies (CHAPTER 5). As the main result we identified the weaknesses and the strengths of the tool and the main points of improvement, so that it can be included in a NWRSA. First, we found, that a guideline for the judgement must be developed (APPENDIX 1). Second, we found that a new step by step procedure for the assessment and the calculation of the final Human Factors Score (HFS) must be developed.

The detailed conclusions for improvement in a NWRSA are figured out.

Chapter list of acronyms

CHL	**Challenging Location**
EB	Empirical Bayes
HFE	Human Factors Evaluation
HFES	Human Factors Evaluation Segment
HFET	Human Factors Evaluation Tool
HFS	Human Factors Score
HSM	Highway Safety Manual
NWRSA	Network-wide Road safety Assessment
PCL	Potentially Critical Location
RSI	Road Safety Inspection

4.1 What is the tool and when to use it

In 2019 PIARC published an interesting document named "Road Safety Evaluation Based on Human Factors Method" (PIARC, 2019a), where it proposed an innovative tool to quantify the road risk related to Human Factors aspects. The tool is called Human Factors Evaluation Tool (HFET) and it was formerly developed by a team of German researchers composed by psychologists and engineers (Birth et al., 2017). The strengths of the tool are mainly three:

- it allows to evaluate Human Factors-related road deficiencies;
- it provides a quantification of the risk by means of numerical value and risk level; and
- it is suitable to be applied during standard road safety inspections.

The tool has been presented as an instrument which can help to identify Human Factors-related deficiencies along the road both to make network safety screenings (i.e., NWRSAs), to analyze high-accident concentration sections, and to carry out accident investigations. The three different possible applications and their steps, as presented in the PIARC document (PIARC, 2019a), are summarized in Figure 4.1.

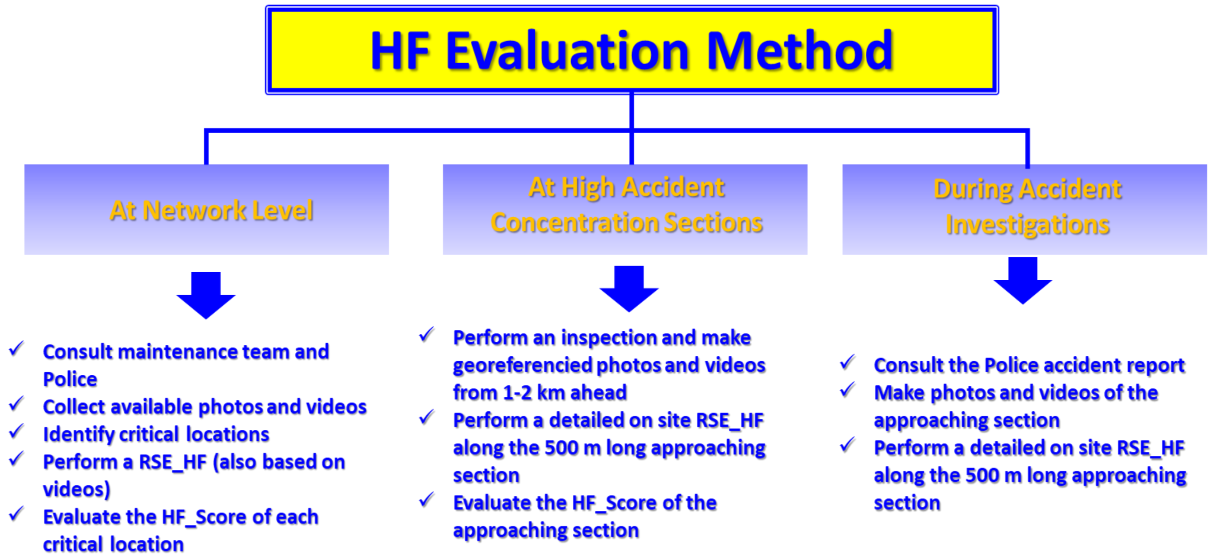

Figure 4.1 – Application fields of the HFET (PIARC, 2019a).

Analyzing the diagram of Figure 4.1 and reading the document in details, it appears that even at network level (i.e., during NWRSA), the role of the HFET it is not to contribute to a general screening of the network, but to contribute to a better definition of the problems that burdened a section already classified as risky (or a single critical location). The section it is not identified using the tool, but it has been prior identified by other means (accident number, wheel tracks beside road's shoulder, grinding marks on the surface of safety barriers, heavy skid marks on the surface of the road, departed elements of cars like mirrors, car lights, bumpers etc., dangerous driving maneuvers or near-by-accidents). Thus, in this case, it cannot be considered as an instrument which can be implemented to carry out a network safety assessment, but as an instrument which can help in a second phase of detailed analysis (e.g. targeted road safety inspections (European Parliament and the Council, 2019)). Therefore, this type of analysis is like the two other ones (high accident concentration section and accident investigation).

Furthermore, to carry out the analysis procedure, the road stretch just before the PCL, and the PCL itself, must be analyzed. For these reasons it can be drafted that the tool was born as an instrument to carry out punctual analysis and thus, in its original form, it is suitable for implementation during targeted road safety inspections. This may discourage its use as network safety assessment tool because it requires the analysis of all the PCLs of a network, which may result in a high time-demanding process. To evaluate the strengths, the weaknesses, and the limits of the application of the HFET to a longer road stretch, different from a single location, the first step of this research was to apply the HFET to two road stretches for a total length of about 23 km. The entire procedure considered to apply the original version of the HFET is discussed in CHAPTER 5. In this chapter, the structure, and contents of the original HFET are discussed, and the amendments proposed to it after testing it on the two roads.

4.2 Tool composition

The tool is composed by three evaluation checklists, one for each Human Factors rule, which allow to obtain a final numerical value representing the risk. Each checklist is divided into different part which are called in this work[12] as:

- investigation topics, which consider the main aspect to investigate;
- subsections, which consider detailed aspects of the road;
- requirements, which are the most specific aspects, and those that must be voted.

Figure 4.2 presents a sample of checklist referred to the first Human Factors rule: the 6 second rule (examples of the other two rules can be found in the PIARC document (PIARC, 2019a)). The checklist is subdivided in two investigation topics: 1st "Moderation of transitional areas" and 2nd "Perception and visibility". The 1st is composed directly by 4 requirements, without any subsections. The 2nd investigation topics in instead composed by 4 subsections and a total of 17 requirements. All the investigation topics, subsections, and requirements are listed in column 1 of Figure 4.2. Column 5 refers to the possible "fulfilment" of the condition (ACTUAL), if any. Column 6 (TARGET) represents the "presence" or the "desired presence" of the Human Factors demand according to the considered road segment. To fulfil the checklists, each requirement should be answered yes (score 1: the condition is present or satisfied) or no (score 0: the condition is not present, is impossible to be analyzed or is not met). The answer is noted in column 5 and 6. Considering the example in Figure 4.2 , the point 2.1b means that the condition is required (target=1) but not satisfied (actual=0), while condition 2.2a is not required or it was impossible to analyze (target=0 and actual=0) (in this case there were no curves).

Once all the requirements have been evaluated and the respective cells fulfilled, the Human Factors Score (HFS) must be calculated. The HFS is calculated summing up the values in the ACTUAL column and in the TARGET column and calculating the ratio between ACTUAL and TARGET, as showed in Eq. 2. The result is thus a percentage.

$$HFS = \frac{\sum_{i=1}^{n} ACTUAL_i}{\sum_{i=1}^{n} TARGET_i} \qquad \text{Eq. 2}$$

[12] Originally, no specific names were provided for the different parts of the tool.

Where:

i = number of the considered condition;

n = total number of conditions;

ACTUAL = score in the "ACTUAL" column;

TARGET = score in the "TARGET" column.

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Notes:	**Road Name**	SR206	**Direction**	North	**Evaluator**	Andrea Paliotto
	Section Name	36_9			**Date**	July 2020
1	**2**	**3**	**4**	**5**	**6**	**7**
4-6 seconds rule						
	v (km/h)	**Lenght (m)**	**Lenght cum. (m)**	**ACTUAL**	**TARGET**	**%**
1. Moderation of transitional area						
- manoeuvre section exists?	90	75	75	1	1	
- response section section exists? (2-3sec)	90	75	150	1	1	
- anticipation section exists? (2-3sec)	90	75	225	0	1	
- advance warning section exists?	90	75	300	0	1	
Transition zone total				**2**	**4**	**50%**
2. Perception and Visibility						
2.1 critical location visible and clearly identifiable						
a. each critical point is obvious and visible (crossings, driveways, road bends, bus/tram stops, ...)				0	1	
b. Visibility is not restricted by plants, buildings, traffic signs, control devices, roadside furniture, …)				0	1	
c. roadside furniture/equipment and traffic control devices are clearly visible (traffic signs and signals, markings, safety barriers)				1	1	
d. day: luminance of surface/traffic signs sufficient				1	1	
e. night: lightning and luminance of surface/traffic signs sufficient, retro-reflection of signs and markings is sufficient				1	1	
2.2 curves are visible						
a. curves are visible (at least 6 sec. ahead to the braking section)				0	0	
b. curve is not on/behind a crest				0	0	
c. shoulder and marking of the outer curve are visible				0	0	
d. visibility on the inner curve is not restricted				0	0	
2.3 intersections — visibility triangle from minor road is not obstructed						
a. priority traffic is visible for at least 6 sec. ahead	-	-	-	0	1	
b. intersection is not on or behind a crest				1	1	
c. intersection is better in a sag then on a crest in a hilly terrain				0	0	
d. intersection is not in or after a curve				1	1	
2.4 intersections — minor road: unmistakable right of way						
a. minor road is narrower than the main road				0	0	
b. surface of the main road is of higher quality than the minor road				0	0	
c. lay-out of main and minor road are not similar				0	0	
d. minor road's surface is clearly distinguishable from the main road's surface (e.g. colour variations or different paving material)				0	0	
Perception and visibility total				**5**	**8**	**63%**
4-6 seconds rule total				7	12	58%

Figure 4.2 – Example of HFET sheet fulfilment.

This calculation is made both for each rule separately and considering the whole rules together (i.e., the "Total HFS"). Considering the whole rules together means to counts all the

"1s" and "0s" of each rule, summing them together following Eq. 2. Even if a HFS for each rule is available after the application of the tool, the Total HFS result must be considered to define the risk of the section related to the analyzed critical location. The results allow to classify the homogeneous segment having a low, medium, or high accident risk, based on the following criteria (PIARC, 2019a):

- **Low risk**: HFS > 60%
- **Medium risk**: HFS > 40% but < 60%
- **High risk**: HFS < 40 %

The possibility of quantifying the risk of Human Factors-related issues, it is an important quality. One of the main limitations of standard RSI is in fact to lack a numerical quantification of the identified risk.

4.3 Outcomes from the test

By its application, the HFET has proven to be a useful instrument to assess the risk related to Human Factors aspects. Nevertheless, some comments can be made based on the first application.

General aspects

1. The tool was developed to analyze single PCLs. If more PCLs are close together and influence each other, the tool offers the possibility to analyze together only locations of few different types. Even in this case, some requirements are shared by more than one PCL, and thus it is difficult to decide which should be considered for evaluation. For example, if the presence of the response section must be evaluated and many PCLs are present, which one must be considered? One solution can be to consider the worst result for each requirement as suggested in the PIARC document (PIARC, 2019a), but the score can be heavily influenced.
2. Score calculation. Score calculation is very simple, and this represents a strength of the tool. Nevertheless, the choice of which critical locations to evaluate, when more than one is present, may lead to wide difference in the result. Above all the major problem can be summarized that a very positive score may shroud other negative aspects by increasing the final score when more PCLs are judged together. A bad intersection analyzed alone will bring to bad results. A bad intersection and a good curve analyzed together will likely bring to better results.
3. Application of the tool to all the PCLs is a very time expending procedure.
4. Sometimes the requirements seem ambiguous, even for a trained inspector. Some sort of guidelines, with some examples, would be necessary to ensure a higher uniformity of the judgements.
5. Risk level thresholds. Generally, the medium risk and the low risk level, both means that accidents are not likely to occur in the analyzed section. Nevertheless, it happens that in

those medium or low risk sections, the section is at high risk for just a single rule (for example the third rule score may be under 40%, but the other two are higher; thus, the Total HFS is higher than 40%, resulting in a medium risk level). High deficiencies in one rule, should be somehow considered, or simply be highlighted. Moreover, sometimes a single judgement may determine if the section is at high risk or medium risk. Thus, rely exactly and only on the Total score may lead to a misleading risk classification.

6. The double voting (ACTUAL and TARGET) may sometimes create confusion. A single evaluation may improve the usability of the tool and reduce the compilation time.
7. The use of street views may help for remote analysis, nevertheless it is always suggested to make on-site inspections and video recordings of the road, mounting the camera very close to the eye of the driver (at list at the same height). Audio registration during the video will help to keep trace of the perceptions and feeling of the driver, because just looking at pictures from camera mounted on the car, may influence the visibility, perception, and comprehension of the PCLs.

First Rule

1. The moderation of transitional area must be compiled based on speed. A definition of the speed to use must be included. Moreover, indications should be provided on how to calculate the length required for each section, both considering the breaking action, and the perception time in response, anticipation, and advance warning sections.
2. Some relevant PCL, such as pedestrian crossing, seems to have little influence.
3. Unmistakable right of way presents many very similar requirements that seems to provide too much weight to the same aspects without considering some other relevant aspects (e.g., intersection angle).

Second Rule

1. Additional lengths calculations should be avoided. It must be considered to take the results from the first rule where different lengths have been already calculated.
2. Trying to uniform some criteria and provide information about terminology (for example the differences between fixation objects and eye-catching objects must be clarified).

Third Rule

1. Additional lengths calculations should be avoided. It must be considered to take the results from the first rule where different lengths have been already calculated.
2. The inspection topics and their subsections should be slightly reviewed for better compliance.
3. Only road alignment influence on expectations is considered. A requirement about general expectations (GEXs) should be included (for example a pedestrian crossing is not expected in a rural road where no houses are visible).

All these aspects are summarized in the SWOT (Strengths, Weaknesses, Opportunities, Treats) analysis chart of Figure 4.3. The specific considerations for the single rules concern the requirements and therefore they are all included in the point f) of Figure 4.3.

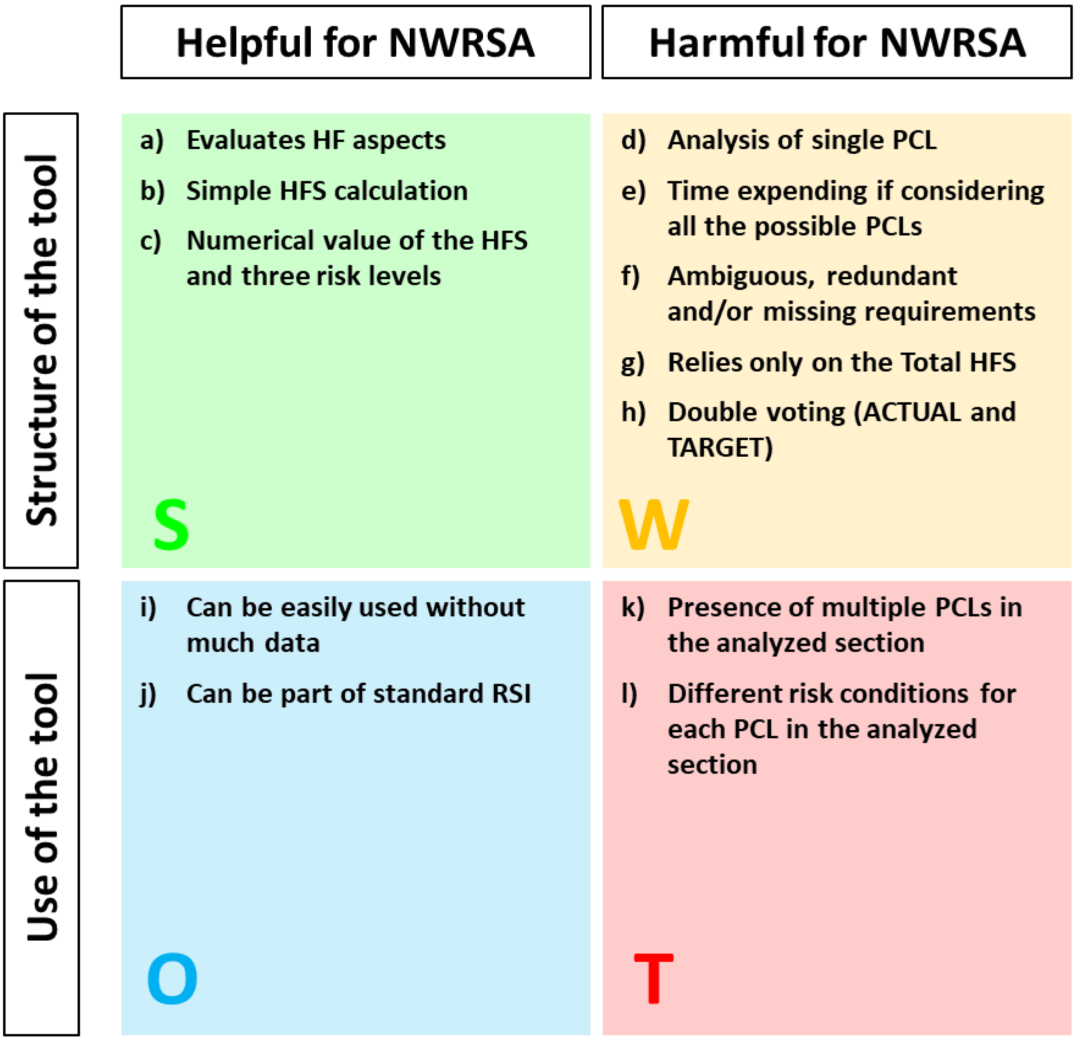

Figure 4.3 – SWOT analysis of the first version of the HFET.

4.4 The updated Human Factors Evaluation Tool (HFET)

Consequently, some modifications have been proposed to the original tool. Those modifications are here summarized. The numbers refer to the weaknesses highlighted in the previous section (4.3).

General aspects

1. The tool structure now allows to analyze more PCLs together if they all belong to the analyzed segment. This is valid also for location of the same type (e.g., two curves). This implementation involves only the format of the tool but needs some deeper changes to the score calculation procedure (see next point).
2. The calculation of the score has been modified. Because of the previous point more locations can be analyzed, and different results will likely result for each requirement.

To overcome this issue, it has been decided to compare the score (i.e., HFS) of each location for each subsection, and consider only the location with the worst section score. The value assigned to each requirement for that location will be used for the computation of the whole rule score and the Total HFS. The choice of taking the worst result as representative, will be discussed in 4.5.

3. The tool must be suitable to be easily and rapidly applied, thus while using the HFET as part of the NWRSA procedure, only the worst PCLs should be analyzed. This fast first screening is up to the inspector. However, even if all the PCLs are evaluated, the results must be consistent. This bring back to the problem of the score calculation, whose solution has been discussed on point 2 of this list. Moreover, to fasten the compiling procedure, an excel file with automatic filling option has been created. The screening process to reduce the number of PCLs to analyze is part of the HFE procedure and will be deeply discussed in CHAPTER 5.
4. Guidelines have been produced with many examples to help inspectors (APPENDIX 1). These guidelines have also the objective of reduce the subjectivity in judgments. The formulation of the requirements has also been revised and checked for consistency.
5. The three risk levels have been confirmed and it is not necessary to introduce additional indices. However, more HFET applications must be considered together (e.g., in the HFE procedure), the results of each rule and not only of the Total HFS must be considered. How to do it is described in 4.5.
6. A single evaluation has been considered, based on three symbols: "na", which means "not analyzable", that is that the requirement cannot be judged (e.g., it is not present), "0", which means that the requirement can be judged, and it is judged negatively, and "1" which means that the requirement can be judged, and it is judged positively. The results will not change by applying the first evaluation method, or the one here proposed.
7. It is strongly recommended, also in the guidelines (APPENDIX 1), to implement on-site inspections.

In addition, the analyzed locations will be called challenging locations (CHLs).

First Rule

1. The developed Guidelines provides instructions on how to consider speed to calculate the maneuver, response, anticipation, and advance warning sections (APPENDIX 1).
2. The influence of all the types of PCLs has been balanced.
3. Unmistakable right of way influence has been reduced and has been introduced the evaluation of the alignment of the minor road with the main road.

Second Rule

1. Additional lengths calculations are avoided. When necessary, the distances are taken from the results already calculated.
2. Criteria and terminology are more consistent and uniform.

Third Rule

1. Additional lengths calculations are avoided. When necessary, the distances are taken from the results already calculated.
2. The inspection topics and their subsections have been reviewed for better compliance.
3. A requirement concerning GEXs has been included.

Overall, some requirements have been modified or written in different words. Detailed description of the final list of requirements chosen is provided in the guidelines (APPENDIX 1).

Consequently, the SWOT analysis chart has been updated. The updated chart is provided in Figure 4.4. The points have the same letters of those in Figure 4.3. The main modifications are highlighted in red. It can be noted that point e) has not be modified. The solution to this issue is included in the procedure itself and will be explained in 5.3.

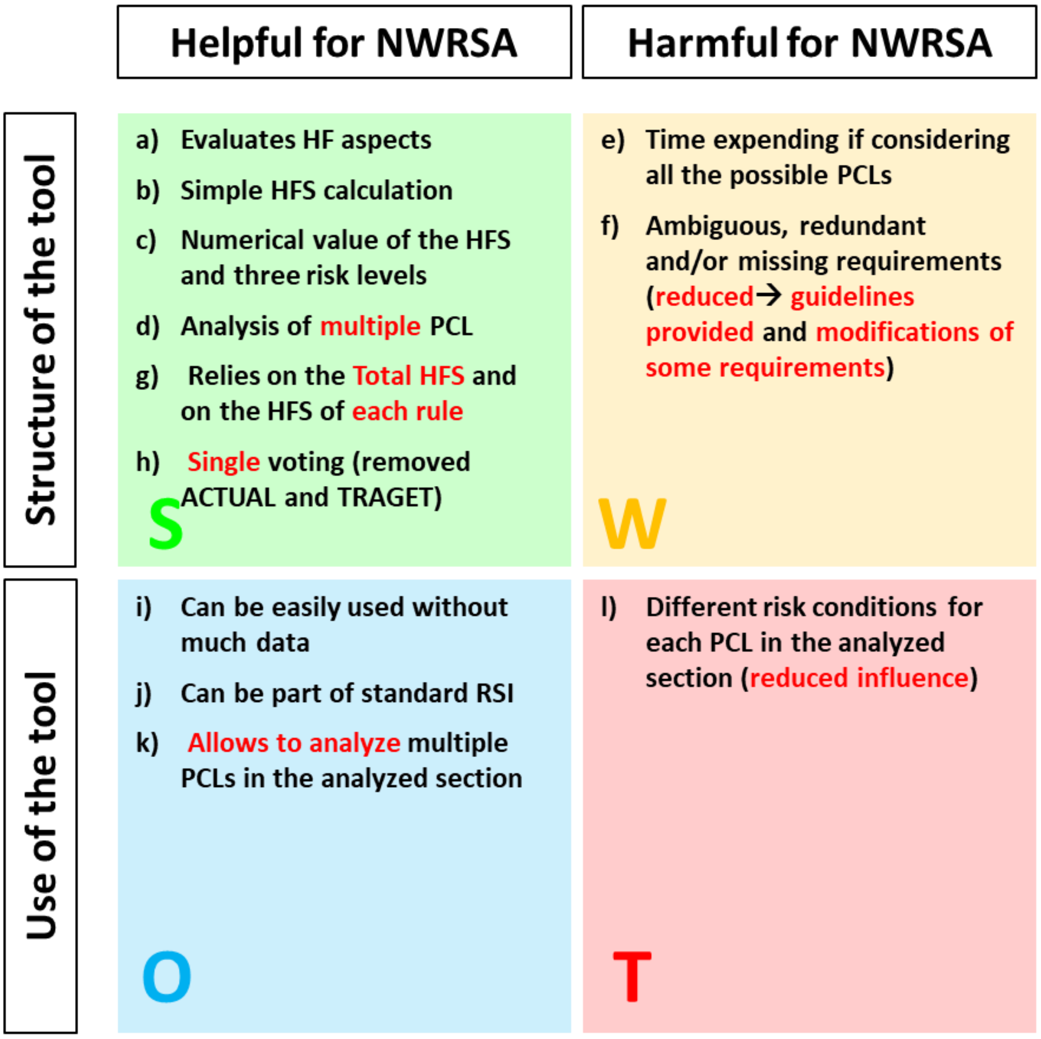

Figure 4.4 – SWOT analysis of the updated HFET.

4.5 The updated calculation of the Human Factors Score (HFS)

The problem of many different objects to analyze (e.g., CHLs and HFES) and to provide quantitative results for the evaluation, has imposed a reflection on what could be the best method to follow. Generally, when a result must be derived from many, some conventional operators are used, such as the average (arithmetic, weighted, etc.). Also, statistics may come into help providing some instruments to evaluate the difference within the same group of elements (e.g., standard deviation). Despite this, while talking about road safety, it must be considered that the higher influence in road crashes is due to critical locations. A section with a localized critical safety issue, is riskier than a section with distributed safety issues of minor relevance, even if, considering the average, they are the same. This relates also to the concept of black spots and the identification and analysis of hazardous road location. Elvik suggested to develop a classification of roadway segments based on their type (road sections of a given length and given number of lanes, junctions with a given number of legs and type of traffic control, interchanges with a given design and ramp configuration, horizontal curves with radius in a given range, bridges of a given design, and tunnels by length and geometry) (Elvik, 2010). The same concept is generally used by APMs (e.g., HSM (AASHTO, 2010)), which require a segmentation of the network into homogeneous sections, which are characterized by the same characteristics. This often produces many small segments (mainly in rural two-lane two-way roads where the road characteristics often varies), or even single locations to analyze alone (e.g., curves and intersections). After analyzing each location, those upon which to intervene are generally those to whom belong the higher number of accidents (if possible, the expected number of accidents). As discussed by Elvik, "hazardous locations should be defined as those forming the top 10%, 5% or 2.5% of the distribution of sites according to the EB-estimate of the expected number of accidents" (Elvik, 2010). Thus, the crucial point is the dangerousness of the single location (or segment), and only to a minor extent the average dangerousness of a segment (or section)[13]. For this reason, it has been decided to give a higher weight to the location (or the segment) with the more critical characteristics when many locations (or segments) must be considered together in a segment (or section).

This criterion will be applied both in using the tool on single road segments, or when considering the aggregation of more segments into a single section for the purpose of NWRSA. Details about the consequence of this choice to the HFET is discussed below, whether the consequence of the same concepts to the whole HFE procedure is discussed in CHAPTER 5.

As stated in 4.4 the updated version of the HFET will consider more CHLs together if their areas of influence overlap. When more than one CHL is judged concerning the same subsection, the problem arises of how to calculate the score. Based on the choice of "adopting

[13] Segments are shorter than sections, as explained in GLOSSARY. Many PCLs can be included in a segment, and many segments can be included in a section.

the worst result", the HFS will be calculated for each subsection and only the CHL with the worst score for that subsection will be used for the calculation of the Total HFS. Consequently, it could happen that within two different CHLs, one presents a worst result for one subsection, and one for another. The consequence is taking the worst of both. This may appear as something that greatly worsens the Total HFS, producing a probable bias within the HFS and the reality. However, it must be remembered that if the two CHLs belongs to the same segment, it means that they overlap, and thus they are influencing each other, and their effect on road safety is worse than the worst effect between the two CHLs. Moreover, this implicitly account also for the presence of multiple CHLs as a source of potentially higher danger. Simply, more dangerous situations are riskier than a single dangerous situation. This also avoid any possible influence of good CHLs that may increase the HFS shadowing some dangerous CHLs.

On the other hand, the whole score calculation of each investigation topic, of each rule, and of the Total, do not account for the worst result. Thus, when CHLs are present that have a very positive HFS, and no CHLs with bad results are present for a specific subsection, some very good subsections may occur, which in turn may influence the HFS of the whole segment, increasing it. The choice of the worst CHLs to consider in the subsection, partially reduce this effect, however, it is crucial to try to not include in the analysis, CHLs that are clearly not dangerous.

To resume, the consequence of this choice on the use of the HFET are:

- the most critical aspects identified by each subsection are considered;
- indirectly the number of the CHLs in the segment is considered;
- it greatly reduces the influence of "good" CHLs (but not eliminate it);
- when very positive subsections are present, they may influence the Total HFS.

CHAPTER 5 DEVELOPMENT OF THE PROCEDURE

Chapter abstract

The Human Factors Evaluation Tool (HFET) have been found to be a suitable instrument which can be used during a road safety inspection (RSI), which provides an analysis of the road safety by means of Human Factors, and which provides quantitative results. Moreover, the HFET is based on the PIARC rules of Human Factors, which fits exactly the expectation-theory. However, the HFET was born mainly to analyze single locations, and this was contrasting with the necessity of a fast network analysis procedure. Thus, some adjustments of the tool have been made to overcome the weaknesses of the original HFET considering its application to a network-wide road safety assessment (NWRSA). One of the main weaknesses identified was that analyzing all the potentially critical locations (PCLs) belonging to a road stretch was a very time-consuming process. Another specific aspect is the segmentation, which is a common problem for all roads risk analyses (including RSIs). Segmentation choice will influence which and how many PCLs belong to each segment. Lastly, the procedure shall be a suitable and practical instrument for road agencies and the outcomes must be suitable to represent the safety level of a network.

In the result, the procedure was divided into three different steps. The first step is mandatory to identify the riskiest PCLs. It assures that a minor number of PCLs is analyzed with the HFET, saving much time for its application. Here, the concept of expectations is translated into engineering qualitative parameters, and this results in an added value also outside the procedure.

During the second step, a first segmentation is made according to the locations that shall be analyzed and their area of influence. Then, the HFET is applied to those segments (Human Factors Evaluation Segments, HFESs). At the end of this process, each HFES is addressed with a score for each Human Factors rule and one general score considering the rules together.

During the third step the results must be achieved with a minor level of detail, but they must assure reliability and consistency. It has been found that the fixed length of about 1 km is the best benchmark for a network assessment section (NAS). For each NAS is calculated a risk code (RC) on a four level risk scale and also defined a ranking, as required by the updated EU Directive (European Parliament and the Council, 2019).

So not only a valid procedure has been defined ready to be implemented in the work of road agencies. It can be applied also very efficiently with less effort (saving about 40% of time, see also 7.4).

Chapter list of acronyms

AADT	Average Annual Daily Traffic
AHP	Analytic Hierarchy Process
AL	Alertness Level
APM	Accident Prediction Model
CCR	Curvature Change Rate
CHL	Challenging Location
CHT	Challenging Transition
CMF	Crash Modification Factor

DSD	Decision Sight Distance
EB	Empirical Bayes
EXSE	Expectation Section
GEX	General Expectation
GIS	Geographic Information System
HFE	Human Factors Evaluation
HFES	Human Factors Evaluation Segment
HFET	Human Factors Evaluation Tool
HFS	Human Factors Score
H	High
M	Medium
L	Low
HSM	Highway Safety Manual
ID	Identification
MT	Motorway
NAS	Network Assessment Section
NWRSA	Network-wide Road safety Assessment
PCL	Potentially Critical Location
PDO	Property Damage Only
PEX	Punctual Expectation
PPI	Perception of Possible Interaction
RC	Risk Code
RH	Rural Highway
RL	Rural Local road
RSI	Road Safety Inspection
SSD	Stopping Sight Distance
TG	Testing Group
V_E	Expected Speed
VIS	Visibility

5.1 Framework of the work

5.1.1 Overview of the steps implemented

The development of the HFE procedure had its focus in the definition of a procedure to carry out NWRSA based on Human Factors and on RSIs, which can provide a classification of the network, based at least on three levels. Even if the structure of the procedure has the potential to analyze all road types, this research has focused in the developing of a procedure able to analyze two-lane two-way rural highways. The different steps implemented to develop the procedure are listed below and depicted in Figure 5.1.

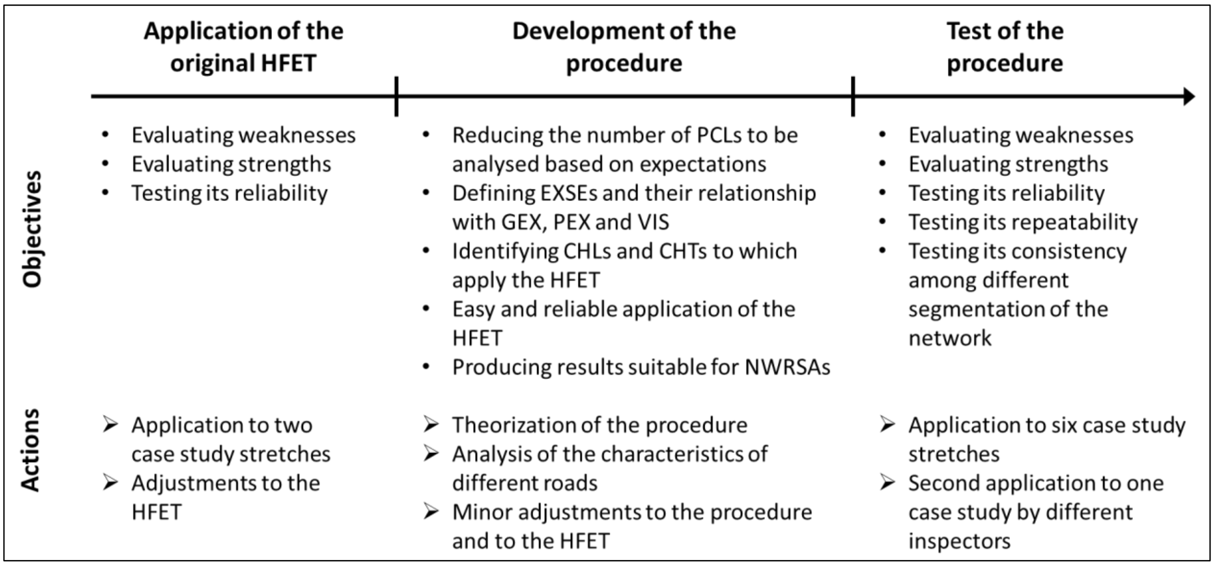

Figure 5.1 – Different steps implemented to define and test the procedure

The first phase of the developing of the HFE procedure was to apply the tool in its original form to two road stretches of a total length of about 23 km of two-lane two-way rural road in Italy. The outcome related to the structure and contents of the tool is discussed in 0. Instead, in this chapter the application of the tool will be presented together with the outcomes that are interesting for the development of the procedure. The first application of the tool also included the evaluation of its effectiveness by comparing the results to the expected number of accidents that have been calculated using an EB procedure. The comparison of the results shown a fair reliability of the tool. However, some issues concerning its application have been found and discussed (see 5.2.4).

The second phase originated the structure of the procedure. The major efforts concern the definition of a fast-screening process to reduce the number of PCLs to evaluate with the HFET, and to determine how to group together the disaggregated outcomes obtained from the application of the HFET. The fast-screening process has been based on the expectation-theory, and thus it will provide the inspectors with some instrument to judge if a PCL is not risky. This process considers the definition of expectation sections (EXSEs), where drivers expectations are assumed to be constant. If the PCL is classified as not risky by this first screening process it will not be evaluated with the HFET. PCLs identified as risky will be promoted to CHLs and will be analyzed with the HFET. Finally, the procedure must provide results that are suitable for a network screening, also considering the “form”; thus, longer section of analysis must be considered. These sections can be identified based on the road agency requirements. However, a semi-fixed length of the sections seems to be a good choice, as discussed in the following. The results of the evaluation of the single (or groups of) CHLs are joint together, and specific criteria must be considered to account for the presence of different results, considering different aspects of Human Factors (different rules). The adopted sections, called Network Assessment Sections (NASs), will be identified by a code (risk code, RC) that accounts for those differences. Also in this case, it has been preferred to give a strong weight to the worst results (see also 4.5); however, the code provide also information about the distribution of the risky area along the segment in order to understand if the section is characterized by a single very risky location, or more risky locations. The procedure was developed on the SR2 stretch already considered in the first step. The characteristics of three German stretches have been then studied and the HFE procedure defined in the second phase has been adjusted to consider also specific characteristics that differ from those of the road upon which it has been developed (SR2 stretch).

In the third phase, the procedure was applied to 5 other stretches, 1 from Italy, 3 from Germany, and 1 from Slovenia. This last step will be discussed in two stan-alone chapters (CHAPTER 6 and CHAPTER 7) where the application to case studies will be presented and the results discussed.

Accidents' data were available for all those analyzed stretches and thus a comparison have been made between the results of the application of the HFE procedure and the number of accidents to test procedure's effectiveness. A detailed analysis of the results has been carried out also to identify if accidents occurred in a specific section may be a consequence of the identified issues, and to analyze the reason behind the difference in the results, where the results differ.

At the end of phase three the procedure has been applied again to one of those road stretch (SR2) by different inspectors, to tests its robustness against repeatability. Finally, a different segmentation has also been considered to evaluate the consistency of different segmentation in the final stage of the procedure (i.e., when grouping the results of the single analysis of CHLs).

Table 5.1 shows how, when, and why, the different road stretches have been considered in the developing process of the procedure.

Table 5.1 – Road stretches considered in the different development phases

Road	First phase	Second phase	Third phase	Additional test
SR2	Analysis with the original HFET	Development of the procedure	Analysis with the final procedure	Analyzed again by different inspectors, and with a different segmentation (in Step 3)
SR206	Analysis with the original HFET		Analysis with the final procedure	
B38		Adjustment of the procedure	Analysis with the final procedure	Analyzed again with a different segmentation (in Step 3)
L3106		Adjustment of the procedure	Analysis with the final procedure	
L3408		Adjustment of the procedure	Analysis with the final procedure	
106			Analysis with the final procedure	

5.1.2 Definition of Potentially Critical Locations (PCLs)

PCLs are those locations that require a change in the driving program. Curves, at-grade intersections, crossings (cyclist, pedestrian, or railway crossings), driveways and accesses, points where the cross section significantly change (adding or removing a lane), points where the road function change (e.g., from rural environment to urban environment), stopping areas such as bus stops and lay-by, are all defined as PCLs. Even if road agencies have no database about these locations, they can be easily identified by driving along the road. Table 5.2 shows the PCLs considered in the procedure. The PCLs are grouped by type (PCL Type) and by different PCLs within each type. A description of each different PCL is provided.

Considering Table 5.2, some words must be spent about the definition of three different PCLs for curve. The decision has been taken considering the Lamm criteria (Lamm et al., 1999) (Lamm et al., 2002) (Lamm et al., 2006). Lamm defined three levels of risk based on the comparison between the V_{85} of two consecutive road elements. If the difference is less than 10 km/h, then the risk is low, between 10 and 20 km/h the risk is medium, and if the difference is more than 20 km/h the risk is high. The higher the difference between the operating speed of two consecutive elements, the higher the probability that the second is unexpected. For this reason, the three curve PCLs has been defined as Curve0, Curve10, and Curve20 (see Table 5.2 for their definitions).

One of the theory at the base of the procedure is that based on the road type, some PCLs are more expected than others, this is in accordance with the self-explaining road theory (Theeuwes, 2017). These concepts are better described in 5.3.3.

Table 5.2. Summary of the considered Potentially Critical Locations (PCLs).

PCL Type	PCL	Characteristics
Curve	*Curve0*	Curve requiring a small change or no change in the speed
	Curve10	Curve requiring a medium change in the speed (between 10 and 20 km/h)
	Curve20	Curve requiring a high change in the speed (more than 20 km/h)
At-grade intersection	*Roundabout*	Junction with rotatory circulation, where drivers from each direction must yield to the car in the junction.
	Signalized	Junction organized with traffic lights.
	With priority	Junction where the drivers travelling on the analyzed road do not have to stop or even yield at the junction.
	Without priority	Junction where the drivers travelling on the analyzed road must stop or yield at the junction (excluding roundabouts).
Crossing	*Pedestrian crossing*	Road area where pedestrians cross the road.
	Cyclist crossing	Road area where cyclists cross the road.
Driveway	*Minor residential*	Access to one or few houses.
	Major residential	Access to a large group of houses.
	Minor commercial	Access to little or few commercial, industrial, or agricultural activities.
	Major commercial	Access to big or many commercial, industrial, or agricultural activities.
Stopping area	*Lay-by*	Areas along the road that allow for a car to stop (for emergency or not).
	Bus stop	Reserved lay-by or simply vertical signs and marking along the road.
	Parking lot	Parking lots along the road.
Railway level crossing (LC)	*With mobile bar*	Railway level crossing intersection with vertical signs, markings, and bars.
	Without mobile bar	Railway level crossing intersection with only vertical signs and markings.
Lane change	*Added/removed lane*	Added/removed lane that changes the cross-section configuration (it includes speed change lanes).
	Diverging lane	Lane splits into two (or more) lanes, which follow different directions.

5.1.3 Definition of road categories

After the concept of PCLs has been defined, it is also necessary to clearly identify the road categories to which the procedure will refer. Based on the concept of self-explaining roads and trying to evaluate the different road categorizations around the world, it has been decided to define three categories of rural roads: motorway, rural highway, and rural local. The present work focuses only on rural highways, however it has been decided to provide the definition also for motorway and rural local road, to better explain the differences between these three categories. These definitions are strictly related to those from EU Directive (European Parliament and the Council, 2019). The categories, which are described in Table 5.3, can be representative of the main categories of rural road that are present around the world, considering their cross-section and their function.

Table 5.3 – Road categories and their characteristics for rural environment

Road category	Description	Function
Motorway (MT)	A road designed and built for motor traffic, which does not serve properties bordering on it and which meets the following criteria: a*) it is provided, except at special points or temporarily, with separate carriageways for the two directions of traffic, separated from each other either by a dividing strip not intended for traffic or, exceptionally, by other means; b*) it does not cross at level with any road, railway or tramway track, bicycle path or footpath; c**) it may not be specifically designed as a motorway and point b) may be not always satisfied, but it has a cross-section that is consistent with (very similar to) motorways standard cross-section, and it develops outside urban area.	Movement between two points at high distance from each other. Characterized with very high travel speed and high to very high traffic.
Rural Highway (RH)	A road design and built for all road users, but mostly for motor traffic and which meets the following criteria: a) it is provided, except at special points or temporarily, with a single carriageway for the two directions of traffic, with only a single lane for each direction; b) it crosses at level with other roads, railways or tramway tracks, bicycle paths or footpaths; c) it may serve properties bordering, even this is not its main function; d) it develops outside the urban areas.	Main: movement between two points at medium or long distance from each other (connection between different cities or regions) and link between motorways and rural local roads. Minor: access. Characterized with medium to high travel speed and medium to high traffic.
Rural Local (RL)	A road design and built for all road users, which meets the following criteria: a) it serves properties bordering, connecting them to the main network (e.g., rural highways) b) it is provided, except at special points or temporarily, with a single carriageway for the two directions of traffic, with only a single lane for each direction (cross-sectional elements are generally smaller than the ones of a rural highway); c) it crosses at level with other roads, railways or tramway tracks, bicycle paths or footpaths; d) it develops outside the urban areas.	Access, movement between two points close to each other and link between rural highway and the final destination. Characterized with medium to low travel speed and medium to low traffic.

**definitions from* (European Parliament and the Council, 2019)
***this specific paragraph substitutes the last paragraph of motorways definition by the Updated Directive of 2019. In this work, the "motorways" classification is not based on the nominal country classification, but it is based on the perception the drivers have of the road. For this reasons, double carriageway roads which are not classified as motorways by national design standards, but has a cross-section, speeds and geometrical features which are consistent with motorways cross-section, speeds, and geometrical features, will be considered as such. The purpose of the analysis is to identify those road sections which create a set of expectations to the driver, thus the purpose is not to identify what they are classified as, but what they seem to be. A road that has a configuration equal to a motorway, will be perceived as such, and the driver will behave as in a motorway.*

These categories are not only oriented to the design of new roads, instead they must try to summarize, in few categories as possible, the existent road categories, because the procedure must be applicable also to existing roads.

To define these three categories, many design standards guidelines have been considered among which:

- Australian design standards (Austroads, 2021) (Austroads, 2019)
- Canadian design standards (TAC, 2017)
- English design standards (Highways England, 2020)
- German design Standards (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2008) (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012)
- Italian design standards (Ministero delle Infrastrutture e dei Trasporti, 2001)
- Portuguese design standards (Instituto da Mobilidada e dos Trasportes, 2010)
- Slovenian design standards (PIS, 2021)
- Swiss design standards (Vereinigung Schweizerischer Strassenfachleute, 1991)

5.2 First field application of the Human Factors Evaluation Tool (HFET)

The first application of the HFET had three main focuses:

- Evaluating the HFET applicability, and identifying its strengths and weaknesses;
- Evaluating if and how the HFET can be integrated into a NWRSA procedure;
- Evaluating the effectiveness and reliability of the results by comparing the results to accidents data.

To compare the results with accident data, it has been decided to consider the application of a predictive model with an EB procedure. The HSM model for two-lane two-way rural road had been chosen (AASHTO, 2010). This won't grant that the risk of the road identified by the HSM procedure with EB adjustments fits exactly the real risk of the road (see the considerations about predictive model in 2.3.1.1), nevertheless it provides useful results for a discussion (and likely more reliable than the simple observed number of accidents). The first application of the HFET has been presented in a published paper by Domenichini et al. (Domenichini et al., 2022). That work is part of this thesis. Moreover, the work presented in the paper has been updated due to the acquisition of additional accident data (mainly PDO) and revised with a focus on rural networks (urban area are considered in the paper but are not considered in this thesis). For both this reasons, the whole process and the obtained results are reported in this thesis.

5.2.1 The analyzed roads

The roads chosen to carry out the first application of the HFET and to test its suitability for implementing a NWRSA, were two two-lane two-way rural road, located in the Tuscany Region in Italy. One of the road stretches analyzed is the Strada Regionale 2 (SR2) from km 281.600 to km 292.400. The second road stretch is the Strada Regionale 206 (SR206) between km 29.600 and 41.400. In Figure 5.2 the north-oriented stretches are depicted on a satellite image. In the figure also urban areas are depicted.

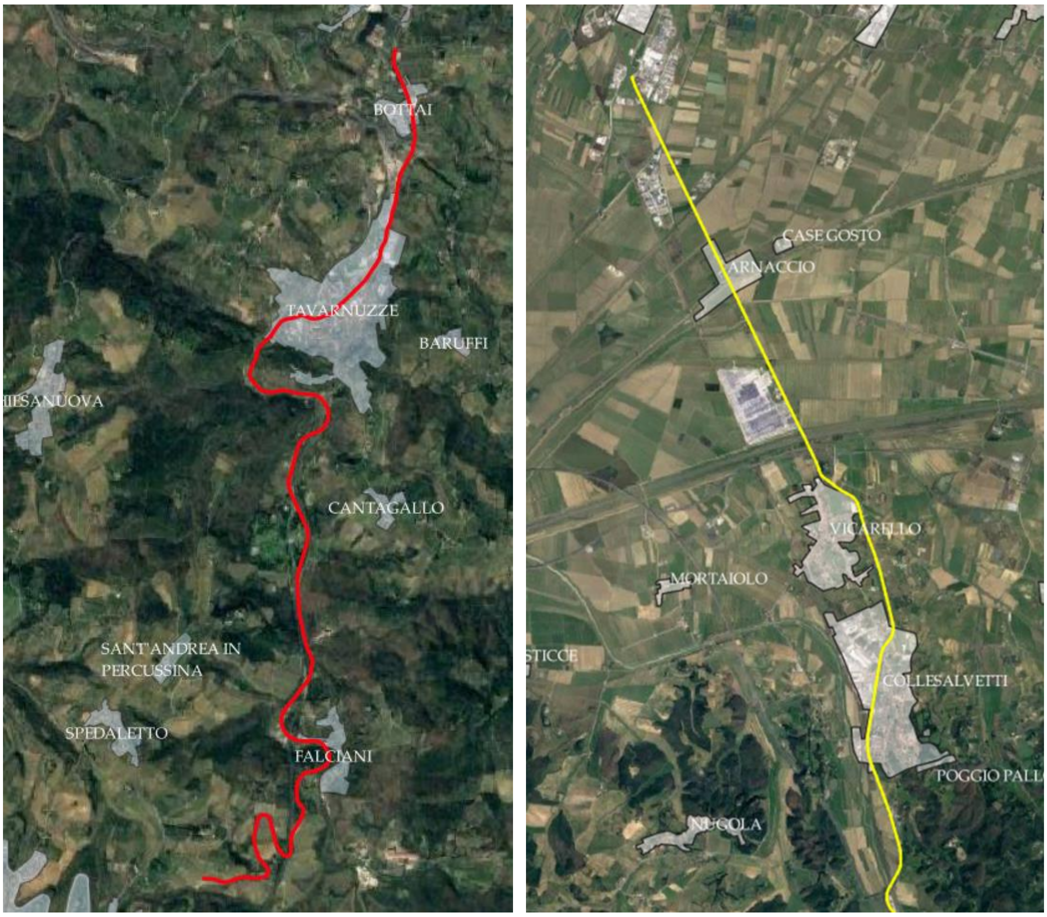

Figure 5.2 – Satellite image of the SR2 (left) and SR206 (right). The Kilometers markers direction is northbound for both the roads.

SR2 description

From south to north, the SR2 moves through an area of hilly terrain for about four km, characterized by many curves of small radius, and then it runs along the Greve river, maintaining a generally low curvature ratio. In the final part, the road pass through two urban areas, reaching an important intersection junction with two roads of higher functional class (two motorways). The road appears quite complex with many driveways and curves of different radius. The average carriageway width is 7.00 m with no or very narrow shoulders and close marginal elements (wider shoulders are present only in the last kilometer). Figure 5.3 shows two views of the SR2, the first, on the hilly terrain, is a sharp curve in the hilly area, while the second is a picture taken about 90 m before an intersection in the plain area

Figure 5.3 – Photos of SR206: on the left km 282.100 northbound, on the right km 288.400 southbound.

SR206 description

The SR206 develops in a flat environment and overall presents low curvature ratio with a high presence of straights and few intersections. The rural part of the road is generally clear and simple. The road passes through some urban areas: one larger in the first part, others smaller along the remaining route. Driveways are present along the margins. The average carriageway width is 7.25 m. Paved shoulders are present in the central part of the stretch and no, or very narrow paved shoulder, on the remaining parts. The left picture of Figure 5.4 shows a segment with shoulders of 1.5 m, while the one on the right shows a segment with shoulders of about 0.5 m. Both the pictures are taken on straights. The monotony of the margins is often interrupted by some advertising panels, as shown in the right picture of Figure 5.4.

Figure 5.4 – Photos of SR206: on the left km 33.700 southbound, on the right km 39.200 northbound.

Reason of choosing SR2 and SR206

The road stretches have been chosen after an analysis of two-lane two-way roads available in the Tuscany Region. The reasons of the choice are listed below.

1. The analysis even of two 11 km stretch requires time and efforts, thus it was not possible to analyze many different roads for the first run of the HFET. The chosen stretches must provide as many differences as possible in the road characteristics to assure that many different aspects are evaluated. The SR2 stretch presents different characteristics, both locally and globally, such as different road curvature, different

road environment, and different environmental (and operating) speed. It mainly develops on a hilly terrain. SR206 instead, presents similar characteristics along the whole stretch, both considering geometrical and functional aspects, and it develops completely in a flat terrain. Moreover, SR2 has a very winding development compared to the SR206. For these reasons, the two stretches present different characteristics even if they both belong to the rural highway category (two-lane two-way rural highway).

2. The roads were formerly made before the new design standards took place, as many other roads in Italy and all over the world, even if some short segments have been updated to current national standards. This type of roads is often the more prone to accidents, thus it will be of great interest to implement an instrument which allow an analysis of those road type.
3. The roads are two-lane two-way rural highways. This category of road is very broad, ranging from road of very high traffic and function (arterial) to road with minor traffic and function in the network (collector), excluding local rural roads. The SR2 can be considered mainly a collector road by means of its traffic (mainly in the country area). The SR206 is instead representative of an arterial road.
4. Accident's data, traffic data, and geometrical data were mainly available for these roads.
5. The roads are well known, and it was possible to easily contact who oversees managing and controlling the road (both road agency and police). Knowing the road means that when a lack of data is present (such as operating speed) more reliable hypothesis may be made.

5.2.1.2 Road databases

The considered databases included the road geometrical design features (e.g., curves, straights), the traffic, and the accidents occurred over a period of 5 years (2014 – 2018). They were provided by the Tuscany Region Administration.

The geometrical features database comprises the horizontal alignment of the road, the vertical alignment of the road and the characteristics of the road cross section. The horizontal elements of the two road are listed in APPENDIX 2. It must be noted that because of the road modification over the years, the km posts are not always consistent with the real length of the road. For this reason, it has been considered as reference for the analysis the real length, starting from the first point of the stretch, which is identified with the first km post (281.600 for SR2, and 29.600 for SR206). From here on, the distances provided are the real distances. The relationship between the km post distances and the real distances are reported in APPENDIX 2.

The traffic database contains the traffic counts provided by inductive loops installed along the road network. The available traffic data are provided in Table 5.4. The missing traffic data have been assumed to have the same trend as the traffic data of an inductive loop with traffic data available for the whole analysis period. Thus, the missing data have been calculated by means of proportion. The consequent error seems negligible because traffic was very stable over the analysis period, as confirmed also by road agencies. Traffic data about minor intersecting roads are not available.

Table 5.4 – SR2 and SR206 traffic data

Road	Starting km post [km]	Ending Km post [km]	Year	Original AADT [veic/day]	Calculated AADT [veic/day]
SR2	280.600	289.000	2014	4201	-
			2015	4146	-
			2016	4279	-
			2017	4354	-
			2018	4572	-
	289.000	292.200	2014	-	11565
			2015	-	11924
			2016	-	12130
			2017	12708	-
			2018	12792	-
SR206	27.800	38.950	2014	-	11842
			2015	-	11732
			2016	-	11877
			2017	11621	-
			2018	12961	-
	38.950	42.400	2014	15381	-
			2015	15239	-
			2016	15430	-
			2017	15104	-
			2018	15404	-

The accidents database was provided by ISTAT (Italian National Statistical Board), by the Tuscany Region Administration and by Police. It contains information about all types of accidents (fatal, injuries and property damage only). Only some of the data were georeferenced. The contents of the accidents databases are presented in APPENDIX 4. In the analysis a total of 58 accidents for SR2 and 53 accidents for SR206 have been considered.

5.2.2 Methodology

The purpose of the first application was to test the effectiveness of the HFET, to understand how to use it, and to highlights if modifications and improvements are required. To test its effectiveness, it has been decided to compare the outcomes of the application of the HFET to two accidents-based performance measures that are accidents' frequency and accidents' rate. To avoid the main accidents-related issues, such as the regression to the mean, it has been decided to apply the HSM predictive model to calculate the number of predicted accidents for the road stretch and to apply the Empirical-Bayes (EB) procedure.

The first activity concerned the segmentation process of the considered test roads to subdivide them in homogeneous segments. Road safety inspections of each homogeneous segment were performed afterwards, according to the procedure described in the PIARC document (PIARC, 2019a), and the Human Factors Score (HFS) was calculated. Finally, the HSM procedure was carried out and the expected number of accidents was assigned to each segment. The calculated HFS values and the accident-base performance measures of each segment have been finally compared for mutual coherence. As shown in Figure 5.5, where the process followed has been schematized, the HFET procedure requires fewer input data compared to the accident analysis. This depicts a first result.

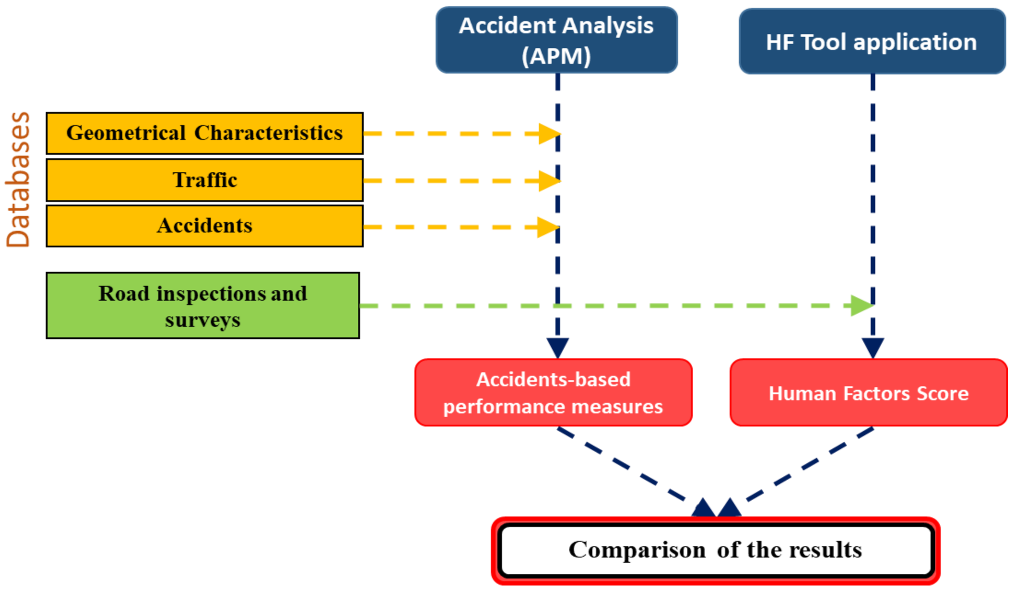

Figure 5.5 - Flow chart of the validation procedures.

It has been decided to consider both accident frequency and accident rate to highlights the difference between these two indices when segment of different length and different traffic are present. Indeed, accident rate is generally used to identify road in-built safety issue, while accident frequency also considers the exposure. Consequently, accident rate can be considered as a better performance measure for the comparison with the HFS (because the HFET analyses the in-built safety of the road), however, the calculation of accident rate present two limitations:

- accidents are considered to have a linear correlation with traffic in the equation of accident rate (see 5.2.2.4), but this is an approximation;
- length can be considered as having an influence by statistics, and this has always been assumed as a linear correlation, but some researchers do not agree on this (Lord and Mannering, 2010); moreover, as discussed in 5.2.4.5, the major influence of accident likelihood is due to the presence of critical locations, which are generally not extended along the whole segment, thus, simply multiply the length for the risk can lead to wrong estimations.

5.2.2.1 Segmentation

The segmentation follows the suggestions of the Italian Guidelines for Road Safety Management (Ministero delle Infrastrutture e dei Trasporti, 2012). Therefore, it has been decided to subdivide the road stretches into homogeneous segments in terms of road environment (urban and rural) and type of road elements (roadway segments and intersections). However, because of the specific configuration of urban roads, where many intersections are present, urban segments are not divided based on the presence of intersections. Consequently, three types of homogeneous segments have been defined: rural roadway segments (i.e., "roadway segments"), rural intersection segments (i.e., "intersection segments" or simply "intersections"), and urban segments. The chosen homogeneous segments length ranged from 200 m to 1000 m. The following criteria were considered for segmentation.

1. *Accidents' event chain*: the accident that eventually led to a crash has its starts far above the point of the crash; it starts when the first operating error occurs, thus considering too short segments may results in some missing information.
2. *NWRSA management procedure*: too short road segments require high efforts in data collection and management. This is also stated in the HSM (AASHTO, 2010) where the suggested minimum length is 0.1 mi (about 160 meters). On the other hand, too much long segments (above 1000 m) may hide specific local critical situations.
3. *Literature review*: 200 m seems a reliable measure of the length of a segment as highlighted also by Italian Ministry of Infrastructure (Ministero delle Infrastrutture e dei Trasporti, 2012) and by Cafiso et al. (Cafiso et al., 2007). However, if segments are very similar by means of relevant explanatory variable, they can be considered together (Cafiso et al., 2018).
4. *road agency request*: the first application was made within a research project for the Tuscany Region administration, which is the road agency. Thus, the segmentation was defined according also to the request of the road agency, which requires the segments to be multiple of 100 m (to compare with a previous segmentation every 100 m).
5. *Intersection influence*: the influence length of an intersection was considered to be 75 m from the intersection geometrical center (Martinelli et al., 2009). If adjacent intersections were closer than 250 m, then the homogeneous segment included all the close spaced intersections and the enclosed road segments.

The segmentation of a road stretch is a very challenging process that requires thoughtful choices, because different segmentation may also lead to different results (Cafiso et al., 2018).

For the present work, urban segments are excluded from the analysis if they belong to an urban area longer than 500 m. Otherwise, they are included because they are likely perceived by the driver as rural or at least, suburban area, with some changes from the previous stretch.

5.2.2.2 *Application of the Human Factors Evaluation Tool (HFET)*

After the segmentation has been defined, the original version of the HFET (PIARC, 2019a) has been applied to each segment, considering all the PCLs within each segment. The PCLs identified on the SR2 stretch were 161 and include intersections, curves, stopping areas, crossings, driveways, and lane changes. The PCLs identified on the SR206 stretch were 94 and include intersections, curves, stopping areas, crossings, and driveways (see 5.1.2 for more insights about PCLs).

During the HFET application, some criteria were adopted in addition to those defined in the PIARC document (PIARC, 2019a). Those criteria are:

- each homogeneous segment has been analyzed in both directions, compiling the check list for each direction, then a merge of the results has been made considering the worst results for each Human Factors requirements;
- when a requirement was sheared between two or more PCLs in the segment, all have been analyzed and the worst judgement has been taken;
- if a PCL's issue belongs to a different segment than the one of the PCLs, as depicted in Figure 5.6, the evaluation will be made for the segment of the PCL.

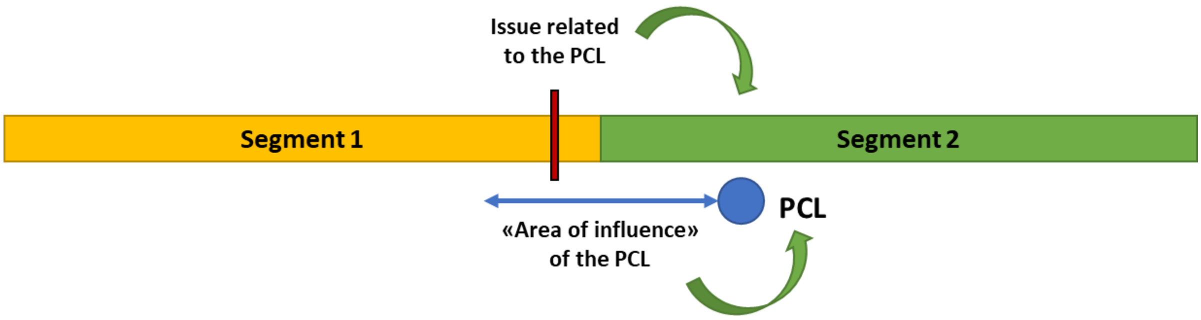

Figure 5.6 – Representation of an issue related to PCL located into another segment

The situation described in Figure 5.6, highlights a limit of a segmentation which is made without previously considering the area of influence of each PCLs. This will be discussed in 5.2.4.

5.2.2.3 *Application of the Highway Safety Manual (HSM) procedure with Empirical Bayes (EB) adjustment*

The HSM procedure has been applied using the IHSDM-HSM Predictive Method software ®. The procedure considers both the calculation of the predicted number of accidents for the period of analysis for each homogeneous segment, and the expected number of accidents using the EB procedure. All available data of each road have been included in the model. The two-lane two-way rural highway model was considered for all the segments, including those classified as Urban segment. The reason is that the segment still has many rural characteristics and that the HSM considers the model for urban arterials only when the road crosses populated area of more than 5000 inhabitants (AASHTO, 2010). The area of interest (around urban segments with a length minor than 500 m) is made of a group of houses that can't reach that value. Thus, it seems more reasonable to apply the rural highway model to those segments.

In order to apply the HSM, which has been developed accounting for the roads' characteristics of the United States, the calibration factor for the rural two-lane two-way model has been derived from that by Martinelli et al. (Martinelli et al., 2009). The calibration coefficient calculated in the research is equal to 0.348. However, in Martinelli's research conducted on two-lane two-way rural roads in the province of Arezzo, the previous HSM model was used, for which the Safety Performance Function is calculated as in Eq. 3.

$$N_{spf,rs} = L \cdot \text{AADT} \cdot 365 \cdot 10^{-6} \cdot e^{-0.4865} \qquad \text{Eq. 3}$$

The formula currently provided by the HSM model differs from the previous one for the exponential term only ($e^{-0.312}$ for the current formula of the model, and$^{-0.4865}$ for the formula of the previous version of the model). Since the formulation of the calculation of predicted accidents was linear and the other variables remained unchanged, it was possible to calculate the calibration coefficient for the formula of the current model, starting from a ratio shown in Eq. 4.

$$C_a = C_p \times \frac{e^{-0.4865}}{e^{-0.312}} \qquad \text{Eq. 4}$$

Where:
C_a = calibration coefficient of the current model;
C_p = calibration coefficient of the previous model.

Consequently, the calibration factor used is equal to 0.292. The calibration factor allows to partially accounts for the different context in which the model is applied. The use of a calibration factor will greatly improve the reliability of the results, even if it does not grant that the US-developed model completely fits the Italian safety characteristics. As an additional measure, the EB procedure proposed by the HSM has been applied, which is here briefly summarized in APPENDIX 2 together with the description of the HSM predictive methodology.

Concerning intersections, it is not possible to clearly address all the accidents to intersection or roadway segments, and it is even not possible to clearly distinguish between intersection and driveways, because many of the minor local road intersecting the SR2 have a driveway function. Moreover, a calibration factor for intersections to account for the Italian conditions, is not present, and some studies shown controversial results about the CMF used by the HSM for intersections (Biancardo et al., 2019). Thus, it has been decided for the purpose of the application of the HSM model, to not consider any intersections. All the intersections will be considered as driveway to partially account for their presence. Accident's data initially addressed to intersection, have been addressed to the corresponding road segment.

The available road characteristics that were included in the calculation, are shown in Table 5.5. Road cross slope was not available and thus the CMF has been set as 1.

Table 5.5 – Available road characteristics included in the model

Characteristics considered
Horizontal element start location
Horizontal element end location
Curve radius
Curve direction
Curve side of the road
Vertical element start location
Vertical element end location
Grade
Lane width
Overtaking maneuver allowed or not
Shoulder width
Shoulder type
Design speed
Driveway density
Roadside hazard rating
Lighting
Automated speed enforcement
Presence of rumble strips

5.2.2.4 *Accidents-based performance measures*

The accidents-based performance measures considered are:

- Accident frequency [accidents/year]: the frequency corresponds to the number of accidents per year in each homogeneous segment, that is the expected number of accidents derived from the application of the HSM model.
- Accident rate [accidents/(years*km*Mvehicles)]: it corresponds to the accident density value divided by the value of the average annual traffic that affected the segment during the analysis period. To obtain more easily readable numerical values, one million vehicles (10^6 vehicles) are considered as units of traffic. Eq. 5 shows how the accident rate has been calculated.

$$T = \frac{n}{L \times 365 \times (\frac{AADT_m}{10^6})} \qquad \text{Eq. 5}$$

Where:

T = accident rate [accidents/(years*km*Mvehicles)]

n = yearly average number of accidents [accidents/year];
L = segment length [km];
$AADT_m$ = average between the average annual daily traffic value (AADT) of each year of the analysis period [vehicles/day].

The number of accidents considered in the three previous accident-performance measures is the results of the application of the Empirical Bayes procedure to the HSM predictive model. To allow an immediate identification of the risk of each considered segment, the values of the accidents-based performance measures were classified considering the thresholds limits adopted by Tuscany Region administration for the whole network (Regione Toscana, 2019):

- **T_{mean}**, that is the average of the values of an accidents-based performance measure;
- **T_{80}**, that is the 80th percentile of the values of an accidents-based performance measure; and
- **T_{90}**, that is the 90th percentile of the values of an accidents-based performance measure.

The thresholds values considered are shown in Table 5.6. The given values are referred to the whole road network managed by Tuscany Region administration and consider only the observed number of accidents. To compare the two approaches considered in the present study (accidents-based approach and non-accidents-based approach), the homogeneous segments have been classified as:

- **Low risk:** performance measure < **T_{mean}**
- **Medium risk**: performance measure > **T_{mean}** and < **T_{90}**
- **High risk:** performance measure > **T_{90}**

Table 5.6 – Accidents-based performance measures thresholds based on the Tuscany Region network

	Acc. Frequency [acc./ years]			Acc. Rate [acc./(years*km*Mvehicles)]		
Segment Type	**T_{mean}**	**T_{80}**	**T_{90}**	**T_{mean}**	**T_{80}**	**T_{90}**
Roadway	0.16	0.20	0.40	0.16	0.28	0.46
Intersections	0.30	0.40	0.80	0.30	0.53	0.88
Urban	1.25	2.20	3.20	0.50	0.82	1.09
Total	0.44	0.60	1.20	0.28	0.48	0.81

5.2.2.5 *Comparison of the results*

The results obtained from the application of the HFET, and the accidents-based procedures were analyzed. The relationship between the results was tested by means of a linear correlation. The results have been tested with the T-test considering a significance level of 5%. The correlation analysis has been performed considering different data sets: a unique dataset, including the results of both the test roads (“Testing Group” 1 – TG1), two separate datasets, one for each test road (TG2) and three separate datasets, one for each type of homogeneous segment (i.e., Roadway Segments, Intersections Segments, Urban Segments) irrespective of the test road (TG3). Moreover, to account for possible relationships that differ from the linear correlation, the segments rankings of the two roads together (derived from the accidents-based performance measure and from the HFET) has been compared by means of Kendall's coefficient of concordance (Kendall's W).

The Kendall's coefficient of concordance is a non-parametric statistic. It can be used for assessing agreement among raters. Kendall's W ranges from 0 (no agreement) to 1 (complete agreement). The Kendall's W can be calculated following Eq. 6:

$$W = \frac{12 \sum_i^n (R_i - \bar{R})^2}{m^2 \, (n^3 - n)} \quad \text{Eq. 6}$$

Where:

W = Kendall's coefficient of concordance;

R_i = sum of the rank of the i-element (Eq. 7);

$$R_i = \sum_i^m r_{ij} \quad \text{Eq. 7}$$

$\bar{R}$ = the average of the obtained R_i;

m = total number of judgments (evaluations) for each element;

n = total number of elements;

r_{ij} = rank of the i-element for j-judgment.

The Kendall's W allows to evaluate the rate of agreement of a group of judgements. In this specific case, it evaluates the ratings of two couples of evaluation procedures: accidents frequency and HFS results, and accidents rate and HFS results. The results are tested considering the χ^2 probability distribution, with a level of acceptance $\alpha = 0.05$.

There is a close relationship between Charles Spearman's correlation coefficient r_S and Kendall's W statistic: W can be directly calculated from the mean (r_S) of the pairwise Spearman correlations r_S using the following relationship (Legendre, 2022).

$$W = \frac{(m-1) \times r_S + 1}{m} \quad \text{Eq. 8}$$

Where:

r_S = Spearman's correlation coefficient.

Eq. 8 is strictly true for untied observations only. The choice of using Kendall's W instead of Spearman r_S was because it is more suitable when the compared variables have the same direction, that is it is not possible that an inverse relationship is present.

5.2.3 Results

5.2.3.1 Segmentation results

For the present work, urban segments are excluded from the analysis if they belong to an urban area longer than 500 m. For this reason, the urban area of Tavarnuzze in the SR2 (between km 289.200 and 291.000), and the urban area of Collesalvetti in the SR206 (between km 31.400 and km 33.400), have been excluded from the analysis.

A big roundabout located in km 291.200 of SR2 has been also dropped out from the analysis because two other roads of higher class (two motorway) concur in the intersection. Traffic data about that specific intersection were not available and the main traffic direction is the one between the two motorways. Thus, accident data can't be compared with those of the other segments of SR2. Such intersection can't be considered as part of the analyzed two-lane two-way road. The intersection is depicted in Figure 5.7.

Figure 5.7 – Roundabout excluded from the first analysis.

Two segments have been also excluded from the SR206 because they comprise two oval-shaped roundabouts with two major intersections that cannot be judged by the application of the HSM model (neither roadway segments model nor intersection model). Those segments are located between km 34.100 and km 34.500, and between km 35.400 and 35.800 and are presented in Figure 5.8.

Figure 5.8 – Two oval-shaped roundabouts of SR206 excluded from the analysis.

The segmentation process results are summarized in Table 5.7 and Table 5.8. A total of 19 homogeneous segments for SR2 and 19 homogeneous segments for SR206 were obtained.

Table 5.7 – The homogeneous segments obtained for SR2.

ID	Length [km]	Segment type	Starts [km]	Ends [km]
281_6	0.600	Roadway Segment	281.600	282.200
282_2	0.500	Intersections	282.200	282.700
282_7	0.200	Roadway Segment	282.700	282.900
282_9	0.700	Intersections	282.900	283.600
283_6	0.300	Roadway Segment	283.600	283.900
283_9	0.200	Intersections	283.900	284.100
284_1	0.200	Roadway Segment	284.100	284.300
284_3	0.300	Intersections	284.300	284.600
284_6	0.300	Roadway Segment	284.600	284.900
285_1	0.300	Intersections	285.100	285.400
285_6	0.900	Roadway Segment	285.400	286.300
286_5	0.500	Intersections	286.300	286.800
287_0	0.800	Roadway Segment	286.800	287.600
287_8	0.800	Intersections	287.600	288.400
288_6	0.400	Roadway Segment	288.400	288.800
289_0	0.200	Intersections	288.800	289.000
291_0	0.500	Intersections	291.000	291.500
291_7	0.300	Urban Segment	291.500	291.800
292_0	0.400	Intersections	291.800	292.200

Table 5.8 – The homogeneous segments obtained for SR206.

ID	Length [km]	Segment type	Starts [km]	Ends [km]
029_6	0.600	Intersections	29.600	30.200
030_2	0.500	Roadway Segment	30.200	30.700
030_7	0.400	Intersections	30.700	31.100
031_1	0.400	Roadway Segment	31.100	31.500
033_4	0.200	Intersections	33.400	33.600
033_6	0.600	Roadway Segment	33.600	34.200
034_6	0.400	Roadway Segment	34.600	35.000
035_9	0.500	Roadway Segment	35.900	36.400
036_4	0.500	Intersections	36.400	36.900
036_9	0.500	Intersections	36.900	37.400
037_4	0.700	Roadway Segment	37.600	38.300
038_1	0.300	Intersections	38.200	38.500
038_4	0.700	Urban Segment	38.500	39.200
039_1	0.300	Roadway Segment	39.200	39.500
039_4	0.400	Intersections	39.500	39.900
039_8	0.300	Roadway Segment	39.900	40.200
040_1	0.600	Intersections	40.200	40.800
040_7	0.500	Intersections	40.800	41.300
041_2	0.300	Roadway Segment	41.300	41.600

Table 5.9 shows the composition of each Testing Groups (TGs) for the comparison: the total number of samples included in each dataset of each group is reported in the second column, while the other columns indicate the number of segments in the sample belonging to SR2 or SR206, and to each segment type, including both the roads.

Table 5.9 – Composition of the Testing Groups

Testing Groups		**Samples**					
ID	**Description**	**Elements in datasets**	**Road**		**Homogeneous segment Type**		
			SR2	**SR206**	**Roadway**	**Intersections**	**Urban**
TG1	**Total**	38	19	19	17	19	2
TG2	**SR2**	19	19	-	8	10	1
	SR206	19	-	19	9	9	1
TG3	**Roadway segments**	17	8	9	17	-	-
	Intersection segments	19	10	9	-	19	-
	Urban segments	2	1	1	-	-	2

It has been decided to consider also TG2 and TG3 to highlight if differences occurred by considering different samples. Indeed, the two roads have some different characteristics, and this may result in differences in the outcomes from the application. Moreover, considering different type of segments will help to understand if the HFET has some limitations in the analysis of specific segment type.

5.2.3.2 *Human Factors Evaluation Tool (HFET) results*

The HFS results of SR2 and SR206, deriving from the application of the HFET, are shown in Table 5.10 and Table 5.11. Table 5.10 provides the average results for each TG considering all the single Human Factors rules and the rules together.

Table 5.11 shows the results for each segment, for each single rule and for the Total HFS. The result is obtained considering the worst results of both the directions, as explaining in 5.2.2.2. The low, medium, and high-risk levels associated to the Total HFS (all rules and directions together) are highlighted in green, yellow, and red colors.

Table 5.10 - Average HFS for each rule

	First Rule	Second Rule	Third Rule	All Rules
Total HSs	49%	68%	69%	64%
SR2	39%	61%	63%	57%
SR206	60%	75%	75%	71%
Roadway	58%	72%	76%	70%
Intersection	42%	63%	64%	59%
Urban	36%	60%	55%	53%

Table 5.11 – HFS results for each rule considering both the direction together

SR2					**SR206**				
ID	**HFS I Rule**	**HFS II Rule**	**HFS III Rule**	**HFS Total**	**ID**	**HFS I Rule**	**HFS II Rule**	**HFS III Rule**	**HFS Total**
281_6	33%	43%	47%	43%	029_6	64%	76%	76%	73%
282_2	38%	68%	65%	59%	030_2	57%	81%	77%	73%
282_7	80%	79%	90%	82%	030_7	75%	82%	87%	83%
282_9	15%	39%	44%	36%	031_1	50%	82%	73%	71%
283_6	30%	71%	72%	67%	033_4	58%	90%	72%	76%
283_9	25%	55%	47%	47%	033_6	40%	87%	79%	72%
284_1	80%	84%	89%	85%	034_6	100%	89%	78%	90%
284_3	56%	71%	81%	72%	035_9	40%	68%	75%	62%
284_6	50%	67%	79%	68%	036_4	50%	69%	63%	62%
285_1	54%	41%	72%	53%	036_9	40%	72%	50%	57%
285_6	31%	54%	52%	48%	037_4	40%	63%	75%	62%
286_5	54%	58%	68%	61%	038_1	40%	65%	80%	64%
287_0	44%	60%	74%	61%	038_4	33%	72%	57%	58%
287_8	15%	67%	50%	48%	039_1	100%	73%	90%	81%
288_6	15%	71%	61%	54%	039_4	60%	63%	81%	69%
289_0	40%	83%	65%	68%	039_8	100%	73%	90%	82%
291_0	19%	42%	39%	34%	040_1	40%	50%	43%	45%
291_7	38%	47%	52%	47%	040_7	44%	64%	80%	66%
292_0	15%	50%	57%	45%	041_2	90%	80%	87%	84%

The result of the application of the HFET is also presented in Figure 5.9 (SR2) and Figure 5.10 (SR206). In these figures the evaluated segments are shown on a satellite image and are colored based on the result of the Total HFS (red: <0.40, yellow: >0.40 and <0.60, green: >0.60).

Figure 5.9 – Results from the First application of the HFET, SR2

Figure 5.10 – Results from the First application of the HFET, SR206

5.2.3.3 Accidents-based performance measures results

The accidents-based results of SR2 and SR206, deriving from the application of the HSM predictive model, are shown in Table 5.12. The frequency of observed, predicted, and expected number of accidents are presented in the table. The frequency is calculated as the total number of accidents in the analysis period divided by the years in the analysis period (2014-2018). The frequency of the expected number of accidents correspond to accident frequency. The accident rate is also presented in Table 5.12 and it is calculated considering the accident frequency divided by the annual traffic (in million vehicles) and the length of each segment (in km). Both the cells of accident frequency and accident rate are colored based on the level of risk accounting for the thresholds presented in 5.2.2.4 considering all the segment types together

("Total" in Table 5.6). The colors have the same meaning as above: red = high risk, yellow = medium risk, green = low risk.

Two graphs are also provided that highlight the relationships between predicted and observed number of accidents and expected and observed number of accidents. The graphs show a fair correlation between expected and observed number of accidents, and a bad correlation between predicted and observed number of accidents. The two graphs are represented in Figure 5.11. The graph on the left represents the results for SR2, while the graph on the right those for SR206.

Table 5.12 – Accidents-based performance measures results

SR2					SR206				
ID	Observed*	Predicted*	Expected *	Acc. Rate **	ID	Observed*	Predicted*	Expected *	Acc. Rate **
281_6	1.40	0.52	0.98	1.05	029_6	0.40	0.74	0.50	0.19
282_2	1.00	0.31	0.71	0.91	030_2	1.00	0.57	0.81	0.38
282_7	0.00	0.14	0.06	0.18	030_7	0.20	0.42	0.29	0.17
282_9	2.20	0.45	1.67	1.54	031_1	0.40	0.31	0.37	0.21
283_6	0.00	0.30	0.09	0.20	033_4	0.00	0.20	0.07	0.08
283_9	0.40	0.23	0.38	1.23	033_6	0.00	0.43	0.18	0.07
284_1	0.00	0.12	0.06	0.18	034_6	0.00	0.78	0.26	0.15
284_3	0.00	0.17	0.08	0.16	035_9	0.40	1.48	0.72	0.34
284_6	0.00	0.15	0.08	0.17	036_4	0.60	0.49	0.56	0.26
285_1	0.20	0.26	0.21	0.46	036_9	0.80	0.49	0.68	0.31
285_6	1.20	0.42	0.78	0.56	037_4	1.00	0.89	0.94	0.31
286_5	0.20	0.19	0.19	0.25	038_1	0.00	0.20	0.07	0.05
287_0	0.00	0.32	0.18	0.15	038_4	1.60	1.06	1.41	0.47
287_8	0.60	0.47	0.53	0.43	039_1	0.20	0.32	0.24	0.14
288_6	0.00	0.29	0.12	0.19	039_4	0.00	0.44	0.14	0.06
289_0	0.00	0.07	0.03	0.10	039_8	0.00	0.33	0.11	0.06
291_0	2.60	1.23	2.40	1.06	040_1	2.20	0.69	1.71	0.51
291_7	1.80	0.66	1.49	1.10	040_7	0.40	0.54	0.45	0.16
292_0	1.80	0.54	1.38	0.76	041_2	0.00	0.39	0.11	0.07

* [acc/year]

** [acc/(year·Mvehicles·km)]

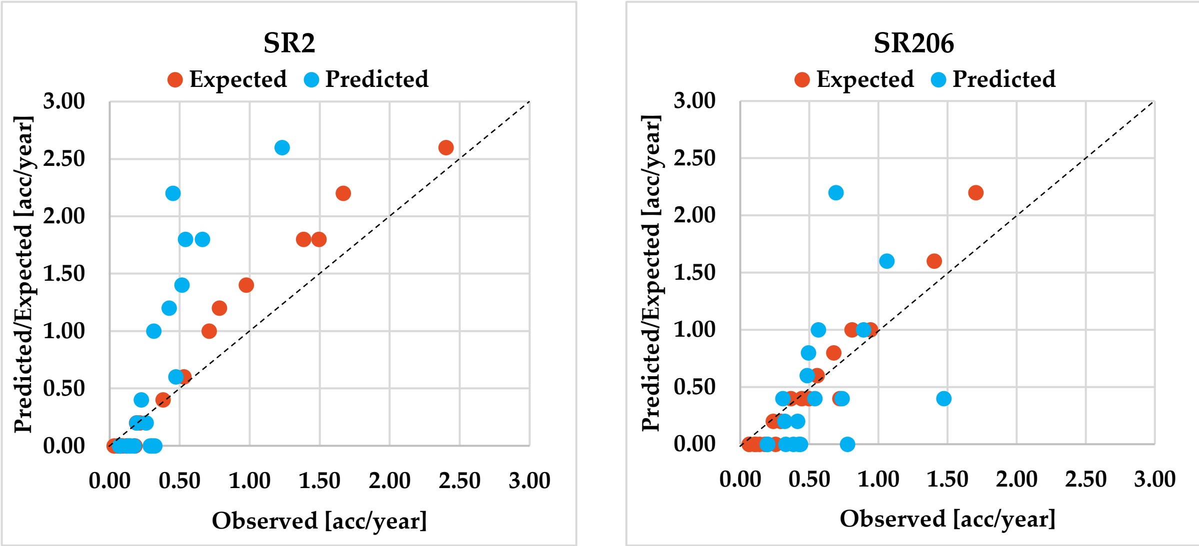

Figure 5.11 – Relationships between predicted and observed number of accidents and for expected and observed number of accidents for SR2 (left) and SR206 (right)

It can be observed that differences are present among the risk levels identified by the two accident-based performance measures (i.e., accident frequency and accident rate). Accident frequency is also influenced by segment length and traffic.

5.2.3.4 Comparison of the results

A comparison of the results has been made to test the effectiveness of the HFET to identify hazardous locations. The comparison is made by comparing:

- the ranking of the analyzed sections by means of Kendall'W;
- the correlation between the results of accidents-based performance measures and HFS, by means of Pearson correlation coefficient.

Both have been made considering three different testing groups: TG1 (all the segments), TG2 (considering separately the segments belonging to each road), and TG3 (considering separately each type of segment).

Ranking comparison

The results of the ranking comparison are summarized in the following tables. Results in detail are presented in APPENDIX 5.

Table 5.13 shows the results of the comparison between accident frequency and the HFS, and accident rate and the HFS, for each different testing group, by means of Kendall's W. The "Accident Frequency" and the "Accident Rate" columns of the tables show the value assumed by the Kendall's W, the χ^2, and the corresponding p-value (level of significance). The significance levels are always below the value of 0.05, thus the hypothesis that the result occurred by chance, can be rejected.

The dataset of urban segment is composed by only two elements and thus it cannot be tested, neither a coefficient can be calculated.

Table 5.13 – Kendall's W results

TG	Description	Elements in datasets	Accidents Frequency			Accidents Rate		
			W	χ^2	p-value	W	χ^2	p-value
TG1	Total roads	38	0.834	61.709	0.002	0.886	65.595	0.001
TG2	SR2	19	0.969	34.895	0.003	0.928	33.411	0.004
	SR206	19	0.825	29.716	0.010	0.794	28.579	0.013
TG3	Roadway segments	17	0.787	25.176	0.017	0.843	26.980	0.011
	Intersection segments	19	0.866	31.168	0.007	0.922	33.189	0.004
	Urban segments	2	-	-	-	-	-	-

Linear correlation

The results of the linear correlation comparison are summarized in Table 5.14. Results in detail are presented in APPENDIX 5.

Table 5.14 shows the results of the comparison between accident frequency and the HFS, and accident rate and the HFS, for each different testing group, by means of correlation coefficient. The "Accident Frequency" and the "Accident Rate" columns of the tables show the value assumed by the Pearson correlation coefficient, the coefficient of determination (R^2), and the critical value of the Pearson coefficient related to the significance level of 5%. The calculated Pearson coefficients are always above the critical value. If the Pearson coefficient is higher than the critical value, thus the hypothesis that the result occurred by chance, can be rejected.

The dataset of urban segment is composed by only two elements and thus it cannot be tested, neither a coefficient can be calculated.

Table 5.14 – Linear correlation evaluation results

TG	Description	Elements in datasets	Accidents Frequency			Accidents Rate		
			r	R^2	$r_{c,\,\alpha=0.05}$	r	R^2	$r_{c,\,\alpha=0.05}$
TG1	Total roads	38	-0.720	0.519	0.36	-0.765	0.585	0.36
TG2	SR2	19	-0.790	0.624	0.48	-0.767	0.588	0.48
	SR206	19	-0.747	0.557	0.48	-0.687	0.472	0.48
TG3	Roadway segments	17	-0.596	0.355	0.51	-0.7	0.510	0.51
	Intersection segments	19	-0.786	0.618	0.48	-0.8	0.620	0.48
	Urban segments	2	-	-	-	-	-	-

5.2.4 Discussion on the results

5.2.4.1 Segmentation

Segmentation has proven to be a challenging procedure that may also influence the subsequent evaluations. This type of problems is common also to both RSIs and accident analysis. Some considerations were made.

1. The HFET allows to analyze single PCLs and their transition area, that is the part of the road that precedes the PCL itself for about 6-10 seconds. The events chain of the possible accident starts and develop in this area. If a PCL is located close to the boundary of a segment, this area may develop in the adjacent segment. If the segmentation is made without considering this, it may lead to some difficulties in the segment judgment. Thus, the process must first identify the PCLs that should be analyzed and then defines the segmentation.
2. Longer segments means that the possibilities of finding PCLs are higher. Thus, for final comparison of different segments, it appears more useful to define segments lengths which are the more similar as possible, to indirectly remove any possible length influence.
3. Segmentation for detailed analysis is not practical for a network level. Moreover, when analyzing the PCLs in both directions, it is not rare that more than one PCLs and their area of influence overlap and influence each other, creating some long segments and some short segments. Thus, it appears a good solution to have a two steps segmentation: one that allows for the analysis of the road, and one that allows to aggregate the results in longer sections suitable for a NWRSA.

5.2.4.2 Human Factors Evaluation Tool (HFET)

The aspects concerning the review of the HFET itself and the suggestions for its improvements considering its general application (also outside the procedure), are provided in 0.

The first identified relevant aspect is that the HFET requires some time to be applied. For the analysis of a single segment (which may contain one or more PCLs) and considering only a single direction, it takes about 30 minutes. Some adjustments, improvements, and its inclusion in an excel file (as described in 4.4), reduce the application time to about 20 minutes. Nevertheless, it is still a quite long process considering analyzing a network. The two road stretches considered contains a total of 255 PCLs (161 for SR2 and 94 for SR206), which translate into 10200 minutes of work because they must be analyzed in both directions. 10200 minutes are about 170 hours, which are about 21 working day (considering 8 hours per day). Therefore, one working month for about 24 km of road. It is too much. Thus, one of the objectives must be the reduction of the number of PCLs that will be analyzed, excluding those ones that clearly do not provide any high risk.

Another relevant aspect is the presence of different results: one for each rule and considering all the rules together. The total HFS (all the rules together) may sometimes hides some critical results of one or two rules because of some very good results of the remaining rules. A deeper analysis of the tool and a discussion with one of their creators (i.e., Dr Sibylle Birth) highlights that accounting for the results of the single rules will improve the analysis reliability. For this reason, the evaluation of the road segment (or section) must consider also the results obtained in each rule, not only the Total HFS.

Finally, as already stated, HFET provides numerical results. This allows to "work" with the numbers, easily defining ranking and evaluate the distribution of the results within the section (e.g., average, and standard deviation values).

5.2.4.3 Accidents-based performance measures

The accidents-based performance measures (i.e., accidents frequency and accidents rate) have been calculated with the application of the HSM predictive method (AASHTO, 2010), which include an EB adjustment procedure. Looking at the results (5.2.3.3), it appears clear that the predictive model itself provide some very different results comparing the predicted to the observed number of accidents (Figure 5.11). These results are greatly "balanced" by the application of the EB procedure. allows for a first consideration: the predictive method likely still requires observed accident data to be effective. A second considerations must be made for the purpose of testing the effectiveness of the whole procedure on the chosen road stretches (CHAPTER 6 and CHAPTER 7). The use of a predictive model with EB adjustment to reduce the bias related to accident data, needs too much data to be implemented (including the evaluation of a calibration factor). Those data are not available for all the stretches considered. Moreover, the year of analysis and the traffic are so that, also considering the EB adjustment, observed accidents data will have a greater weight in the computation of the expected number of accidents. Thus, it appears a reasonable choice to directly consider the number of observed accidents, then to calculate the number of expected accidents.

A third consideration must be made considering the two different accidents-based performance measures and their comparison with the HFET results. The accidents frequency includes traffic data and segments length. This means that the number of expected accidents per year will increase with an increase in segment's traffic and length. The accidents rate instead does not include the influence of traffic and length. It provides a number representative of the level of risk of the road itself. If the traffic increase in a specific road segment, theoretically it is expected that the number of crashes will increase, but the value of the accidents rate will still be the same. The HFET doesn't account for the influence of traffic, for this reason the comparison should be mainly made between the results of the accidents rate, and the HFET. About length, the HFET only partially and indirectly accounts for the length. The more the PCLs in the analyzed segment, the higher the possibility of bad results. In turn, the longer the segment, the more probable to find a higher number of PCLs. This confirms one of the statements from 5.2.4.1, that is to choose segment of similar length for the risk level definition.

5.2.4.4 Comparison of the results

Ranking comparison

Considering the three different testing groups (TG1, TG2, and TG3), the results show good concordance considering the Kendall coefficient of concordance (5.2.3.4). The results demonstrated that a ranking based on the HFET results, is very similar to a ranking based on accidents rate (and accident frequency). Moreover, the proactive quality of the tool makes it usable also when accident data are not present.

Considering the risk level and the comparison between accidents rate and HFS, 30 out of 38 segments (about 79%) result to be classified as the same risk level considering TG1 and TG2 (where the thresholds for accidents rate is defined accounting for all the types of segments together), and 26 out of 38 (about 68%) for TG3 (where the thresholds for accidents rate is defined accounting for each segment type alone). A significative difference is represented by the roadway segments results where only 8 out of 17 (about 43%) segments have been classified with the same risk level. Moreover, considering roadway segments, when a difference is present, the accidents rate is always of a higher level than the HFS. This is due to the general minor number of accidents occurring in the network on this type of segment, as depicted with the threshold's values in Table 5.6. Therefore, the thresholds values are lower and the possibilities to exceed them are greater. It can be also observed that the "total" thresholds values and the intersections' thresholds values are very similar, while roadway segments' thresholds values are about half. This suggested that the number of roadway segments in the network is low. However, to state some certain conclusions, the entire network segmentation considered to obtain those thresholds must be analyzed. For this reason, considering the "total" thresholds to define the risk level of each segment, seems to be a more reliable solution.

The thresholds choice may influence the risk level of the segment, for this reason the thresholds definition is not trivial. Many times, thresholds for accident-based performance measures are chosen based on the percentile distribution (like the thresholds used in this work and provided by the Tuscany Region). This can be both a strength and a weakness. It is a strength because it allows to adapt the judgement for specific site and to find out the most critical segments within a specific group. On the other hand, it is a weakness because it doesn't provide a fixed threshold to universally comparing the risk level of different site. The HFET instead, provides a defined thresholds which are the same among different site.

Linear correlation comparison

The results show a negative correlation between the HFET results and the accident-based performance measures results. The correlation coefficient results are very similar for each TG and considering both the two accidents-based performance measures; however, the same trend as the ranking comparison can be noted: accidents rate results are closer to the HFET results for TG1 and TG3, while the accidents frequency results are closer to the HFET for TG2. Despite the clear negative correlation, the correlation coefficients are not strong, and observing the plotted distribution of the results (APPENDIX 5), it can be drafted that a linear correlation would probably not be the most fitting equation. Anyway, the objective of this comparison was not to define the exact relationship between the two measures. Identifying the most suitable equation is not possible because of the too little samples, both for the final comparison and for the developing of an accurate APM (developed according to the local data).

Summary of findings

Based on the first application of the HFET, the following conclusion can be drafted that are useful to the implementation of a NWRSA procedure:

- segmentation process must account for the area of influence of each PCL;
- a double segmentation should be considered: one for the application of the HFET, and one for summarizing the results for a NWRSA;
- the sections representing the segmentation for the NWRSA must be long enough to be representative and should be the same length as far as possible;
- the number of PCLs to analyze must be reduced, without compromising the results;
- the results should account also for the results for each Human Factors Rule, and not only for the Total HFS;
- the results of the HFET clearly help to identify critical locations.

Thus, the NWRSA procedure should account for those requirements.

5.2.4.5 *Consideration about the influence of exposure*

By theoretical means, a linear correlation between the number of accidents and length of a homogeneous segment, is expected. On the other hand, this assumption it is only theoretical because road conditions vary continuously[14] (Hauer, 2015), thus it is difficult to find a homogeneous segment with continuous characteristics.

Therefore, trying to define a conceptual equation for risk, while analyzing road safety, it seems better to not account for the segment length. This is even more clear when thinking of possible accident causation. Triggering factors related to road are due to changes in the road conditions to which drivers must adapt[15]. The failed adaptation to the new conditions may cause an operational mistake and can result in an accident (see 3.1.3). Implicitly, the longer the segment analyzed, the higher the possibilities of changing in the road conditions. But this does not mean that the risk account for a generic length. It accounts for the number of possible critical situations. The length of a segment may influence the occurrence of an accident under specific circumstances, which are peculiar to that specific accident causations, for example accidents due to fatigue, or a very long curve with short radius after a long straight. Lengths of specific elements may influence the probability of an accident, but a direct relationship between length and the whole number of accidents does not seem to correctly describe the reality. Nevertheless, assuming accidents as a totally random variable, implies by means of

[14] Road conditions means all the characteristics of the road which may influence the driver behaviour and thus the occurrence of an accident, such as geometrical conditions, environment conditions, region where the road develops, driveways density and so on.

[15] Triggering factors not related to road are not considered in this analysis, because they cannot be eliminated by road improvements.

statistical analysis that the longer the stretch analyzed, the higher the possibilities of an accident. For this reason, this assumption works very well with regression models, where, to date, it is impossible to account for all possible differences in road conditions and:

- the greater the length, the higher the possibility to find an accident along the road;
- the greater the length, the higher the possible number of differences in the road conditions, and thus, the higher the possible accidents triggering factors.

Thus, even if useful to make statistical approximation of the reality from observed data, it seems theoretically not correct to include the length of the segment into the risk equation[16].

Moreover, the assumption that the segment length directly influences the number of accidents sometimes leads to some problems modelling an APM because while other unaccounted factors are present, length can't be considered an independent variable (Srinivasan and Bauer, 2013).

Another example is about intersections, where the length is not accounted while computing the exposure (AASHTO, 2010). This is intuitively correct, because intersections can be assimilated to points while compared to the whole network. Nevertheless, if it is accepted that the length of a segment has an influence on the number of accidents, is it possible to say that intersections with a wider extension should be more prone to accidents compared to smaller intersections (for example intersection with longer turning lanes, or roundabout with longer circulatory roadway).

The difference in the statistical models is present because the difference in the length of roadway segments is higher than the difference in intersections' lengths, however, if we assume that length has a specific influence, it should be always considered.

If the length is not considered in the exposure, the only independent variable that influence exposure is traffic volume[17]. Some considerations must be made also concerning this variable.

First, traffic is not always considered in safety analysis, and its use is linked to the type of analysis and the aim of the analysis. An example is provided by the Swiss regulation about identification of black spots, where the exposure is not considered (VSS, 2015). Road administration must be sure to what they are searching. Talking about accidents in general, the use of exposure, highlights the general risk of an accident on a road, while the exclusion of exposure from the equation, allows to identify the riskiest road locations in term of only road

[16] More precisely, it must be included only where it has a direct influence on the probability of occurrence of a specific event.

[17] Also in this case, the focus is on road characteristics, including its functional characteristics. Other aspects concerning for example the vehicles fleet characteristics and the population characteristics (e.g., driving capacities) are not considered, even if on a general point of view, they contribute to the exposure.

characteristics. This means that if traffic heavily flows in different period, the number of accidents will probably change, while the road risky characteristics are still the same. The intervention priority is up to the road administration and, generally, the choice is to intervene where more accidents occur, thus including traffic in the equation.

Another aspect that must be considered about traffic is that it does not influence only the exposure, but also the probability of occurrence of a specific event, and it may influence the severity of an accident. Possible combinations are many, but a single simple example can clarify these statements. A road with few vehicles may results in no or very few rear-end collision accidents, while a road with many vehicles may have a higher number of rear-end collision. This increase it is not simply due to a higher exposure, but because traffic conditions improve the possibilities of this kind of accident.

Both these concepts have been considered in developing the procedure. The first leads to the identification of sections of semi-fixed length for the NWRSA results presentation (see 5.3.5), while the influence of traffic has not been considered and it has been decided to mainly focus on the in-built safety, without considering exposure (see final paragraph of 5.4).

5.3 The Human Factors Evaluation (HFE) procedure

5.3.1 Objectives of the procedure

The intended procedure was developed based on the main objectives of the research, and on the specific requirements derived from the first application of the HFET. These are listed in the followings.

Main objectives

a) Definition of NWRSA procedure, that
b) Is based on Human Factors
c) Includes visual inspection of the road (European Parliament and the Council, 2019)
d) Is a pro-active procedure (European Parliament and the Council, 2019)
e) Provides at least three level of risk (European Parliament and the Council, 2019)

To account for the Human Factors aspects, it has been decided to include the PIARC HFET in the procedure.

Concerning the first application of the HFET to two test roads, some requirements for its inclusion have been found.

Requirements

d) A double segmentation should be considered: one for the application of the HFET, and one for summarizing the results for a NWRSA. Segmentation required for the application of the HFET should be made after identifying the area of influence of each

PCL. The sections representing the segmentation for the NWRSA must be long enough to be representative and should be the same length as far as possible.

e) The number of PCLs to analyze must be reduced, without compromising the results.
f) The results should account also for the results for each Human Factors Rule, and not only for the Total HFS.

The whole procedure must finally be tested both considering its reliability, i.e., effectiveness in identify risky road sections, and its repeatability, i.e., the possibility of obtaining the same results with application from different inspectors. Moreover, also the consistency of the procedure against different segmentation shall be tested.

The following paragraphs provide a description of the structure of the procedure and the choices made to satisfy the listed objectives and requirements.

When to apply the procedure

The procedure has been developed to analyze rural roads; however, the term "rural" must account not for administrative conditions, but for environment conditions. That is, a road classified as urban that has clear rural characteristics can be evaluated with this procedure. The procedure cannot be used to analyzed long road stretches with many PCLs, such as driveways, intersections, pedestrian crossings, and a clear urban environment, because drivers change their behavior when such characteristics are present. An indicative density of about 1 PCL every 10 m can be used as reference. Nevertheless, if such density conditions are present, but for a distance shorter than 500 m, the segment should be included in the analysis.

5.3.2 Structure of the procedure

To achieve all the objectives set, following the identified requirements, the procedure will be divided into three different steps, according to the conceptual scheme shown in Figure 5.12.

The **first step** (top-down process) allows to make a first screening of the road to identify the PCLs which have a high possibility to be critical. The screening is made without a detailed analysis of the road. In these steps expectations play a fundamental role. Indeed, the screening process is based on the evaluation of the difference between reality and possible expectations induced by the road, considering the three aspects discussed in 3.7, that are punctual expectations (PEXs), general expectations (GEXs), and visibility (VIS). In this step the road is divided into different segments which have the same characteristics in terms of factors influencing expectations. In the end of this step all is ready for the identification of CHLs.

In the **second step** (evaluation process) the CHLs are identified based on the expectations parameter defined in step 1 for each PCL. Once all the CHLs have been identified, their area of influence is also identified (i.e., CHTs) and eventually they are grouped in HFESs. The HFET is than applied to each HFES. The results obtained are four HFSs for each HFES (one for each of the three rules and one Total HFS). This process requires a visual detailed inspection of the road.

The **third step** (bottom-up process) allows to organize the results so that they are suitable for a network classification (longer sections, i.e., NASs). This means to group many HFESs into singles NASs. For each NAS, a risk code RC is calculated, which accounts for the different results between each HFES and each rule within the NAS, and for the distribution of the results. The RC allows to both identify four different levels of risk and to make a ranking of the NAS.

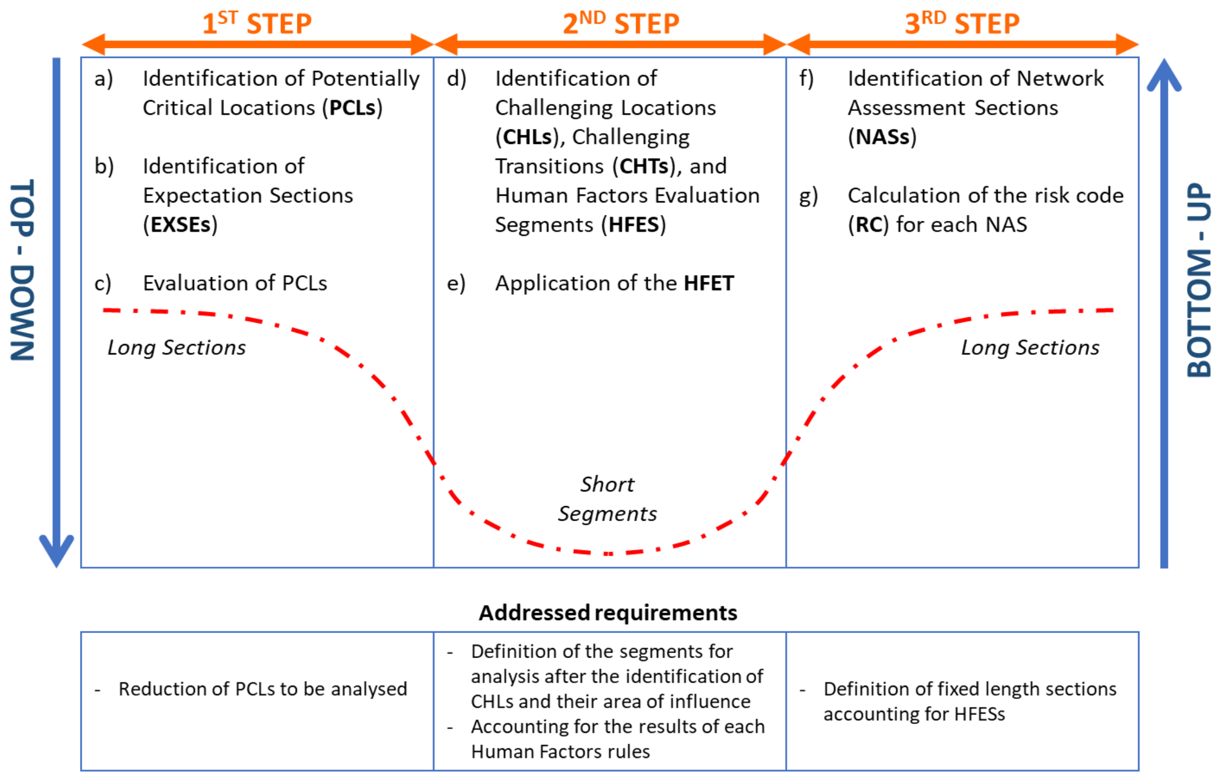

Figure 5.12 – Conceptual scheme of the procedure

5.3.3 The first step of the procedure

The main aim of the first step is to identify the characteristics of the roads analyzed considering their influence on driver expectations. In this step, the basis for a first screening is set (identification of CHLs, in step 2) and the PCLs are qualitatively evaluated. The evaluation of the PCLs is carried out by judging the level of compliance between possible expectations induced by the road, and the real road development and configuration. This is done by assigning to each PCL a risk level for the GEXs (three risk level: high, medium, and low), VIS (three risk level: high, medium, and low), and PEXs (two risk level: high and low). The assignment is made taking care of:

- GEX: how the PCL is expected considering the EXSE to which it belongs (a pedestrian crossing cannot be expected within a wood where no buildings are visible);
- VIS: evaluate if sufficient DSD is present based on the expected speed and alertness that the driver is expected to have while driving that specific EXSE that includes the analyzed PCL (the driver needs more time to see, understand and react to the pedestrian crossing

considered in the previous example; if the road stretch they are driving is a fast road stretch in a wood where no buildings, or intersections, or driveways are visible, where the attention to the road, and the alertness, are reduced);

- PEX: specific configuration of the road and of the field of view close to the PCL; this is done through fast visual inspection of the road by Human Factors experts. Contrary to GEX and VIS, which can be calculated, PEX derive from qualitative judgments of inspectors. For this reason, only two level of risk are considered for PEX, which mean: "some main issues are present" (high risk level), or "no or very low issues are present" (low risk level).

All these processes will be explained in the following paragraphs, considering the three main sub-steps, which are:

- Identification of PCLs;
- Identification of EXSEs;
- Evaluation of PCLs.

5.3.3.1 Identification of Potentially Critical Locations (PCLs)

PCLs are short road stretches ranging from few meters (punctual, e.g., pedestrian crossings) to some tens of meters (extended, e.g., curves and intersections), which requires a change in the driver's driving program to be driven under safety conditions. PCLs are any areas where drivers must adapt their driving program by changing speed, braking, steering, or changing lanes. The list of the main PCLs to be considered is presented in 5.1.2.

The identification of PCLs is the simple process of identify all locations along the road stretch under inspection. If a specific PCL is identified which does not belong to the list presented in 5.1.2., it must be considered anyway (in this case, all the evaluations concerning GEX, PEX and VIS, must be made by the inspector, without any automatic procedure). All the PCLs should be identified, taking note of their position (i.e., kilometers/miles post) and their subcategory, referring to Table 5.2 of 5.1.2.

An example of the result of the "identification of PCLs" process is presented in Figure 5.13, where colored dots on a satellite image, represent the position of each PCL. The dots have different color to represent different types of PCLs. The image shows the road stretch of the SR2 analyzed in the first application of the HFET. The identified PCLs are 161 (this case study is discussed in 6.3.1).

Figure 5.13 – Identification of PCLs, example from the case study of SR2

The identification of PCLs may require some time, however those data are often available to road agencies and, if not, this could be a useful update of the road agency's database. Moreover, the identification of PCLs doesn't require any specific instruments, and can be made also in office using GIS software.

5.3.3.2 *Identifications of Expectation Sections (EXSEs)*

EXSEs are road sections that are uniform for some specific characteristics. Those characteristics are the causes and clues that contribute to create driver general expectations, and thus influence what drivers expect to find on that specific road stretch. For this reason, it can be stated that within the same EXSE the GEXs are the same. Thus, the main problem to solve was to understand how to identify GEXs. As explained in the introductory chapters, there are many factors influencing GEXs; however, this first step must be fast and thus cannot account for all the possible concurring factors in a detailed way; it must consider only the most influencing factors. For this reason, it has been decided to consider three main road characteristics, which are also easily identifiable. These road characteristics are:

- the road category;
- the road winding;
- the road perception of possible interaction (PPI).

The combination of these three *design characteristics* determines the *operating characteristics* of the stretch, which are the **Expected Speed (V_E)** and the **Alertness Level (AL)**. The EXSE identification procedure is conceptually represented in Figure 5.14. The minimum length suggested for an EXSE is of 1 km.

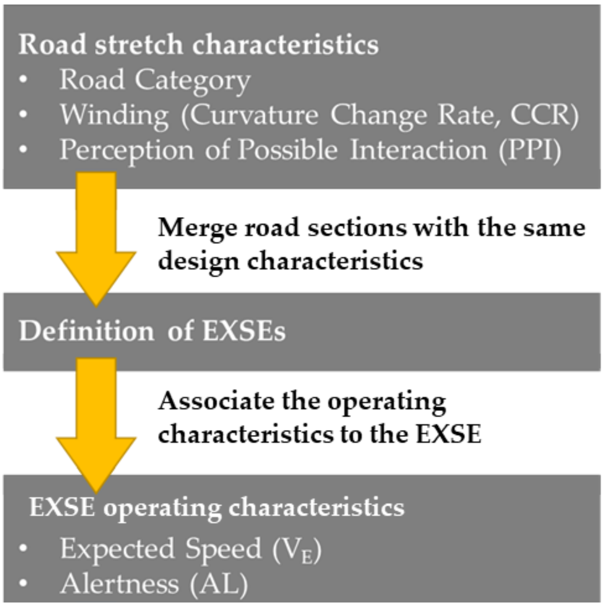

Figure 5.14 – Logic scheme for the definition of an EXSE

The road categories considered in this work, have been listed in 5.1.3. Those categories, considering the rural roads, are motorways, rural highways, and rural local roads. It is useful to remember that this work focuses on rural highways, thus all the further considerations will be made accounting that all the analyzed roads will be rural highways. A clear identification of the road category is crucial to behave correctly. This is at the center of the concept of self-explaining roads.

Winding

Three level of road winding can be identified: high winding, medium winding, and low winding. The high winding level is assigned to road stretches with many curves of short radius and generally long development. A road of medium winding level is characterized with many curves of high radius and medium development. The whole stretch presents a sinuous development, but drivers can generally drive quite fast in that stretch. The low winding level is instead characterized by many straights and only few curves with generally high radius and low development. An example of three different road winding is presented in Figure 5.15. The road considered is again the SR2 from km 280.600 to km 289.600. The red stretch, which is a high winding stretch, is characterized by a high number of curves with small radius (min.: 36 m, max.: 270 m, average: 110 m, density: 7.75 curve/km); the green stretch is characterized with many tangents and curves with a very high radius (min.: 140 m, max.: 510 m, average: 280 m, density: 3.2 curve/km); the yellow stretch is a medium winding radius, which presents some curves with a medium radius and few straights with low development (min.: 100 m, max.: 290 m, average: 160 m, density: 8.5 curve/km).

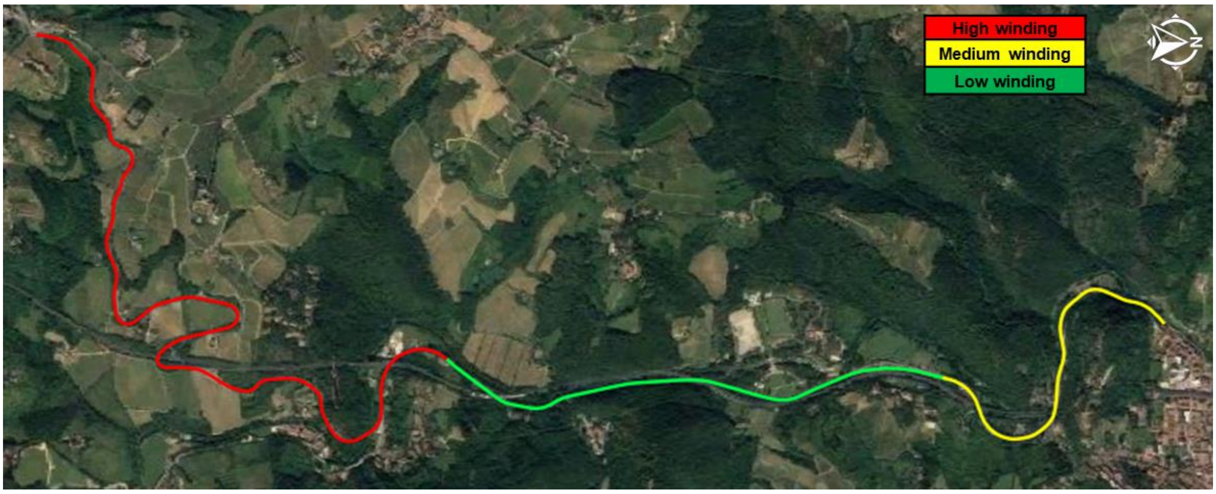

Figure 5.15 – Example of three road stretches of different winding, SR2 from km 280.600 to km 289.600

Even if some qualitative assumptions can be made, it is suggested to measure winding by means of CCR. The CCR is defined as the sum of the absolute values of angular changes in the horizontal alignment divided by the total length of the road section and is calculated using:

$$CCR = \frac{\sum_{i=1}^{n} |\gamma_i|}{\sum_{i=1}^{n} L_i} \qquad \textit{Eq. 9}$$

where:
CCR = curvature change rate (gon/km);
γ_i = angular change of the geometric element i (gon);
L_i = length of the geometric element i (km);
n = number of geometric elements of the road section (tangents, circular curves, clothoids);

The CCR values have been calculated for the example in Figure 5.15 and the results are shown in Figure 5.16. The graphical representation of the CCR shows that it can be generally clearly identified considering the trend of the cumulative angular changes.

The following threshold are suggested to identify the winding level based on the CCR value:

- High winding: CCR > 350 gon/km
- Medium winding: 350 gon/km ≥ CCR ≥ 160 gon/km
- Low winding: CCR < 160 gon/km

The threshold between the low level and the medium level is also supported by the study of Marchionna and Perco (Marchionna and Perco, 2008), which identifies the threshold of 160 gon/km as the limit for 90 km/h operating speed in curve. Greater values of CCR will result in operating speeds lower than 90 km/h. According to the operating speed model of Marchionna and Perco (Marchionna and Perco, 2008), a CCR of 350 gon/km corresponds to about 80 km/h of desired speed (V_{des}). V_{des} is the speed to which drivers tend under unconstrained conditions, thus it is the upper value of the speed range. Additional details about the CCR and the related statistics of some case studies analyzed can be found in APPENDIX 6.

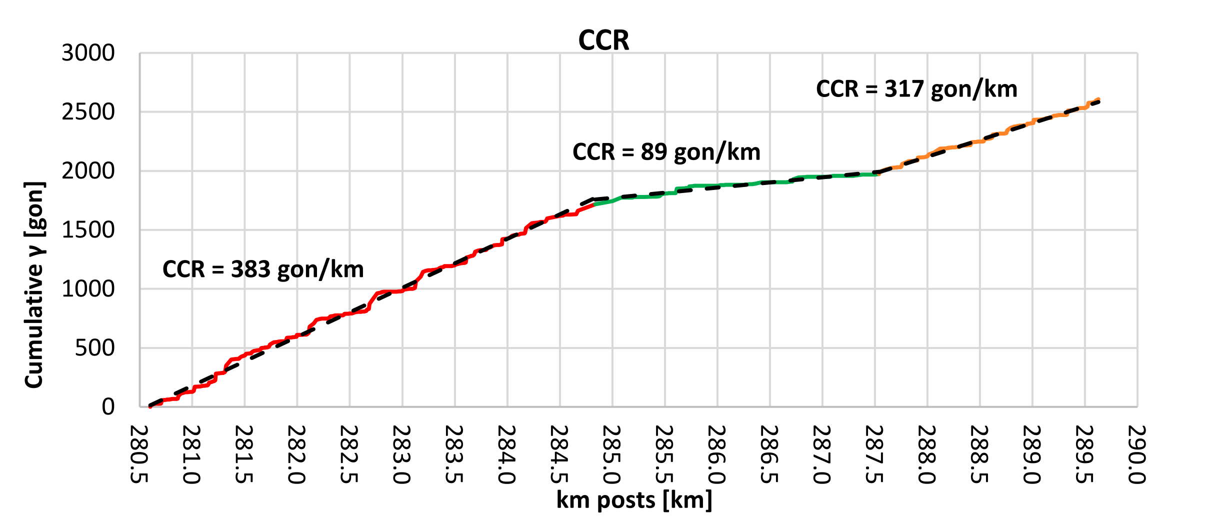

Figure 5.16 – CCR evaluation, SR2 from km 280.600 to km 289.600

Perception of Possible Interaction (PPI)

The PPI concept concerns the possibilities for a car travelling the section, to find locations where an interaction with other road users is possible. For example, urban areas generally have a high PPI, because of the presence of many driveways, at-grade intersections, and pedestrian crossings. However, even if the interaction is due to the presence of those specific locations, the perception of possible interaction is generally due to the road environment. For this reason, it must be not considered only the presence of those specific locations, but mainly if they are clearly perceived. Taking again the example of the urban area, the driver will first perceive an environment that is urban, with many houses, commercial activities, and a different cross-section. Consequently, it will also expect a change in the number of interaction and points of conflict, and they will adapt their driving behavior to drive under safe condition in that environment. Instead, if the driver travels in a rural stretch in the countryside with many driveways from some industrial activities and residential area which are not directly visible, he will probably feel to be traveling an area of reduced possibilities of interaction (low PPI), even if the conflicts points are present in a high number. Therefore, the inspector judging the PPI must consider the perceived environment and not the actual development of the road. The inspector should judge the stretch considering three level of PPI:

- High level: only urban area can be considered at high level. High level means that houses and activities are clearly visible on the roadsides. The cross-section is clearly an urban cross-section, with sidewalks or pedestrian paths on road margins. Crossings, driveways, at-grade intersections are clearly present in a high number.

- Medium level: this level represents the lower level for urban area and the upper level of rural area. Such PPI is often representative of suburban area, where the density of houses and commercial activities is reduced. Medium level can also address short rural road stretches which pass through small village or a group of houses along the road.
- Low level: only rural area can be considered at low level. Low level means very few or no perceived possible interactions. The surrounding environment is almost totally natural, without any trace of anthropization, if not the road itself.

Some examples of medium and low level rural roads are provided in APPENDIX 7.

The evaluation of the PPI is subjective. However, a survey has been carried out within a sample of 69 people from Italy, considering the same images proposed in APPENDIX 7. In the survey people were asked about four different questions for each image. The respondents should answer to the same question for all the images and then move to the next question. The questions asked were the following.

- How much attention is needed to drive safely on this stretch of road (much, moderate, little)?
- How much comfortable and easy would be driving on this road (much, moderate, little)?
- How probable is it that a little further on the road are there points where it is necessary to slow down (much, moderate, little)?
- Which speed range (in km/h) do you think is acceptable (considering safety and functionality) to travel on this road (30-50, 50-70, 70-90, 90-110)?

The respondents were asked to answer intuitively, without thinking too much time on the answer. The obtained answers were incredibly concordant, as depicted in the summary graphs from Figure 5.17, Figure 5.18, Figure 5.19, and Figure 5.20. The images are numbered from 1 to 24. The first 11 images refer to medium PPI level, while the images from 12 to 24 refer to a low PPI level (see APPENDIX 7). By analyzing the results of the survey globally, it appears that the medium PPI road images have been judged as attention-demanding, not very comfortable, with a high risk of encountering a PCL further on, and that should be travelled at low speeds. On the other hand, low level PPI road images, have been judged as requiring low attention, comfortable to be travelled, with low risk of encountering a PCL further on, and that should be travelled at high speeds.

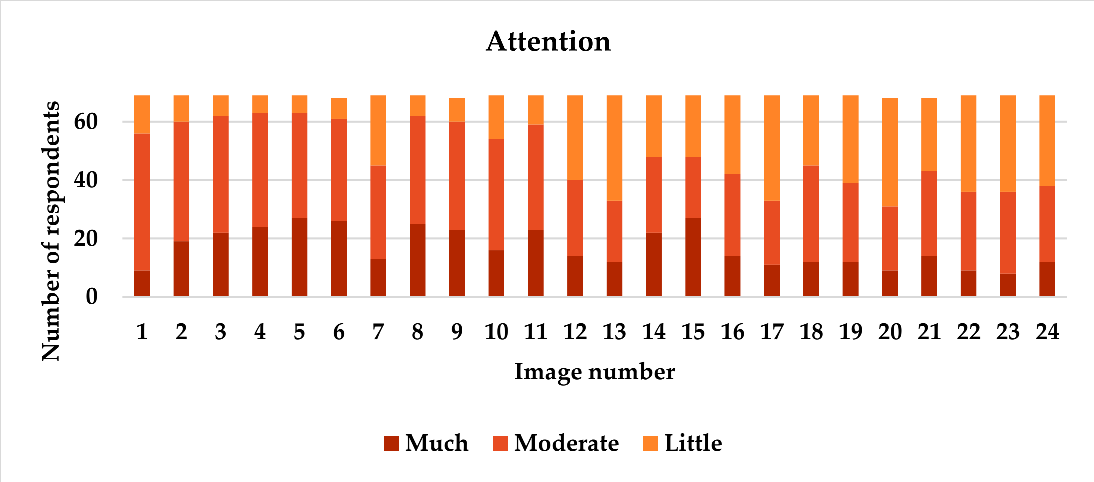

Figure 5.17 – Results of the "Roads' perception" survey concerning attention

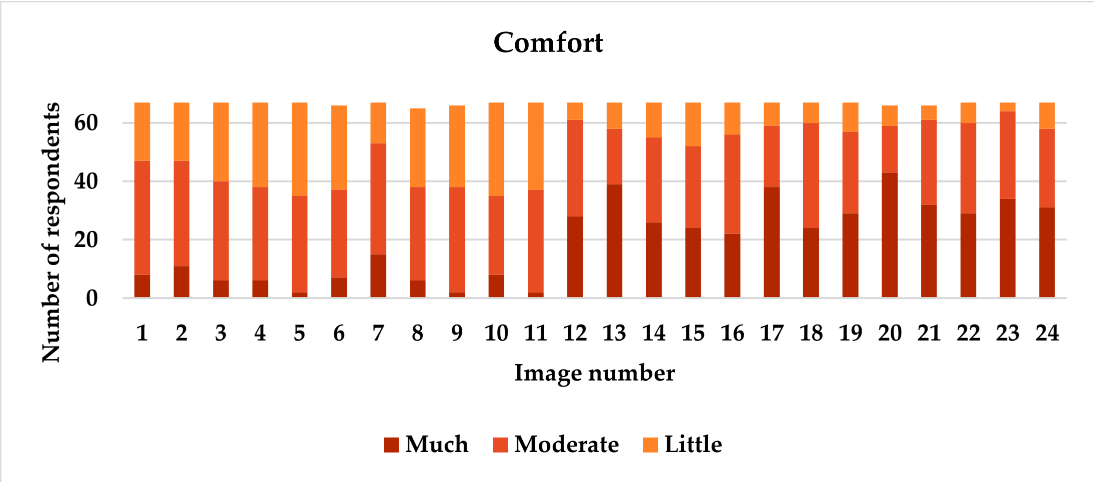

Figure 5.18 – Results of the "Roads' perception" survey concerning comfort

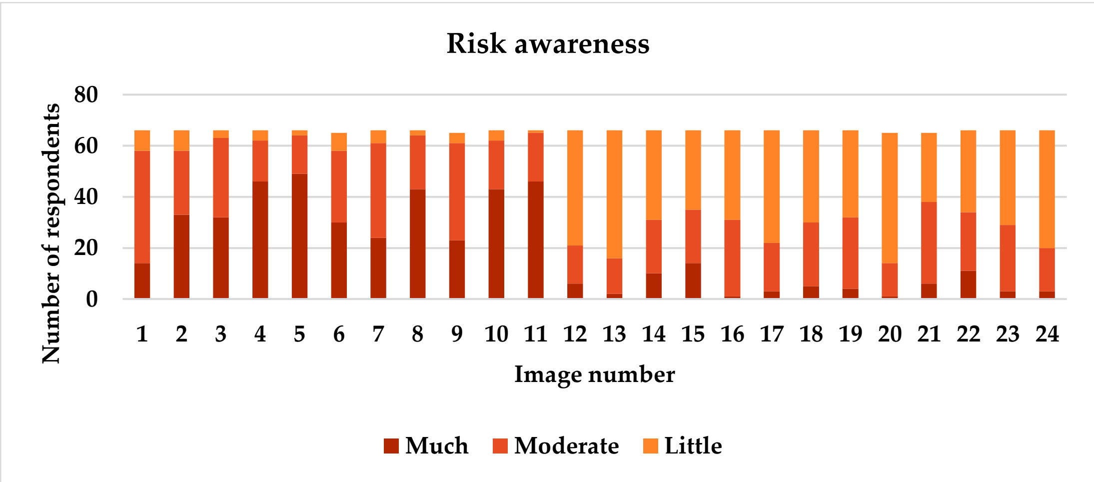

Figure 5.19 – Results of the "Roads' perception" survey concerning risk awareness

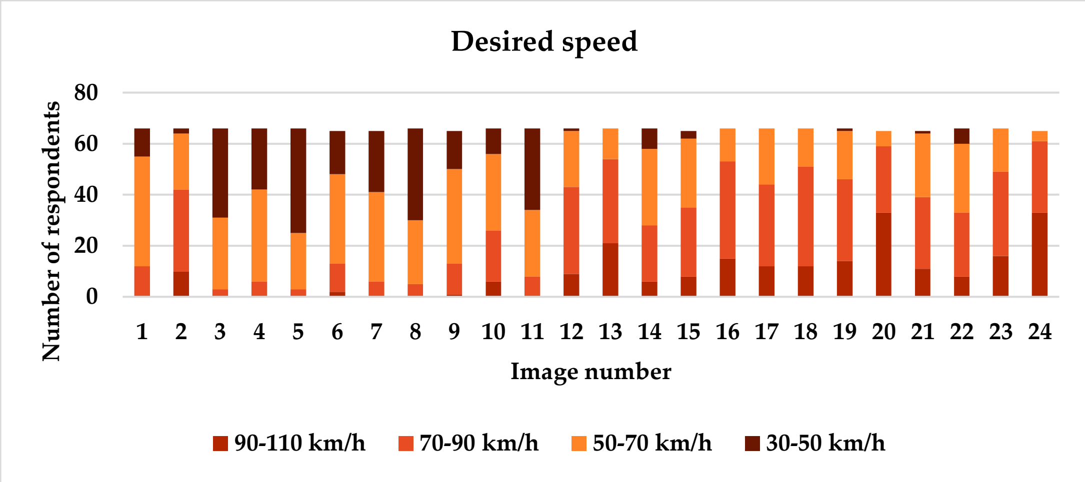

Figure 5.20 – Results of the "Roads' perception" survey concerning desired speed

Additional analysis of the results also helps to prove some assumptions and conclusions described in the previous chapter, such as the influence of road winding and PPI levels on the desired speeds and alertness. Disaggregated analysis of the results of the survey, is presented in APPENDIX 8.

The results from the surveys are consistent with the results from Weller et al. (Weller et al., 2008), where they identified that driver behavior can be highly influenced by the perceived environment, specifically consider three type of environment: monotonous, comfortable, and demanding.

After the road category, the CCR level and the PPI level have been defined, it is possible to identify each EXSE within the analyzed stretch. Moreover, the combination of this characteristics, determine the operating characteristics of the EXSE, that are the Expected Speed (V_E) and the level of Alertness (AL).

Definition of Expectation Sections

EXSEs are road stretches characterized by the same level of winding and PPI. There is no limitation in the maximum length of an EXSE, but it is suggested to set a minimum length of 1 km. These indicative values consider that an EXSE should be travelled for at least 60 seconds to let it influences the driver's driving program. Table 5.15 shows the distances travelled in 60 seconds considering a constant speed in a range between 120 km/h and 50 km/h.

Table 5.15 – Distance travelled in 60 second according to different speeds

Speed		Distance
Km/h	**m/s**	**m**
100	28	1667
90	25	1500
80	22	1333
70	19	1167
60	17	1000
50	14	833

The EXSE must be identified without considering the travel direction. Considering only the rural highway road category, based on the design characteristics (winding and PPI) it is possible to determine the operating characteristics of the stretch (V_E and AL), as illustrated in Table 5.16.

Table 5.16 – Operating characteristics based on design characteristics for rural highways

Winding	PPI
H	M
H	L
M	M
M	L
L	M
L	L

V_E	AL
M	H
M	M
M	M
H	L
M	M
H	L

The process of the identification of EXSEs for the SR2 stretch example is described below.

1. *Road category*. The road has been initially divided into three parts based on the road category (thus considering also urban area and rural area) as represented in Figure 5.21. This segmentation accounts for the road category.
2. *Winding.* Data about geometry allow to calculate the CCR for the whole road stretch. As showed in Figure 5.22 and Figure 5.23, four different area can be identified that have four different CCR of about respectively: 383 gon/km, 89 gon/km, 283 gon/km, and 107 gon/km.
3. *PPI.* The PPI has been evaluated as low for the first stretch of the road (the longer stretch before the urban area), and medium for the remaining road stretch after the urban area (thus the subdivision is the same as those of Figure 5.21.

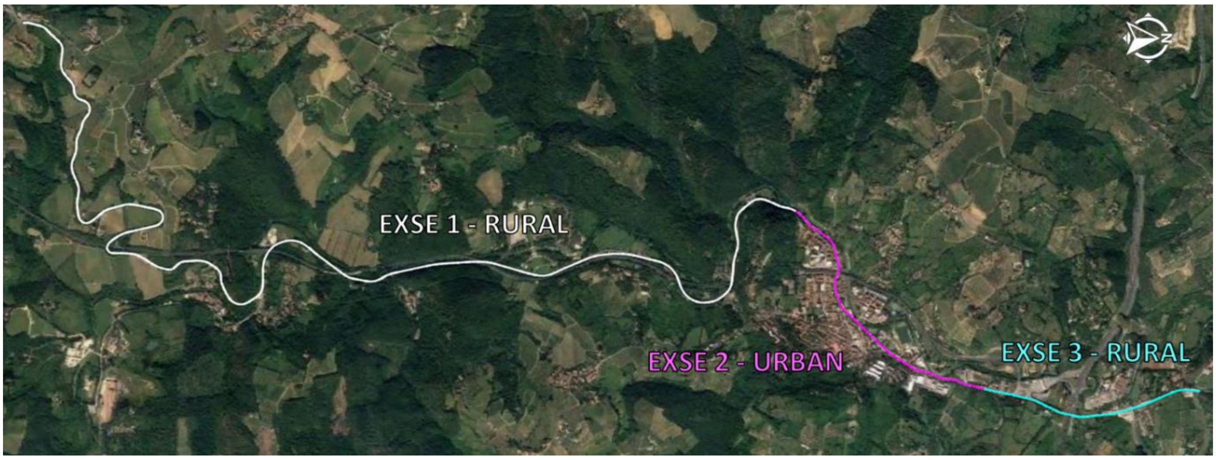

Figure 5.21 – Example of EXSEs identification, considering only the first level of analysis.

The stretch has been thus divided into four EXSEs (the urban one is excluded) as illustrated in Figure 5.24.

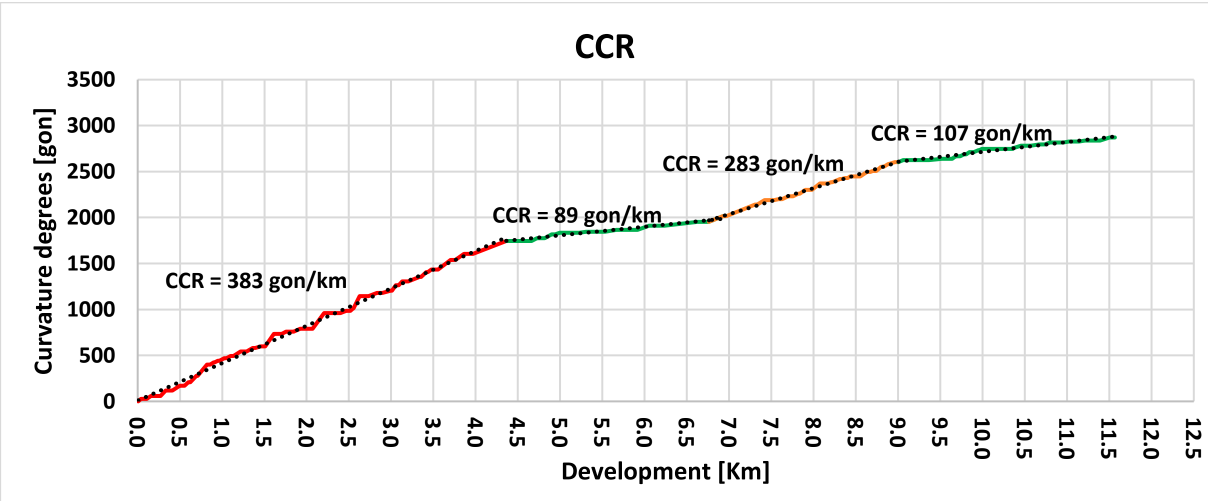

Figure 5.22 – Identification of area with the same CCR, CCR graph

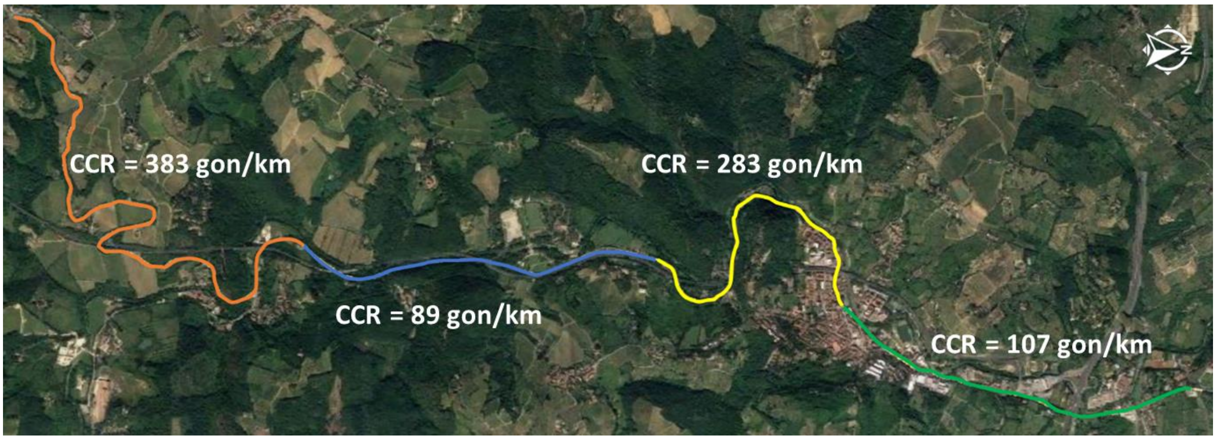

Figure 5.23 – Identification of area with the same CCR, graphical representation

Figure 5.24 illustrates the EXSEs identified in the case study of SR2. The characteristics of each identified EXSE are here briefly described. The EXSEs characteristics can be found in Table 6.34 (see 6.3.1.1), where the case study is presented.

- EXSE 1: Rural area with no (or few) houses visible along the margins. Very curvy road that goes up/down the hill. Two intersections and many driveways (but mostly not visible). High winding (CCR = 383 gon/km), low PPI.
- EXSE 2: Rural area with no (or few) houses visible along the margins. Very straight road that goes along the river, in the valley. Few intersections and driveways. Low winding (CCR = 89 gon/km), low PPI.
- EXSE 3: Rural area with many houses along the margins, with few driveways and one intersection. Curvy road. Medium winding (CCR = 317 gon/km), low PPI.
- EXSE 4: Suburban area (two urban area shorter than 500 m). Many driveways and intersections. Few curves with high radius. Low winding (CCR = 109 gon/km), medium PPI.

Figure 5.24 – Example of EXSEs identification from the case study of SR2

For this road stretch the speed actuated by the inspectors and the ranges of V_E have been compared. The comparison is qualitative, and the speed data (number of speed recordings) are not sufficient to be representative. However, the actuated speeds are in line with the ranges of V_E derived from the EXSE identification process. The comparison is shown in APPENDIX 9.

Expected Speed

Based on the combination of road category, winding, and PPI level, it is possible to define V_E. V_E is a range of speeds which can be expected to be held by drivers along the same EXSE. V_E is influenced both by the road category, the road winding, and the road PPI. Four speed level are defined, which are all described in Table 5.17.

Table 5.17 – Level and ranges of Expected Speed

Symbol	Speed level	V_E
F	Very high (Motorway/Freeway)	>100 km/h
H	High	80-100
M	Medium	50-80
L	Low	0-50

V_E does not refer to speed limits. However, speed limits are indirectly included in the definition of V_E because they depend[18] on road category, road winding, and the road interactions (they do not depend directly on PPI, but on the effective presence of conflict points). Moreover, the influence of speed limits has been proven to be less relevant for speed than other aspects such as CCR and the presence of conflict points (Donnell et al., 2018). The definition of VE derived from the analysis of many design standards and considering different operating speed equations for rural roads. All these considerations are reported in APPENDIX 9.

Table 5.18 summarized the V_E associated with all the possible combination of the stretch characteristics in terms of road category, road winding and road PPI. The road category acronyms are the same presented in Table 5.3 (Motorway = MT, Rural Highway = RH, Rural Local = RL). As expected, the V_E for motorways is always of level F (freeway). Rural highways level is always greater than L. In a rural environment, the level L (low speed, 0-40 km/h) is possible only in local road under specific conditions, which are high winding and medium PPI. The difference with a high winding rural highway is mainly in the different cross-section and the driver awareness of being in a road of a lower hierarchical level. These assumptions are also supported by the findings of Weller et al. (Weller et al., 2008), Charlton et al.(Charlton and Starkey, 2017), and Qin et al. (Qin et al., 2020). These last two studies, underlying the importance of road environment in the driver's choice of speed. The most interesting thing resulting from the studies is that a higher influence is due to the presence of houses, driveways, and intersections. Further considerations and the theoretical basis about the V_E definition, can be found in APPENDIX 9, where several design standards and operating speed models have been analyzed.

The level of PPI greatly influences the level of V_E: to a medium level PPI, corresponds a medium level of V_E. The road winding causes a reduction of the level of V_E only when considering an "high" level of winding.

[18] Probably it would be better to say that they "generally depend on" but the cases of speed limits used for different reasons are few. Note that in this procedure the traffic conditions are not considered, and only the in-built safety of the road is evaluated, thus V_E is not influenced by traffic.

Table 5.18 – Expected Speed related to the stretch characteristics

Road category	Winding	PPI	V_E
MT	M	L	H
MT	L	L	F
RH	H	M	M
RH	H	L	M
RH	M	M	M
RH	M	L	H
RH	L	M	M
RH	L	L	H
RL	H	M	L
RL	H	L	M
RL	M	M	M
RL	M	L	M
RL	L	M	M
RL	L	L	H

These theoretical results are confirmed by the "Roads' perception" survey carried out, whose results are summarized in Figure 5.25, and which is described in detail in APPENDIX 8. From Figure 5.25 it can be observed that for the high winding road, even with a low PPI, most of the respondents chose a speed range between 50 km/h and 90 km/h, thus a medium level of V_E. With a medium level of PPI, both considering low or medium winding level, respondents hardly chose speed ranges higher than 70 km/h, thus confirming the strong influence of PPI. This is also confirmed by the judgements of the road images with low PPI levels, where the respondents generally chose speed ranges above 70 km/h.

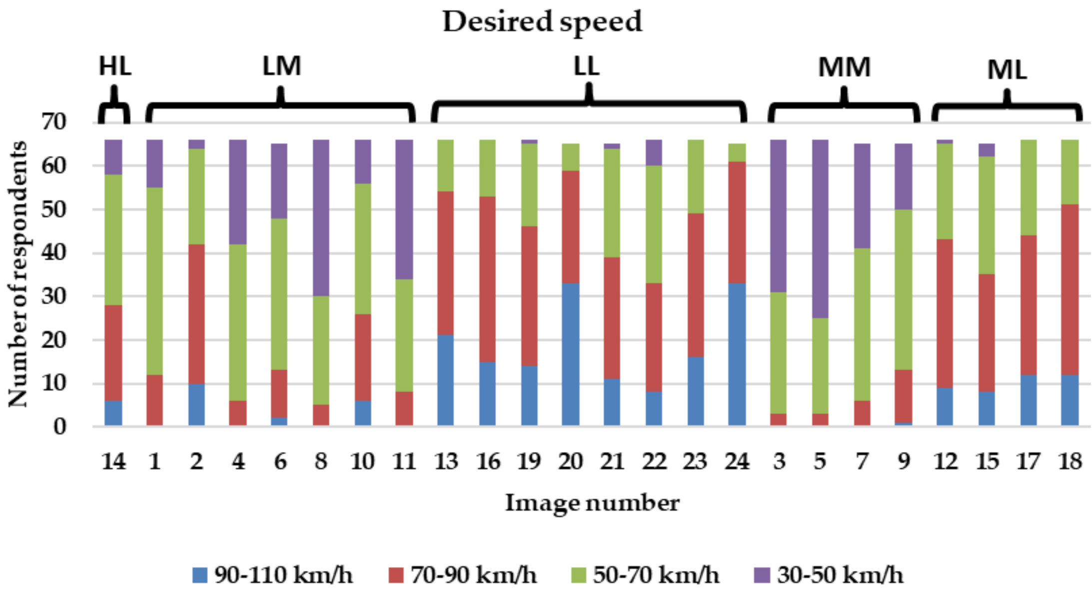

Figure 5.25 – Desired speed choices grouped by the combination of winding (first letter of the code) and PPI (second letter of the code) levels.

Level of alertness

As stated in 3.3.2, alertness is a crucial parameter in road safety because it measures the capacities of the driver to detect and react to non-standard situations. Moreover, the higher the level of alertness, the higher the "available" resources for managing workload (see 3.3.1). If the situation doesn't require (or seems to not require) any specific attention, the driver will drive limiting the resources allocated to the driving task. When some issues on the road arise, the attention and alertness of the driver increase, so as the resources, to let they better face those issues. However, this activation requires time (see 3.3). For this reason, an adequate level of alertness, is expected to improve the response of the driver to the road stimuli, mainly reducing the response time, and it is expected to let the driver be more conscious about of the situation.

As already said, the level of alertness will increase when the road provides some stimuli that catch the attention of drivers and let drivers think that likely they will be forced to change their driving program according to the occurrence of some road issues further on.

For this reason, the level of alertness is strictly related to the PPI, and to the road category (to which the PPI is strictly related in turn). The road winding has a minor influence on the level of alertness.

Concerning the rural highways, ALs coincide with the PPI levels, except if the road winding level is high. In this case, the AL increase, because of the higher attention required to drive on that road.

The results from the "Roads' perception" survey support the theoretical assumptions for low and medium level winding (see Figure 5.17, Figure 5.18, and Figure 5.19 and APPENDIX 8).

Moreover, it must be underlined that, while research has been made accounting for the influence of the environment on speed, the evaluation of alertness (or attention) while driving, is considered mainly as an appendix of workload research. Alertness alone is treated mainly in psychological laboratory studies outside the driving field.

The AL associated to each combination of road type/winding level/PPI level is summarized in Table 5.19.

Table 5.19 – Alertness level related to the stretch characteristics

Road category	Winding	PPI	AL
MT	M	L	L
MT	L	L	L
RH	H	M	H
RH	H	L	M
RH	M	M	M
RH	M	L	L
RH	L	M	M
RH	L	L	L
RL	H	M	H
RL	H	L	H
RL	M	M	M
RL	M	L	M
RL	L	M	M
RL	L	L	L

5.3.3.3 *Evaluation of Potentially Critical Locations (PCLs)*

The PCLs are evaluated judging their level of VIS, GEXs, and PEXs. The level of VIS is representative of the relationship between the available distance and the effective distance required to see, perceive, and choose how to deal with the PCL. The level of GEX is representative of the possibilities to find the PCL on an EXSE having the same characteristics of the one of the analyzed PCL: the reduced the possibilities, the more the PCL is unexpected. The level of PEX is representative of the information and clues provided by the environment where the PCL is located, and how they influence driver's perception of them. The procedure allows to automatically define the levels of VIS and GEX based on the PCL and EXSE characteristics; however, under some specific conditions, the inspector may decide to "manually" change the results. This may occur when the PCL does not have standard characteristics, e.g., a roundabout with non-standard yield conditions, or when the PCLs belong to a type not considered in the procedure (the list of PCLs considered is presented in 5.1.2).

PEXs are not judged in an "automatic" way. The risk level of PEXs must be judged by the inspector.

Assessment of the visibility (VIS) level

To assess the VIS level the visibility of the PCL must be checked. The visibility of locations along the road is commonly used in engineering; however, most of time the distance checked is the SSD (stopping sight distance). For specific locations, many design standards also account for the DSD (decision sight distance). SSD considers an instinctive reaction to face a sudden problem and avoid an accident, while the DSD account also for the time needed to correctly perceive and plan how to react to a specific situation on the road.

As discussed in 3.6, PIARC defines a general DSD considering subdividing the space (and time) approaching the PCL into four different sections. From the one closer to the PCL, the sections are maneuver section (where the breaking action is mainly carried out), the response section (2-3 seconds, mainly necessary to the driver to set the maneuver), the anticipation section (2-3 seconds, necessary to comprehend the location), and the advance warning section (4 seconds, necessary under specific conditions to advise drivers about oncoming location). A well-designed road should have both the maneuver, response, and anticipation sections, for this reason PIARC defines the First Rule of Human Factors (4-6 seconds rule). Consequently, the assessment of the VIS level consider that optimal conditions are when the PCL is visible from a distance travelled in more than 6 seconds. This means that the maneuver, response, and anticipation sections, are present (assuming that the maneuver section will hardly take more than 2 seconds, otherwise it means that a long emergency breaking is required, and SSD must be considered). The travelled distance D2 is calculated considering the higher speed in the range of the V_E, multiplied for t_2 seconds, as defined in Eq. 11. The time t_2 is considered as 6 seconds for EXSE with a low AL, 5 seconds for EXSE with a medium AL, and 4 seconds for EXSE with a high AL[19]. The higher the alertness of the driver, the less the time necessary to perceive and detect the PCL.

$$D2 = \frac{\max(V_E)}{3.6} \times t_2 \qquad \textit{Eq. 10}$$

Where:
D2 = thresholds distance between the medium and low VIS level [m];
t_2 = 6 for low AL, 5 for medium AL, and 4 for high AL [s].

Table 5.20 shows the outcome of the calculations for the two V_E levels for RHs. Within that distance, the PCL must be clearly and continuously visible.

Table 5.20 – DSD to account for VIS for each V_E level, upper thresholds

V_E Level	Speed range [km/h]	Max(V_E) – 10 [km/h]	Distance (6s) [m]	Distance (5s) [m]	Distance (4s) [m]
H	80-100	100	170	140	112
M	50-80	80	135	112	90

[19] Considering 6 seconds or less as the "optimal" threshold may appear not precautionary, however when calculating the distance, the considered speed is the maximum of VE range. This compensates the choice of a relative reduced time. It must also be noted that detailed and more precise calculations are possible, but are not suggested at this stage, because a fast screening is required now to exclude the less dangerous PCLs from a detailed analysis (that will be carried out in Step 2).

If the visibility is higher than the calculated distance, thus it can be assumed that the PCL has no visibility problem, and thus the VIS level is low (i.e., at low risk).

On the other hand, if the available sight distance is less than the distance travelled in 4 seconds, considering the lowest speed in the V_E range (D1), the PCL has a dangerous visibility problem.

$$D1 = \frac{\min{(V_E)}}{3.6} \times t_1 \qquad \text{Eq. 11}$$

Where:
D1 = thresholds distance between the medium and high VIS level [m];
t_1 = 4 [s].

Table 5.21 shows the outcome of the calculations for the two V_E levels for RHs. Such distances are very similar to the SSD.

Table 5.21 – DSD to account for VIS for each V_E level, lower thresholds

V_E Level	Speed range [km/h]	Min (V_E) [Km/h]	D1 [m]
H	80-100	80	90
M	50-80	50	56

The three possible level of VIS are summarized in Table 5.22. D is the available distance. The VIS level must be defined for each direction.

Table 5.22 – Definition of the VIS level

VIS level	Condition
High (risk)	D<D1
Medium (risk)	D1<D<D2
Low (risk)	D>D2

Assessment of the general expectation (GEX) level

GEXs are the general expectations, and they refer mainly to the influence of driver experience on their perception and, consequently, on their expectation about the road. Measuring GEX is not directly possible, because expectations are an abstract concept. However, according also to the self-explaining road concept, the expectancy of specific PCLs in a specific road and environment, can be qualitatively identified. As a matter of fact, a pedestrian crossing is not expected on a road developing in a desert with no buildings for miles. This conscious idea is still unconsciously present while driving. Even if the driver doesn't think about where they are travelling, and thus, doesn't think if a specific PCL is expected, this is automatically and unconsciously done by all the sensing, processing, and perception processes described in 3.5.

The concept that knowledge acquired from experience, which can be consciously recalled in the mind, also influence the unconscious perception, is at the basis of the assessment of the GEX level.

Also in this case, three GEX levels have been defined: high, medium, and low, from the most unexpected to the most expected. These levels are assigned to each PCL based on how much the driver expect to find that PCL on a specific EXSE. Comparing the PCLs present along the EXSE to the characteristics of the EXSE itself, it is possible to define how much the PCL is expected. The relationship between different type of PCLs and the GEX level has been investigated considering a review of design standards of several countries (Italy, Germany, England, Slovenia, Portugal, Australia, Canada, Austria, Switzerland). The outcome of this process is presented in Table 5.23, where the assumed GEX level is presented for each PCL, for each combination of winding and PPI.

The definition of the GEX levels by theoretical assumptions, has been compared to the results of a survey of 20 participants. The survey was very long to be fulfilled (it takes more than one hour), and thus it was not possible to find more respondents.

The survey has been carried out in two phases. In the first phase the respondents must evaluate what type of PCLs is more expected by comparing couples of PCLs' type. In the second phase, the respondents were asked to evaluate what PCL is more expected within PCLs of the same type. In this case the evaluation was made comparing couple of PCLs too.

To determine a numerical score representing the expectations to find a specific PCL (weight) and which can also allow to make a ranking within the PCLs, it has been chosen to use the Analytic Hierarchy Process (AHP) (Saaty, 1987). The AHP is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s. It represents an accurate approach to quantifying the weights of decision criteria. Individual experts' experiences are utilized to estimate the relative magnitudes of factors through pair-wise comparisons. Each of the respondents compares the relative importance each pair of items using a specially designed questionnaire.

The PCLs types have been compared for each combination of winding and PPI for a total of 6 groups of comparison. Then, for each combination of winding and PPI, and for each PCLs type, the PCLs belonging to that type have been compared, thus 42 groups of comparison (the PCLs types are 7). A total of 48 excel files containing the AHP have been sent to the respondents. The excel file has been derived from the work of Goepel (Goepel, 2018).

Table 5.23 – GEX levels for each combination of winding and PPI, from literature review

PCLs Type	PCLs	Winding / PPI level (H = high, M = medium, L = low)					
		L/L	L/M	M/L	M/M	H/L	H/M
Curve	Curve0	L	L	L	L	L	L
	Curve10	M	M	L	L	L	L
	Curve20	H	H	M	M	M	L
At-grade intersection	Roundabout	M	M	M	M	M	M
	Signalized	H	H	H	H	H	H
	with priority	L	L	L	L	L	L
	without priority	H	H	H	H	H	H
Crossing	Pedestrian Crossing	H	M	H	M	H	M
	Cyclist Crossing	H	M	H	M	H	M
Driveway	Minor residential	L	L	L	L	L	L
	Major residential	M	L	H	M	H	M
	Minor commercial	L	L	L	L	L	L
	Major commercial	M	L	H	M	H	H
Stopping area	Parking lots	H	H	H	H	H	H
	Lay-by	L	L	L	L	M	M
	Bus stop	L	L	L	L	L	L
Railway level crossing	with mobile bar	M	M	H	H	H	H
	without mobile bar	H	H	H	H	H	H
Lane change	Added/removed lane	M	H	H	H	H	H
	Diverging lane	H	H	H	H	H	H

The weight calculated for each PCLs type and for each specific PCL have been multiplied to obtain a global score. It has been decided to normalize the weights of each single PCLs' weight with the maximum among them, to obtain that the most expected PCL within a PCLs type is given the same value as the weight assigned to the PCLs type. The equation is shown in Eq. 12. The weight values are those directly calculated with the application of AHP, while the expectation value is the product of those weights for each PCL.

$$E_{C,T,X} = W_{C,T} \times \frac{W_{C,T,X}}{\max(W_{C,T,tot})} \qquad \text{Eq. 12}$$

Where:

$E_{C,T,X}$ = expectation value for the single PCL, for combination "C", PCLs type "T", and PCL "X";

$W_{C,T}$ = weight value of the PCL type, for combination "C", and PCLs type "T";

$W_{C,T,X}$ = weight value of the single PCL, for combination "C", PCLs type "T", and PCL "X";

$W_{C,T,TOT}$ = all the weight values of PCLs of the same type, for combination "C", and PCLs type "T".

The results from the application of the AHP are shown in Table 5.24 and Table 5.25. More insights about the results are provided in 0.

Table 5.24 – Expectation values and weights values for each PCL , for combinations LL, LM, and ML

	LL			LM			ML		
	W_T	$W_{T,X}$	$E_{T,X}$	W_T	$W_{T,X}$	$E_{T,X}$	W_T	$W_{T,X}$	$E_{T,X}$
Curve0	0.13	0.70	**0.13**	0.07	0.71	**0.07**	0.36	0.47	**0.36**
Curve10		0.21	**0.04**		0.21	**0.02**		0.43	**0.33**
Curve20		0.09	**0.02**		0.08	**0.01**		0.10	**0.08**
Roundabout	0.18	0.30	**0.11**	0.18	0.26	**0.10**	0.15	0.29	**0.08**
Signalized Int.		0.10	**0.04**		0.16	**0.06**		0.07	**0.02**
Int. with priority		0.48	**0.18**		0.46	**0.18**		0.56	**0.15**
Int. without priority		0.12	**0.05**		0.11	**0.04**		0.07	**0.02**
Pedestrian Crossing	0.09	0.51	**0.09**	0.14	0.51	**0.14**	0.08	0.60	**0.08**
Cyclist Crossing		0.34	**0.06**		0.30	**0.08**		0.33	**0.04**
Minor residential	0.21	0.40	**0.21**	0.25	0.30	**0.25**	0.16	0.42	**0.16**
Major residential		0.11	**0.06**		0.23	**0.19**		0.11	**0.04**
Minor commercial		0.36	**0.19**		0.28	**0.23**		0.37	**0.14**
Major commercial		0.13	**0.07**		0.18	**0.15**		0.09	**0.04**
Parking lots	0.18	0.14	**0.05**	0.17	0.29	**0.12**	0.14	0.08	**0.02**
Lay-by		0.49	**0.18**		0.30	**0.12**		0.44	**0.13**
Bus stop		0.37	**0.14**		0.41	**0.17**		0.47	**0.14**
RC with mobile bar	0.07	0.83	**0.07**	0.07	0.84	**0.07**	0.04	0.73	**0.04**
RC without mobile bar		0.17	**0.02**		0.16	**0.01**		0.27	**0.02**
Added/removed lane	0.13	0.19	**0.13**	0.13	0.15	**0.13**	0.07	0.11	**0.07**
Diverging lane		0.11	**0.08**		0.10	**0.09**		0.06	**0.04**

Table 5.25 – Expectation values and weights values for each PCL , for combinations MM, HL, and HM

	MM			HL			HM		
	W_T	$W_{T,X}$	$E_{T,X}$	W_T	$W_{T,X}$	$E_{T,X}$	W_T	$W_{T,X}$	$E_{T,X}$
Curve0	0.27	0.43	**0.27**	0.27	0.43	**0.27**	0.27	0.43	**0.27**
Curve10		0.43	**0.27**		0.43	**0.27**		0.43	**0.27**
Curve20		0.14	**0.09**		0.14	**0.09**		0.14	**0.09**
Roundabout	0.18	0.33	**0.12**	0.18	0.33	**0.12**	0.18	0.33	**0.12**
Signalized Int.		0.08	**0.03**		0.08	**0.03**		0.08	**0.03**
Int. with priority		0.52	**0.18**		0.52	**0.18**		0.52	**0.18**
Int. without priority		0.08	**0.03**		0.08	**0.03**		0.08	**0.03**
Pedestrian Crossing	0.10	0.60	**0.10**	0.10	0.60	**0.10**	0.10	0.60	**0.10**
Cyclist Crossing		0.30	**0.05**		0.30	**0.05**		0.30	**0.05**
Minor residential	0.19	0.41	**0.19**	0.19	0.41	**0.19**	0.19	0.41	**0.19**
Major residential		0.17	**0.08**		0.17	**0.08**		0.17	**0.08**
Minor commercial		0.31	**0.15**		0.31	**0.15**		0.31	**0.15**
Major commercial		0.11	**0.05**		0.11	**0.05**		0.11	**0.05**
Parking lots	0.13	0.13	**0.03**	0.13	0.13	**0.03**	0.13	0.13	**0.03**
Lay-by		0.46	**0.13**		0.46	**0.13**		0.46	**0.13**
Bus stop		0.42	**0.11**		0.42	**0.11**		0.42	**0.11**
RC with mobile bar	0.04	0.74	**0.04**	0.04	0.74	**0.04**	0.04	0.74	**0.04**
RC without mobile bar		0.26	**0.02**		0.26	**0.02**		0.26	**0.02**
Added/removed lane	0.09	0.09	**0.09**	0.09	0.09	**0.09**	0.09	0.09	**0.09**
Diverging lane		0.09	**0.09**		0.09	**0.09**		0.09	**0.09**

The expectation values (E) are also presented into graphical form in Figure 5.26. The same graph shows the two adopted threshold values of 0.10 and 0.05. The value of 0.10 corresponds to the mean value of the obtained results. The GEX level is defined based on these thresholds. For an E greater than 0.10, the GEX level is low (low risk, the PCL is expected), for E between 0.05 and 0.1, the GEX level is medium, and for E lower than 0.05 the GEX level is high (high risk, the PCL is unexpected).

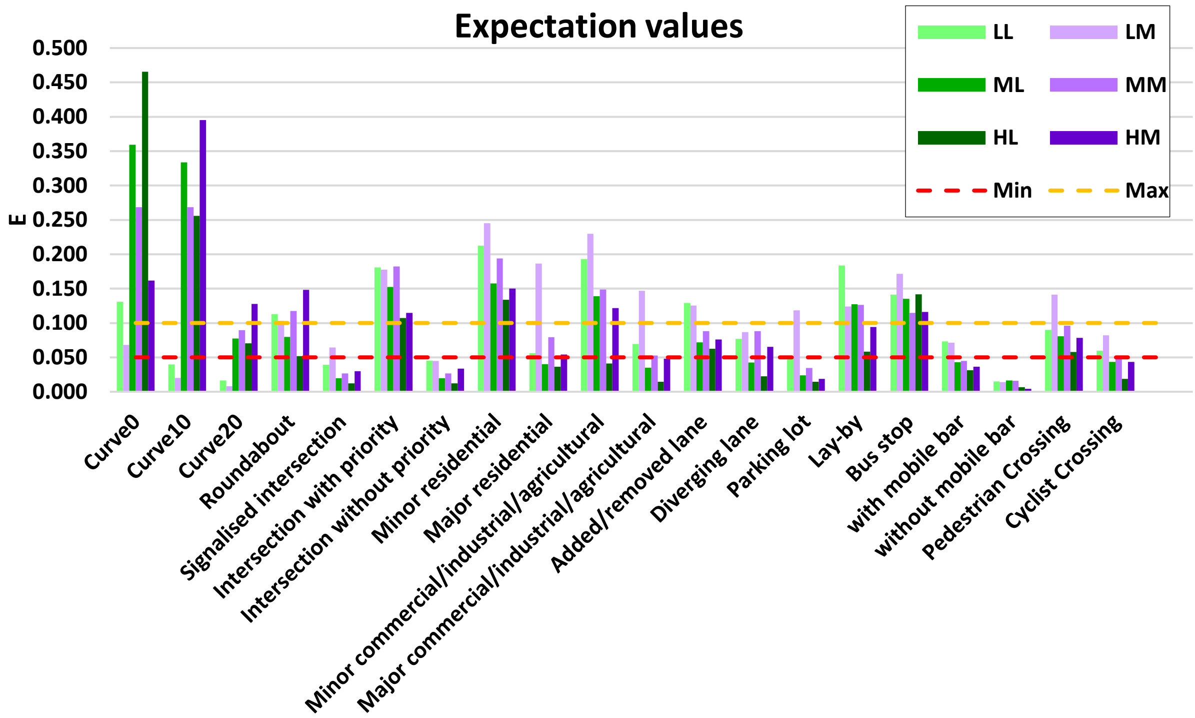

Figure 5.26 – Expectations values calculated for each PCL

Based on the results shown in Figure 5.26, a new table like Table 5.23 can be drafted. While Table 5.23 consider the risk level of expectancy (GEX level) defined by the author, which is based on literature review, design standards review, and author experience, Table 5.26 shows the results of the risk level of expectancy just considering the outcome of the AHP. Cells containing a level different from those in Table 5.23 are colored red, while cells with the same level of those from Table 5.23 are colored green.

The comparison between the two assignments shows a good correspondence. However, some differences are present.

Concerning the curve PCLs type, it appears that Curve0, that are curve where no change is speed is required, are always highly expected (thus a low level of risk). The result from the AHP (both looking at Table 5.26 and Figure 5.26), highlights that even those curves are less expected when EXSEs are characterized by low winding and medium PPI. Nevertheless, this kind of curve is not critical, thus it has been decided to keep the "L" level, as in Table 5.23. Curve10 are also generally not critical if no additional issue is present along the curve (e.g., field of view composition). Thus, it has been decided to keep the evaluation of "M" for Curve10 in EXSEs with low curvature. Curve20 are likely present in high winding roads but are unexpected on low winding road.

Table 5.26 - GEX levels for each combination of winding and PPI, results from the AHP

PCLs Type	PCLs	Winding / PPI level (H = high, M = medium, L = low)					
		L/L	L/M	M/L	M/M	H/L	H/M
Curve	Curve0	L	M	L	L	L	L
	Curve10	H	H	L	L	L	L
	Curve20	H	H	M	M	M	L
At-grade intersection	Roundabout	L	L	M	L	M	L
	Signalized	H	M	H	H	H	H
	with priority	L	L	L	L	L	L
	without priority	H	H	H	H	H	H
Crossing	Pedestrian Crossing	M	L	M	M	M	M
	Cyclist Crossing	M	M	H	H	H	H
Driveway	Minor residential	L	L	L	L	L	L
	Major residential	M	L	H	M	H	M
	Minor commercial	L	L	L	L	H	L
	Major commercial	M	L	H	M	H	H
Stopping area	Parking lots	M	L	H	H	H	H
	Lay-by	L	L	L	L	M	M
	Bus stop	L	L	L	L	L	L
Railway level crossing	with mobile bar	M	M	H	H	H	H
	without mobile bar	H	H	H	H	H	H
Lane change	Added/removed lane	M	H	H	H	H	H
	Diverging lane	H	H	H	H	H	H

The evaluation concerning at-grade intersections, show a high degree of agreement too. Intersections with priority are always expected and intersection without priority are always unexpected. This means that while the driver is travelling a highway, which is a road of high rank (that comes only after a motorway), they expect to do not have to yield. Signalized intersections may need the driver to stop, thus are again unexpected. The outcome from the AHP is M for low winding and medium PPI, but for coherence with the other results with the same PPI level (M/M and H/M), it has been decided to keep the "H" level, as in Table 5.23. Roundabouts are likely more expected even if they require the driver to yield. Roundabouts are quite common also looking at design standards, when road of the same rank join together (e.g., two rural highways). This is somehow addressed also by the respondents, who in addition classified as "L" the GEX level when the PPI level is medium. Standard roundabouts are generally clearer, easy identifiable, and it is known how to deal with them, thus the outcomes from the AHP are taken. The relevant aspects which will influence the evaluation of a roundabout are VIS and PEX, if the roundabout is a standard roundabout. This last condition must be stressed, because if the roundabout is not standard, then the inspector should "manually" judge if it is expected or not. For example, a roundabout where the yield conditions are different, is completely unexpected.

Concerning crossings, the differences between the results from literature review and the

AHP are more marked. Pedestrian crossings are mainly judged as medium GEX level by the respondents. However, pedestrian crossing can be a big deal in rural highways away from any urbanized area. For this reason, it has been decided to keep the classification from Table 5.23, defining H level for low PPI, and M level for medium PPI. The same considerations can be made for cyclist crossings, even if the respondents classified this kind of crossing more unexpected than pedestrian crossing.

Driveways PCLs type shows a high degree of agreement too. Minor driveways are always expected; thus, the possible deficiencies will likely be related to VIS or PEX. Major driveways are instead not always expected, and the road winding influence expectations, because major driveways are generally related to industries, big residential areas, commercial activities like supermarket, and thus they are hardly built in mountain or hilly area, where generally the road has more curve. Curvy road can be present also in plain terrain, like big commercial activities can be present also along curvy roads, but those are rare cases, and generally it is the opposite. This demonstrates the strength of experience. The difference with AHP results concerns minor commercial/industrial/agricultural driveways. Minor commercial/industrial/agricultural driveways are judged as H for H/L combination, but all the other levels for the same PCL are L. Specific critical conditions cannot be found for this classification, and thus it has been decided to also set this level on L. It must be noted that major driveways, both residential and commercial, should have been resulted very similar to at-grade intersection with priority. However, intersections are generally more visible, the road characteristics change (should change), and are also signalized. Most of time, driveways do not have such characteristics, even if major driveways. Moreover, most of the time driveways are not consider as critical conflicts point where the driving program should be changed. On the opposite, at-grade intersection with priority are anyway perceived as a critical location on which keep the attention. Thus, it seems a reasonable choice to classified major driveways with a higher level of risk, concerning expectancy.

Stopping areas present some differences concerning the parking lots. Respondents from the AHP judge that parking lots are not unexpected if the road has low curvature (low winding). However, parking lots cannot be present on rural highways. Thus, the GEX level of parking lots is always of high risk (H).

Railway crossings are also generally unexpected. Railway crossing with mobile bar are more expected than those without bar.

Lane changes are also unexpected. Adding or removing a lane or let the road splits (diverge) are not common in rural highways. This does not automatically mean that this PCL are risky. They are unexpected and thus they must be clearly signalized and must be clearly visible.

The final GEX levels are presented in Table 5.27. The results presented in Table 5.27, can be used as a reference, but the inspector can judge independently about the risk of a specific PCL, considering the characteristics of the EXSE and the specific characteristic of the PCL itself.

Table 5.27 – Definitive GEX levels for each combination of winding and PPI

PCLs Type	PCLs	Winding / PPI level (H = high, M = medium, L = low)					
		L/L	**L/M**	**M/L**	**M/M**	**H/L**	**H/M**
Curve	Curve0	L	L	L	L	L	L
	Curve10	H	H	L	L	L	L
	Curve20	H	H	M	M	M	L
At-grade intersection	Roundabout	M	L	M	L	M	L
	Signalized	H	H	H	H	H	H
	with priority	L	L	L	L	L	L
	without priority	H	H	H	H	H	H
Crossing	Pedestrian Crossing	H	M	H	M	H	M
	Cyclist Crossing	H	M	H	M	H	M
Driveway	Minor residential	L	L	L	L	L	L
	Major residential	M	L	H	M	H	M
	Minor commercial	L	L	L	L	L	L
	Major commercial	M	M	H	M	H	H
Stopping area	Parking lots	H	H	H	H	H	H
	Lay-by	L	L	L	L	M	M
	Bus stop	L	L	L	L	L	L
Railway level crossing	with mobile bar	M	M	H	H	H	H
	without mobile bar	H	H	H	H	H	H
Lane change	Added/removed lane	M	H	H	H	H	H
	Diverging lane	H	H	H	H	H	H

Assessment of the punctual expectation (PEX) level

PEX levels consider the composition of the road and the road environment, thus the composition of the field of view and its influence on the right perception of the road. These conditions must be evaluated close to the PCL, starting from about 6-10 seconds before the PCL. Unfortunately, it is not possible to define objective criteria to calculate the PEX level, thus this process is up to the inspector. To assess the PEX level of each PCL the inspector must drive along the road stretch in both directions, trying to figure out if some PEX issues are present. Because of the subjectivity of this evaluation, it has been decided to consider only two levels of PEX: low risk and high risk. Low risk level means that there aren't any or only few issues. High risk means that many issues are present, or also few big issues.

The evaluation should be carried out without a deep analysis. The evaluation must consider what has been described in section 3.6.1.2, which is related to the Second Rule of Human Factors (field of view rule). The main aspects to consider, are reported in Table 5.28. The table is divided into three main investigation topics ("density and shape of the field of view", "elements in the lateral roadside environment support optimal lane keeping", and "depth of the field of view") with their relative subsections. The contents of this table represent a sort of checklist to remember to the inspector what to look at. Generally, it can be assumed that if inspectors find some issues concerning two out of three of the investigation topics, then the PCL should be classified as high level of PEX. However, this is not a rule, the inspector must try to understand if found issues are relevant. For this reason, to carry out the assessment, the inspector must be trained about Human Factors.

Table 5.28 – Aspects to consider while assessing the PEX level

DENSITY AND SHAPE OF THE FIELD OF VIEW
Monotony of road section and surroundings
Long/far visible approaching sections before CHL
ELEMENTS IN THE LATERAL ROADSIDE ENVIRONMENT SUPPORT OPTIMAL LANE KEEPING
Structures above the road
Presence of eye-catching objects
Illusion-free optical guidance
Carriageway width changes are well delineated
Roadside objects appear to be vertical
Curve's framing
DEPTH OF THE FIELD VIEW
Dominant eye-catching objects support the detection of the Challenging Location
Presence of optical illusion
Course of the road clearly visible

5.3.4 The second step of the procedure

In the second step the main and detailed analysis of the road is carried out and the HFET is applied to the Human Factors Evaluation Segments (HFESs). The HFESs are segments composed by one or more challenging Transition (CHTs), which in turn are each linked to a Challenging Location (CHL). Each HFES, CHT, and CHL must be defined for each direction.

The updated version of the HFET allows to analyze at the same time all the CHLs belonging to the same HFES. The second step is divided into three main sub-steps:

- Identification of CHLs;
- Identification of CHTs and HFES;
- Application of the HFET.

5.3.4.1 *Identification of Challenging Locations (CHLs)*

CHLs are PCLs that are not clearly perceived by the driver, because of some problems concerning VIS, GEXs, and/or PEXs. The consequence is that the driver doesn't change his driving program, or tries to change it too late, causing hazardous maneuvers. A PCL is promoted to CHL when at least one risk level related to expectations (VIS, GEX or PEX) is high, and one is medium. This concept is clarified in Table 5.29, where all the possible combinations of VIS, GEX, and PEX levels are presented, together with the outcome of each combination.

Table 5.29 – Combinations of VIS, GEX, and PEX levels, for the identification of CHLs (CH = CHL, PC = PCL)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
VIS	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
GEX	H	H	H	M	M	M	L	L	L	H	H	H	M	M	M	L	L	L
PEX	H	H	H	H	H	H	H	H	H	L	L	L	L	L	L	L	L	L
Results	**CH**	**CH**	**CH**	**CH**	**CH**	**CH**	CR	**CH**	**CH**	CR	**CH**	**CH**	CR	CR	**CH**	CR	CR	CR

A PCL could be CHL only for one direction of travel. For this reason, in the analysis it must be specified for which direction the location is challenging. Figure 5.27 shows the PCLs identified as CHLs on a satellite image of the SR2 stretch. The stretch is the same taken in the previous example of Figure 5.13. The points represent each location. A total of 61 CHLs have been identified in this stretch. The PCLs were 161, thus a great reduction has been made.

Figure 5.27 – Identification of CHLs, example from the case study of SR2.

5.3.4.2 *Identification of Challenging Transitions (CHTs) and Human Factors Evaluation Segments (HFESs)*

Once the CHLs have been identified, the area to evaluate with the HFET must be chosen. This area is the road stretch preceding and including the CHL and it is called Challenging Transition (CHT). CHT started typically 10-12 seconds before the CHLs and can include other elements of the road that are not CHLs, or even other CHLs. If the latter is the case, thus the two overlapping CHTs (one for each CHL) must be merged, creating a single CHT. This final CHT is then called Human Factors Evaluation Segment (HFES) because this is the segment that will be evaluated with the HFET.

The scheme in Figure 5.28 summarizes the three steps required. CHLS and CHTs must be considered first in one direction and then in the other direction, because based on the direction of travel, they can change. Consequently, also HFES will be differentiate for each direction.

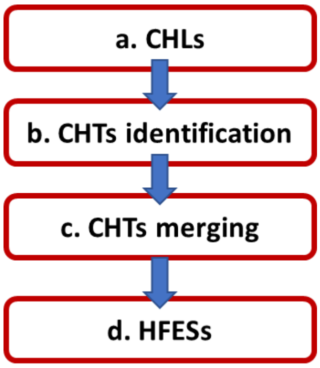

Figure 5.28 – Scheme of the CHTs and HFESs definition procedure

As said before, the typical length of a single CHT is the distance travelled in 10-12 seconds. This time derives again from the First Rule of Human Factors and include all the sections. The distance is measured starting before the CHL and ending in the point where the CHL starts. If the CHL is not punctual (e.g., a curve), the length of the CHL must be added to the previously calculated CHT distance, because the whole CHL must be part of the CHT. The speed required to calculate the distance can be considered as the maximum speed in the EXSE's V_E range, reduced by 10 km/h, as shown in Eq. 13.

$$D_{CHT} = \frac{\max(V_E) - 10}{3.6} \times t_3 \qquad \textit{Eq. 13}$$

Where:

D_{CHT} = distance travelled in 10-12 [m];

t_3 = 10-12 [s].

Table 5.30 shows the calculated distances for the two different V_E levels. Nevertheless, those distances do not need to be exact, they must be used as references. Inspectors may decide to reduce or increase those distances if the operating speed seems to be very different than the speed considered in Eq. 13. Distances less than 150, or higher than 300 m, are discouraged.

Table 5.30 – D_{CHT} for each V_E level

V_E Level	Speed range [km/h]	Max (V_E) – 10 [km/h]	Distance (12s) [m]	Distance (10s) [m]
H	80-100	90	300	250
M	50-80	70	233	194

Figure 5.29 shows an example of two CHLs with their CHT (again from SR2). One CHL is represented by a pedestrian crossing, in purple; the other CHL is represented by a curve, in yellow. The two CHTs are overlapping, thus they will be merged to create a single CHT, that is a HFES. The HFES in the example of Figure 5.29 is about 450 m long and it is represented in red.

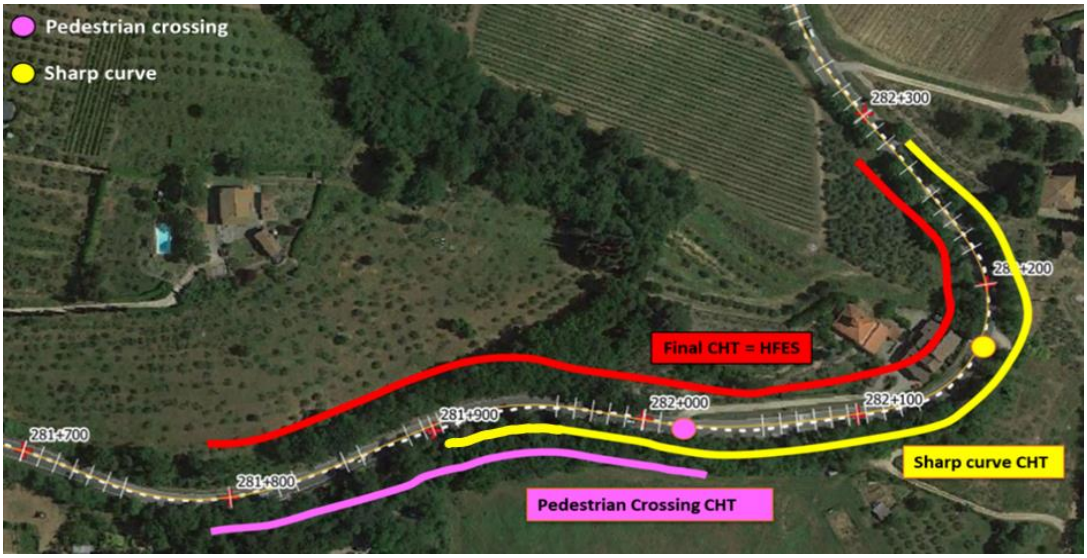

Figure 5.29 – Identification and merging of overlapping PZs

5.3.4.3 *Application of the Human Factors Evaluation Tool (HFET)*

The HFET is provided by three different sheets, each of them representing one of the rules of the Human Factors. The tool should be applied following the guidelines provided in APPENDIX 1.

The results will provide the Human Factors Score (HFS) that is representative of how the principles of First Rule, Second Rule, and Third Rule are respected. Moreover, also the Total HFS is calculated, which considers the results of all rules together.

Figure 5.30 shows an example of results from SR2 case study. The HFESs are colored based on their Total HFS results: red means HFS < 40% (high risk), yellow means 40% ≤ HFS ≤ 60% (medium risk), and green means HFS > 60% (low risk).

Figure 5.30 – HFESs colored based on the Total HFS result: HFS < 40% (red), 40% ≤ HFS ≤ 60% (yellow), HFS >60% (green)

In the end of this sub step, the higher level of detail of the procedure has been reached. The results must now be translated in a form suitable for NWRSAs.

Specific consideration for the application of the tool

Some non-standard conditions may arise. The most common are listed below, with some suggestions on how to manage this condition to save time while applying the HFET, without changing the results. These suggestions are based on the experience derived from the case studies analyzed.

- Each CHL that is overlapping or ends within 50 meters of the start of another CHL of the same type, can be considered together, as a "series of -*CHL name*-" (e.g., series of driveways).
- Driveways located at at-grade intersection (within 50 meters from the center of the intersection) can be considered as part of the at-grade intersection.
- Turning lanes which are part of at-grade intersections, are considered as at-grade intersection.
- Despite the preceding considerations, while applying the HFET, if the requirement requires to judge the CHL considering the PCLs around it (be that a single PCL or a series of PCLs), for that requirement all the PCLs must be evaluated as different PCLs.
- If a series of CHL is considered, then the worst condition between the CHLs of the series, must be judged.

5.3.5 The third step of the procedure

The third step is needed to group together the results obtained from the analysis of HFESs. Longer sections are more useful while implementing a NWRSA because they can be more easily represented and because often road administrations prefer to intervene on longer road stretches("iRAP Methodology fact sheets - iRAP," n.d.). These sections are called Network Assessment Sections (NASs). Moreover, the results obtained from the second step of the procedure for each HFES, must be unified in a single result that is representative of the NAS. For these reasons, the third step of the procedure concern the:

- Identification of NASs;
- Calculation of the Risk Code (RC) to assign to each NAS.

5.3.5.1 Identification of Network Assessment Sections (NASs)

NASs are road stretch taking as a reference by road agency. The results of the procedure will be provided for each NAS and the result of each NAS will qualify the NAS as target of intervention. Furthermore, the results will let to rank each NAS, allowing the road agency to define its intervention priority.

The scope of the NASs is thus related to the scope of the road agency. For this reason, road agencies may choose the length of the NASs based on their requirements: small NASs means that the interventions will focus on smaller segment, generally this choice derived from low available resources, while longer NASs means that road agency want to intervene on longer stretches even if few elements in the stretch are very critical, and this is generally a good choice when higher resources are available. Another possibility to have a specific length of each NASs is because some other evaluations have been made that have a specific segmentation length and the road agency want to compare the results of this procedure with the results of some other.

All these possibilities are made possible because of the flexibility, at this step, in the choice of NASs length. The NASs length must be chosen by road agency and not by inspectors, however inspectors may suggest the length to consider based on their experience and on the characteristics of the roads in the network.

Some limitations should be considered to account for the road category and its characteristics. On non-motorway roads, NASs with a length higher than 5 km are discouraged because the road can greatly differ within 5 km. Moreover, if the road is quite complex with a changing environment, lengths of maximum 2 km are suggested. Finally, it is recommended to divide the network into NASs of the same length as possible. Considering all these aspects, for rural highway, a semi-fixed length segmentation of about 1 km is suggested. Semi-fixed means that the segments should be as more as possible of a length of 1 km; however, HFES must be wholly included in a NAS, and it is not possible to cut a HFES, thus the case of NAS of exactly 1 km are rare. The length of 1 km is long enough to be applied on the network (Ministero delle Infrastrutture e dei Trasporti, 2003) but it still quite short to provide sufficient focused results.

Another possibility could be to identify sections that are homogeneous by traffic, however for this first implementation of the procedure, this possibility has been discarded. The main reasons of the choice are:

- this procedure focus on road in-built safety, thus it analyzes the road risks, regardless of the amount of traffic;
- traffic data of rural highway are often not reliable, because of the low density of the traffic count points;
- sectioning by traffic would mean generally to section at intersections; however, intersections could be CHLs and belong to a HFES, which cannot be cut, thus the section will for certain include a road segment with different traffic (even if very short);
- sectioning with a fixed length indirectly account for the influence of length in the possibilities of accidents occurrence;
- because of the choice of give more weight to critical conditions, too long section have more probabilities to create some bias, that is a long stretch is judged mainly based on the result of a single PCL.

These considerations have been proven by testing different segmentation for the case studies of SR2 and B38. For these stretches a segmentation of 2 km lengths and a segmentation based on traffic have been considered. The results are presented and discussed in 7.3.

After NAS have been identified, all the road stretches which belong to NAS, but do not belong to HFESs are classified as Inconspicuous Segments (INCSs). Road stretches that are part of a NAS but not part of HFES and have not been evaluated, are called INCSs and are considered segments with a Total HFS of 100%. This means that they are in very good conditions. Such an assumption, which is largely optimistic about the road conditions (rarely any segments can achieve a score higher than 90%), has little impact on the final calculation of the code, because the algorithm used to compute the code gives more weight to dangerous HFES, and thus to low HFS results (see also 4.5). However, the INCSs' score value must be defined because it influences the computation of the weighted average and of the standard deviation, which are of no importance for the risk level definition but have a minor importance for the ranking of the NAS and are useful to have an idea of the number of risky segments within the section. The influence of an INCSs' score value of 100%, highlights if a great variance is present within the NAS. If a lower value would have been taken, the result of the standard deviation cannot easily show the differences. INCSs are considered in each direction too.

5.3.5.2 Calculation of the Risk Code (RC)

Focusing on the objectives of that the new procedure should reach, the code to assign to each NAS must allow for the identification of at least three safety level and should allow for a ranking of the NAS (and thus a network safety ranking). Moreover, the first application of the HFET and the discussion with authors of the first version of the HFET, underline the necessity of considering not only the Total HFS, but also the results for all three rules.

Therefore, each NAS will be defined by an alphanumerical code that is divided in three parts as showed by Figure 5.31: a first part composed by a letter and a number, a second part composed by a number and a third part composed by two numbers.

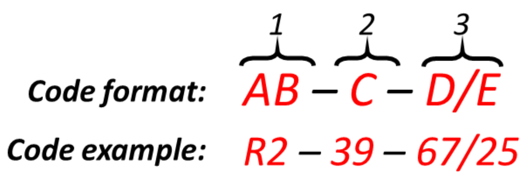

Figure 5.31 – Example and format of NAS final Risk Code (RC)

The first term is the most important. It identifies the safety level of the NAS, and the ranking is made mainly based on it. It represents an evaluation that considers all the rules and the Total results within the NAS. The second term gives a numerical value that represent the most critical HFES within the NAS. The last term is instead a measure of the variance of the results within the same NAS. It allows to understand if within the same NAS a single critical area is present, but the remaining part of the NAS is in good condition (or the opposite).

The alphanumerical values in Figure 5.31 have the following meanings:

- **A** = letter representing the worst level of HFS present, including the HFS for each rule and the Total HFS (R = red, at least one score < 0.40 within the rules, Y= yellow, no red scores and at least one score $\leq$ 0.60 within the rules, G = green, all other results), for both directions;
- **B** = The number of results of level "A" (see before), considering the worst results of the HFs for each rule and the Total HFS (min = 0, max = 4);
- **CC** = The worst Total result within the NAS.
- **DD** = Weighted Average of the Total HFS and length, of each HFES and INS;
- **EE** = Standard Deviations of the Total HFS, of each HFES and INS, considering the segment length;

The RC refers to both directions considered together. The ranking of the NASs will follow a two-level ranking. The first ranking identifies the risk level of the NAS, and thus it is based into four groups:

- very high risk: "AB" part of the code is equal to "R4";
- high risk: "AB" part of the code is equal to "R2" or "R3";
- medium risk: "AB" part of the code is equal to "R1", or "Y4";
- low risk: all the remaining cases.

These four risk levels are consistent with the number of different risk level required from the new European Directive (European Parliament and the Council, 2019).

Level high and very high, both means a high probability of accident occurrence, while medium and low risk can be associated to a low risk of accident.

The second level ranking considers instead a ranking within the same risk level. This second ranking is made following the criteria presented in Table 5.31. It must be considered each parameter composing the code, following the order they are presented (AB-C-D/E). This means that considering the same results of part "A" of the code, priority will be given to the NAS which has a higher part "B". If equal, then the one with lowest value of part "C" will have the priority, then the one with the lowest part "D", and if all the previous parameters are the same, the priority will be given to the NAS with the higher part "E" value. Generally, part D and E of the code are not necessary for the purpose of the ranking, however they provide important information about the composition of the NAS, which can help the road agency in the following stage of intervention. At the end of step 3, the ranking is obtained for all the NASs belonging to the road network.

Table 5.31. - Ranking criteria within the same risk level group.

Priority	A	B	C	D	E
Higher	R	High value	Low value	Low value	High dispersion
Lower	G	Low value	High value	High value	Low dispersion

The results of the case study example of SR2 are presented in Table 5.31. The table shows the results of the RC assigned to each NAS, the corresponding safety level, and the rank of the NAS within all the NAS of this case study. The safety levels are also included by a graphical representation in Figure 5.32. Very high-risk sections are represented in dark red, high-risk sections in red, medium risk sections in yellow, and low risk sections in green (there are no low risk section).

Table 5.32. – Results from the procedure applied to the SR2 case study

NAS ID	RC	Safety level	Rank
NAS 1	R1-47-92/18	Medium	9
NAS 2	R4-34-51/25	Very High	1
NAS 3	R1-42-63/27	Medium	4
NAS 4	R1-44-70/26	Medium	6
NAS 5	R1-45-76/26	Medium	7
NAS 6	R1-40-64/28	Medium	3
NAS 7	R1-46-74/26	Medium	8
NAS 9	R1-43-78/26	Medium	5
NAS 10	R3-40-76/28	High	2

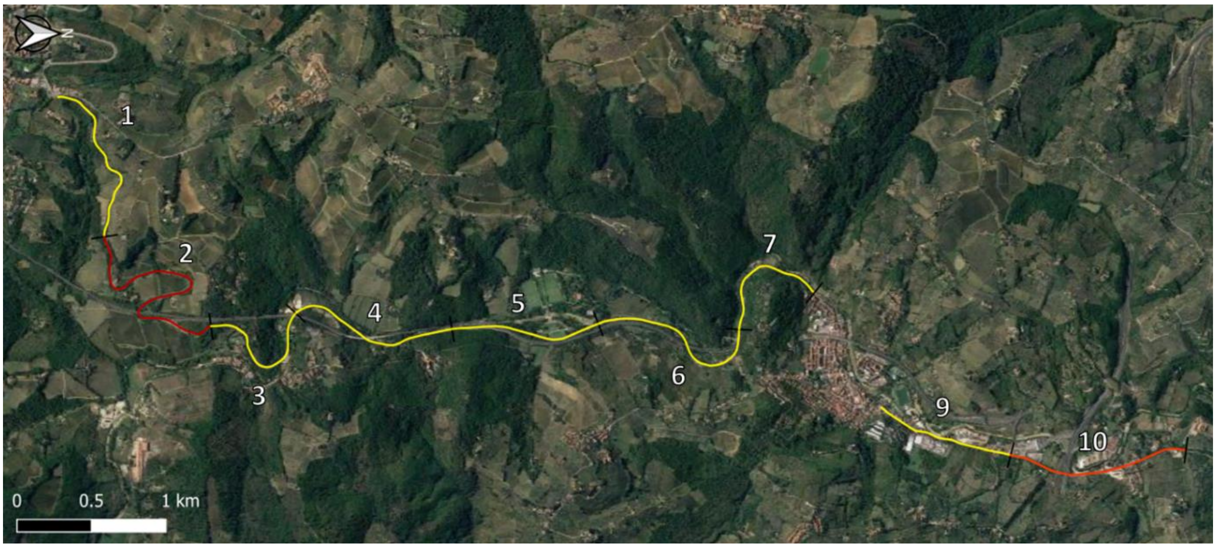

Figure 5.32 – Graphical representation of the safety levels of the NAS in the SR case study

Highlights about the code composition

The first part of the code must clearly identify the safety level of the section. This is the most important part of the code. The composition of the first part of the code is based on the followings criteria.

a) It is more relevant a single high risk location than many of medium risk (see also 4.5).
b) More importance is given to deficiencies that concern different aspects (i.e., Human Factors Rule). For example, if a NAS comprises many HFESs with high risk concerning the First Rule but no high risk level for the other rules (or Total HFS), it will be judged as less critical compared to a NAS with the same number of HFESs that have been classified as high risk concerning the First Rule, and one HFES classified as high risk concerning the Second Rule.
c) Considering the worst results for each rule's HFS and the Total HFS, partially address the influence of more than one HFES, because the more the number of HFES results, the higher the possibilities of a high risk result.
d) Very high risk level (R4) can be reached if at least one HFES within the NAS has one high risk level result for one of the rules and for the Total. This assure no "false positive", that is a very high risk that is only due to the composition of four different HFESs with a single high risk (different between each other).
e) When the level of risk is the same, the classification is made considering the Total HFS of each HFES, thus accounting for deficiencies in the road perception which are concurring together.

5.4 Main points of the procedure

As a main result the Human Factors Evaluation procedure was defined to work in a Network-wide Road safety Assessment. It is structured in three steps, each one aiming at reaching specific objectives.

The **first step** is probably the most relevant part of this research. It allows to make a first screening of the road to identify the potentially critical locations which have a high possibility to be at high-risk. The screening process is based on the evaluation of the difference between the real road situation and possible expectations induced by the road, considering punctual expectations, general expectations, and visibility. In this step the road is divided into different sections which have the same characteristics in terms of factors influencing expectations (those sections are called "expectation sections", i.e., EXSE). This is a fundamental step of the procedure because of three reasons.

1. It provides inspectors an overview of the road, forcing them to understand what expectations drivers have about a specific road stretch. This will help making the next evaluations.

2. It measures the risk related to the difference between expectations and real road situation, and the visibility of the potentially critical locations (it translates these principles into engineering items).
3. It allows to identify the most relevant (dangerous) potentially critical locations to include into the analysis and thus to reduces the number of potentially critical locations to be analyzed in detail. This saves much time (and thus resources) in the Step 2 of the procedure (considering the outcomes from the applications presented in CHAPTER 6, the average reduction in the number of locations to be analyzed is 57%).

In the **second step** (evaluation process) the riskiest potentially critical locations are identified based on the expectations parameter defined in step 1. They are grouped based on their area of influence into segments, namely Human Factors Evaluation Segments (HFESs). The segmentation process is thus made after the definition of the CHLs, allowing to overcome some common segmentation limitations (mostly to avoid that the area of influence of a specific location is located in two different segments). The HFET is than applied to each HFES. This process requires a visual detailed inspection of the road. The visual inspection carried out during this step, can be carried out together with standard RSI procedure, because it doesn't require any specific additional operations. It can be carried out only with video recordings or street view without any other design sketches or accident data, if not available. This is another strength of the whole procedure. The structure and mechanics of the HFET have been modified and adapted to fit the procedure requirements.

The **third step** allows to organize the results so that they are suitable for the classification of network's segments. This means to group many HFESs into singles network assessment sections (NASs). For each NAS, a risk code is calculated. The risk code allows both: to identify four different levels of risk and to make a ranking of the network assessment section, following the requirements of the EU Directive (European Parliament and the Council, 2019). The HFE procedure, allows to define specific length for the network assessments sections, based on the road agency 's requirements. However, as highlighted in this research, it has been found that a segmentation of a fixed length of 1 km, could be the best choice.

Traffic, accidents, and the procedure

As discussed in 5.2.4.5, traffic is not always considered in safety analysis, and its use is linked to the type of analysis and the aim of the analysis.

The HFE procedure analyze the risk of a wrong perception of the road, which may induce drivers to wrong actions and may results in accidents. This type of analysis, and its focus, is on the relationship between the single driver and the road. The level of risk identified by the procedure can be seen as the risk of a driver driving alone to be involved into an accident. This means that traffic is not considered. Therefore, the procedure allows to obtain the safety level of the road itself. This is a huge benefit from the engineering point of view.

Considering this approach, it is possible to exclude the influence of exposure (i.e., traffic) from the results of the procedure.

Nevertheless, two aspects must be considered about traffic: one general aspect and one specific for the HFE procedure. The first is that traffic does not influence only the exposure, but also the probability of occurrence of a specific event (e.g., accident type), and it may influence the severity of an accident (with low traffic, speeds are generally higher).

The second aspects, which directly interest the HFE procedure, is that perception of the road is greatly increased when drivers can see a vehicle travelling the road in front of them. That vehicle become the main reference for their driving and, overall, most of the factors influencing the driver perception of the road reduce their influence (the influence of some factors may increase, but overall, they decrease). Of course, the first car of a possible queue, is still totally influenced from the road and its environment, but the relationship between the traffic and risk of an accident change (because the following cars may have the heading car as a guide) will be not linear. For this reason, it can be useful for further analysis not to only consider traffic, but also traffic distribution, introducing the variable "possibility of vehicles queue".

It must be also underlined that reliable traffic data are not always available for rural highways, because of the many points the traffic would change. Thus, also the inclusion of traffic, must be carefully considered.

Considering the outcomes of the application of the procedure (CHAPTER 7), the influence of the second aspect can be considered to have a reduced impact because the analyzed roads are mainly characterized by medium traffic and free-flow conditions are expected to be much more than congested flow. Unfortunately, detailed traffic data were not available for all the analyzed roads and specific analysis were not possible.

This would be an interesting field for further research.

CHAPTER 6 APPLICATION OF THE PROCEDURE

Chapter abstract

After the procedure has been defined, it has been applied to six different road stretches from different European countries: 2 from Italy, 3 from Germany, 1 from Slovenia, for a total of about 65 km. All those stretches were two-lane two-way rural highways, even if with some different characteristics. Geometric data and accident data have been provided for all those stretches. A screening of the accident data has been made to ensure that only accidents are included which are linked to Human Factors, while others are discarded (effects of alcohol/drugs, illness, animal runover, icy road, insufficient road grip, etc.).

Geometric and accident data, together with the main road stretches' characteristics are firstly described, discussed, and analyzed, then the results from the different step of the procedure are presented for each analyzed road stretch. The outcome was that for the six analyzed roads 55 network-wide assessment sections (NASs) had been defined. Most of the NASs had a medium risk score (35), only 4 have a low risk score, and 13 have a high risk score where action should be taken as soon as possible. The developed procedure turns out as efficiently and applicable.

Chapter list of acronyms

AADT	Average Annual Daily Traffic
AL	Alertness Level
CCR	Curvature Change Rate
CHL	Challenging Location
DEC	Decreasing
EXSE	Expectation Section
FI	Fatal and Injury
GEX	General Expectation
HFE	Human Factors Evaluation
HFES	Human Factors Evaluation Segment
HFET	Human Factors Evaluation Tool
HFS	Human Factors Score
ID	Identification
INC	Increasing
INCS	Inconspicuous Segment
NAS	Network Assessment Section
PCL	Potentially Critical Location
PDO	Property Damage Only
PEX	Punctual Expectation
PPI	Perception of Possible Interaction
PTW	Powered Two Wheeler
RC	Risk Code
V_E	Expected Speed
VIS	Visibility

6.1 Characteristics of the analyzed roads

A brief description of the main characteristics of the analyzed roads and of their related accidents databases is provided in this chapter. Accidents databases were used to calculate the accident rate performance measures for each NAS, which has been used in turn to define a NAS ranking based on observed accidents. The comparison between the results from the application of the procedure and the analysis of the occurred accidents will provide a measure of the effectiveness of the procedure to identify dangerous locations. Moreover, the analysis of accidents type and causes reported from the police, may help to understand if problems identified by the procedure are the same which have may influenced the accident occurrence. This may provide additional insights about the procedure capacity to identify road safety issues.

6.1.1 Italian stretches

Two stretches have been considered from Italy: the SR2 and the SR206. The SR2 road stretch has been the core of this research. This stretch was used for the first application of the original version of the HFET, and then, together with the three German roads, was used to develop the final version of the procedure. Moreover, it has been also used for a double application of the last version of the procedure. The second application was carried out by a different inspection team composed by two master degree students of the University of Florence that were trained about Human Factors (Di Michele and Lanuza, 2022). The SR206 was also considered for the first application of the original version of the HFET and was lastly considered for the application of the final version of the procedure.

6.1.1.1 Roads description

SR2 and SR206 are two rural highway located in the center of Italy, that differ among each other for both geometrical and functional characteristics. The description of the two roads has been already provided in 5.2.1. The two road stretches considered for the application of the procedure are longer than those considered in the first application. The SR2 stretch ranges from km 280.600 to km 292.400 (11.8 km total), and the SR206 stretch ranges from km 27.800 to km 42.400 (14.6 km total). The road stretches are depicted in Figure 6.1

The traffic database has been provided by the Tuscany Region. For SR2, it derives from two traffic station located at km post 286.000 and at km post 290.000. The analysis period considered for traffic is 2014-2018. For the SR206 it derives from two traffic station located at km post 037.000 and at km post 041.000. The analysis period considered for traffic is also 2014-2018. The available traffic data are the same considered in the first application of the HFET and have been presented in Table 5.4.

The roundabout located at km 291.000 of SR2 was excluded from the analysis as it includes traffic from two motorways, and those traffic data are unavailable. Instead, all the SR206 have been considered in the analysis.

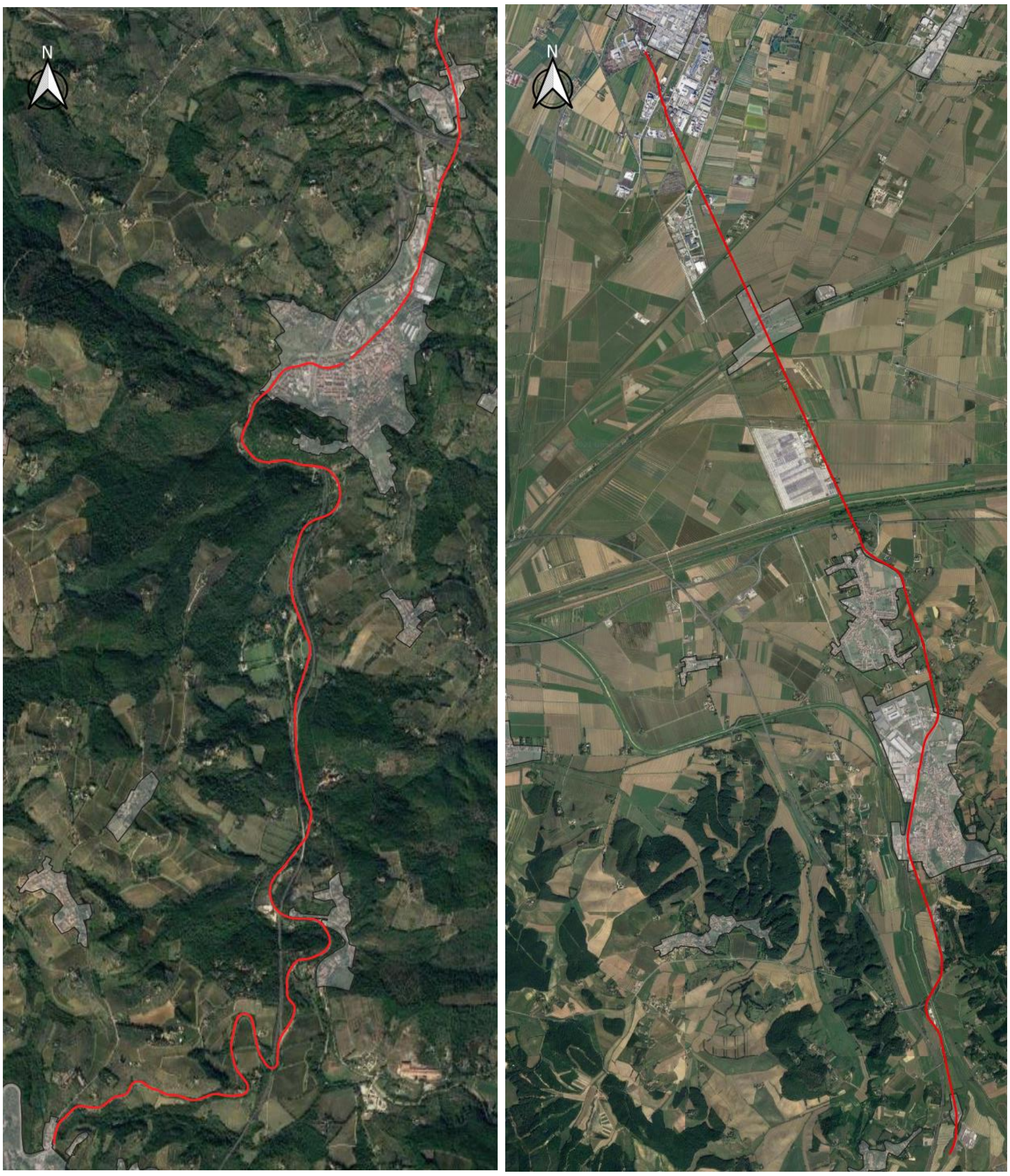

Figure 6.1 – SR2 (left) and SR206 (right) overview on a satellite image

6.1.1.2 Accident database

The accident database considered to calculate the accident rate contains both severe and PDO accidents. The PDO data were not available both for SR2 and SR206 during the first application of the original version of the HFET. The severe accidents database was provided by ISTAT (Istituto Nazionale di Statistica), while the PDO database was provided by local police. Detailed information about both databases is provided in APPENDIX 4. Despite the large amount of information contained in the databases (mainly in the severe accidents database), only few data were considered, because many data were not relevant for the scopes of the analysis. These data are presented in Table 6.1 for the severe accidents (the data concerning the road identification are implicitly considered). The number refers to the list presented in APPENDIX 4.

Table 6.1 – Severe accidents attributes considered for Italian stretches

#	Name	Description
1	anno	Year of the accident occurrence
11	intersezione_o_non_interse3	Accident occurred at intersection or not
12	fondo_stradale	Surface conditions (e.g., wet surface)
14	condizioni_meteorologiche	Atmospheric conditions
15	natura_incidente	Accident type (e.g., rear-end, lateral, with pedestrian, etc.)
16	tipo_veicolo_a	Vehicle “a” type
17	tipo_veicoli__b_	Vehicle “b” type
18	tipo_veicolo__c_	Vehicle “c” type
19	veicolo__a____circostanze_10	What vehicle “a” was doing - 1
20	veicolo__a____circostanze_11	What vehicle “a” was doing - 2
21	veicolo__b____circostanze_13	What vehicle “b” was doing - 1
22	veicolo__b____circostanze_14	What vehicle “b” was doing - 2
113	descrizione_strada	Road description (location of the accident description)
116	chilometri	Km
117	ettometrica	Hm (hectometric)
118	Trimestre	Trimester

In addition, geographical coordinates were used when available.

Sometimes the database doesn’t contain information about the position of the accident on the road (neither with geographical coordinates, neither with km post indication). When this occurred, the position of the accident was defined looking at “descrizione_strada” attribute and “intersezione_o_non_interse3” attribute. If the clear location of the accident cannot be identified, the accident has been discarded.

SR2 accidents

An overview of the accidents occurred in the analysis period 2014-2018 on the SR2 is presented. The accidents refer to those occurred within the analysis sections (accidents occurred in sections not belonging to the analysis, such as urban areas, are excluded). Table 6.2 shows the number of observed accidents divided by severity and years. A total of 71 accidents occurred in this period, among which 59 was severe accidents (fatal-injury accidents, FI) and only 12 were PDO. This first data tells that the road has some deficiencies concerning one or both of the following aspects:

- inadequate passive safety;
- inadequate speeds.

In fact, both two aspects may influence the accident severity. The procedure does not account for the passive safety, but accounts for speed issues. Looking at the distribution of accidents on a satellite image in Figure 6.2, it appears that both accident types are equally distributed, thus it can be stated that the possible passive safety and speed issues are present along the whole stretch. However, some bias may also be present. It must be noted that many times when PDO accidents occurred, the police are not called, and the citizens make all the administrative requirements by their own. To have a complete list of PDO accidents insurance companies must provide the data and, in this case, they refuse to provide any. Considering the homogeneous distribution shown in Figure 6.2, it can be assumed that, if some PDO accidents data are missing, they would be homogeneously distributed. Thus, it has been decided to keep the PDO data.

Finally, among the different years, years 2015 and 2017 shown a very low number of FI accidents comparing to the other years. However, no specific conditions occurred in those years, thus these differences are probably due to accidents fluctuations over the years (regression to the mean).

Table 6.2 – Number of accidents per severity and year, SR2

Accident Severity	Year	Number of accidents
FI	2014	16
	2015	6
	2016	11
	2017	9
	2018	17
PDO	2014	6
	2015	2
	2016	1
	2017	2
	2018	1

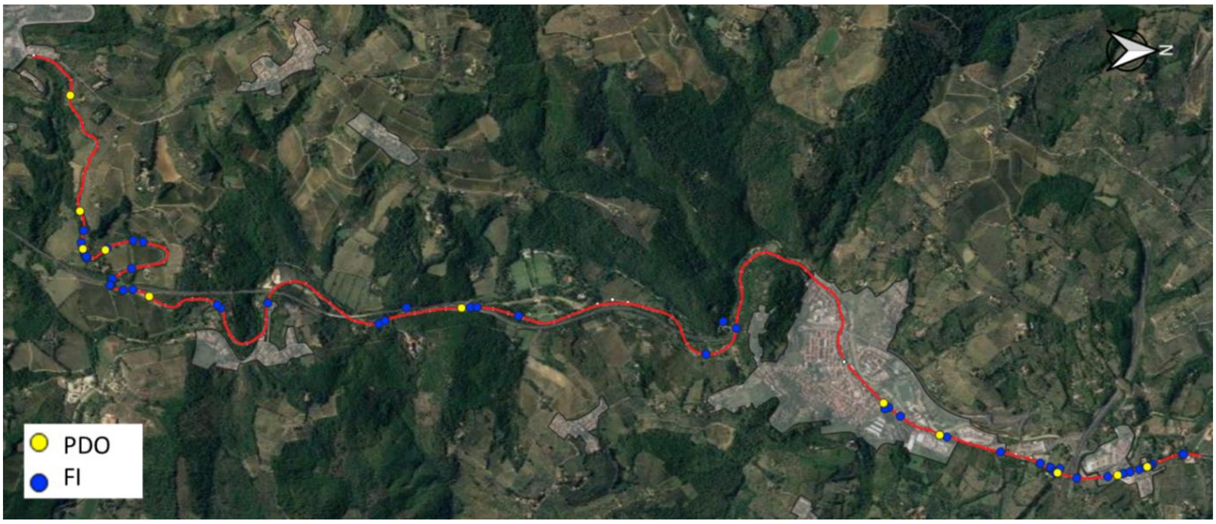

Figure 6.2 – Distribution of FI and PDO accidents, SR2

The severe accidents database contains much information, for this reason the accidents have been analyzed also considering: the location of the accident, the surface conditions, the type of the vehicles involved, and the alleged main contributing/triggering factor. This last attribute is also provided for the PDO accidents. The many options for each attribute have been grouped to few typologies as possible. The results are shown in Table 6.3 (accident location), Table 6.4 (surface condition), Table 6.5 (road user type), and Table 6.6 (alleged main contributing factor). The number of accidents in a single raw of Table 6.5 represent the number of accidents where the vehicle type/road user is present. More than one type of vehicle may be involved in the same accidents, thus the total number of accidents in this table is greater than 59.

Table 6.3 – Number of accidents grouped by accident location and year, SR2

Accident Location	2014	2015	2016	2017	2018	Total
Intersection/Driveways	5	3	5	3	4	20
Tangent	7	3	4	5	8	27
Curve	4	0	2	1	5	12

Table 6.4 - Number of accidents grouped by surface conditions and year, SR2

Surface conditions	2014	2015	2016	2017	2018	Total
Dry	12	5	10	7	12	46
Wet	4	1	1	2	3	11
Icy	0	0	0	0	2	2

Table 6.5 - Number of accidents grouped by vehicle type and year, SR2

Vehicle type/road user	2014	2015	2016	2017	2018	Total
Passenger Car	12	6	8	9	15	50
Commercial vehicle	2	1	1	1	2	7
Powered Two Wheeler	5	3	9	2	6	25
Cyclist	1	0	1	0	0	2
Pedestrian	1	0	1	0	0	2

Table 6.6 - Number of accidents grouped by alleged main contributing factor and year, SR2

Alleged main contributing/triggering factor	2014	2015	2016	2017	2018	Total
No information	7	1	3	0	2	13
Excessive Speed	3	3	3	4	8	21
Not give the right of way	2	1	2	2	3	10
Irregular maneuver	2	0	2	2	2	8
Falling from vehicle	2	0	0	0	0	2
Hard braking to turn/stop	2	1	1	2	2	8
Not clear	4	2	1	1	1	9

Some considerations could be drafted from the analysis of the observed number of accidents.

Looking at Table 6.3 most of the accidents occurred on tangents. However, looking at the position of accidents, they're still very close to curve and driveways and, in many cases, also the alleged main contributing/triggering factor suggests an influence of the presence of driveway and/or curve. This highlights that some error in the accident report may have occurred.

The results from Table 6.4 show only two severe accidents were caused by icy road. It has been decided to discard those accidents because they refer to very unusual conditions. Accidents under wet conditions are instead kept, because even if wet conditions worsen the situation, they cannot be the main triggering factor of an accident (that is what the HFET looks at).

Table 6.5 shows that passenger cars are the most involved vehicle type/road user, followed by powered two wheelers (PTWs).

The last table shown, Table 6.6, it is probably the most relevant for this analysis. As suggested by the distribution of crash severity, speed plays a crucial role in accident occurrence. About 30% of the observed number of accidents occurred (also) because of high speed. About 15% of accidents occurred because of drivers do not give the right of way (or do not stop), and about 10% of accidents occurred because of irregular maneuvers. Two accidents occurred because of falling from the vehicle. Those accidents, and the ones belonging to the "irregular maneuvers" have been discarded. Two examples of irregular maneuvers are drivers trying to stop along the road where not allow or driving parallel to a PTW on the same lane (not during overtaking). These types of maneuvers cannot be induced by a wrong perception of the road. Another 10% of accidents occurred because of a hard breaking to turn or stop where allowed. These accidents are often associated with a reduced available distance from the preceding vehicle, thus are very close to the "irregular maneuvers" classification. However, the abrupt braking maneuver is likely present in this type of accidents, and this maneuver is often due to a sudden facing of something unexpected. For this reason, it has been decided to keep this type of accidents. Finally, about 10% of accidents main contributing/triggering factor are not clear or cannot be the true main factor (for example "driving with dazzling headlight" cannot be a factor alone). It has been decided to keep this last type of accidents. Accidents with no information about the contributing/triggering factors were included too.

Therefore, a total of 59 accidents has been considered in the analysis, without any differentiations between accident severity: the scope of the procedure is to identify sections that potentially could generate accidents, despite accident's consequences.

SR206 accidents

An overview of the accidents occurred in the analysis period 2014-2018 on the SR206 is presented. Table 6.7 shows the number of observed accidents divided by severity and years. A total of 102 accidents occurred in this period, among which 84 was severe accidents (fatal-injury accidents, FI) and only 18 were PDO. Unfortunately, one on the municipality to which the road belongs, does not provide any accidents data. For this reason, it has been decided to not consider PDO data in the SR206 analysis. The accidents distribution is shown on a satellite image in Figure 6.3.

Similar to SR2, accidents have been analyzed also considering: the location of the accident, the surface conditions, the type of the vehicles involved, and the alleged main contributing/triggering factor. The many options for each attribute have been grouped to few typologies as possible. The results are shown in Table 6.8 (accident location), Table 6.9 (surface condition), Table 6.10 (road user type), and Table 6.11 (alleged main contributing factor).

Table 6.7 – Number of accidents per severity and year, SR206

Accident Severity	Year	Number of accidents
FI	2014	11
	2015	20
	2016	17
	2017	24
	2018	12
PDO	2014	5
	2015	5
	2016	2
	2017	4
	2018	2

Figure 6.3 – Distribution of FI and PDO accidents, SR206

Table 6.8 – Number of accidents grouped by accident location and year, SR206

Accident Location	2014	2015	2016	2017	2018	Total
Intersection/Driveways	5	13	11	15	7	51
Tangent	6	7	6	9	5	33
Curve	0	0	0	0	0	0

Table 6.9 - Number of accidents grouped by surface conditions and year, SR206

Surface conditions	2014	2015	2016	2017	2018	Total
Dry	10	16	16	20	11	73
Wet	1	4	1	4	1	11
Icy	0	0	0	0	0	0

Table 6.10 - Number of accidents grouped by vehicle type/road user and year, SR206

Vehicle type/road user	2014	2015	2016	2017	2018	Total
Passenger Car	11	18	14	23	10	76
Commercial vehicle	1	4	4	4	4	17
Powered Two Wheeler	4	4	7	6	2	23
Cyclist	0	2	0	0	0	2
Pedestrian	1	0	1	0	0	2

Table 6.11 - Number of accidents grouped by alleged main contributing factor and year, SR206

Alleged main contributing/triggering factor	2014	2015	2016	2017	2018	Total
No information	0	0	3	2	0	5
Excessive Speed	6	4	5	7	3	25
Not give the right of way	0	5	3	3	3	14
Irregular maneuver	3	5	3	5	1	17
Falling from vehicle	0	0	1	0	1	2
Hard braking to turn/stop	0	0	1	0	1	2
Not clear	2	6	1	7	3	19

Looking at Table 6.8 most of the accidents occurred at intersections and driveways, and no accidents occurred on curves. This can be expected because of the low number of curves in the stretch. However, many times curves are a problem precisely when placed between very long straights. In this case, curves are likely well defined, visible, and comply with drivers' expectations. The intersections/driveways related issues highlight some problem concerning speed and visibility. The speed problems may derive from a bad composition of the field of view or because driveways and intersections are not expected.

The results from Table 6.9 show that no severe accidents were caused by icy road. Thus, no accidents will be discarded because of surface conditions.

Table 6.10 shows that passenger cars are the most involved vehicle type, followed by PTWs. This data will not influence the analysis too, because the influence of the road perception on drivers/riders' behavior is the same (severity of accidents instead will vary).

Table 6.11 highlights the alleged main contributing/triggering factors. As suggested by the distribution of crash severity, speed plays a crucial role in accident occurrence. About 25% of the observed number of accidents occurred (also) because of high speed. About 20% of accidents occurred because of drivers do not give the right of way (or do not stop), and about 20% of accidents occurred because of irregular maneuvers (which are not caused by a wrong perception of the road). Accidents due to irregular maneuver have been discarded, like in SR2 stretch. The two accidents due to "falling from the vehicle" were discarded too. Another 10% of accidents occurred because of a hard breaking to turn or stop where allowed. These accidents will be considered in the analysis, as for SR2. Finally, accidents with the main contributing/triggering factor not clear or with no information were included too (the considerations are the same made for SR2).

Therefore, a total of 65 FI accidents has been considered in the analysis.

6.1.2 German stretches

The German stretches were used to refine the procedure after a first version was made considering the SR2. A different country and roads with different characteristics helped to identify some specific minor modifications to implement, in the procedure and in the HFET too. To define these modifications, the roads characteristics were analyzed and the HFET was applied to some locations. The main contribution to the development of the procedure was to identify (to confirm) the thresholds value for CCR and the PPI levels. After the final version of the procedure was drafted, it was totally applied to those three German stretches, and then the results compared with accident data.

Considering the three roads to which the stretches belong, the B38 differs from L3106 and L3408, because it is classified as a higher category. Indeed, the letter "B" stands for Bundesstraße (plural: Bundesstraßen). Bundesstraßen are federal highways that cross regional boundaries of regions (Land) and can be considered as rural arterials. These roads primarily serve national traffic. In contrast to motorways, federal highways (unless they are signposted as motorways) are not used exclusively for high-speed motor vehicle traffic. When their main cross section is two-lane two-way, they can be analyzed in the category "rural highways" (as the stretch analyzed in this research). On the other hand, the letter "L" at the beginning of the name stands for Landesstraße. The term Landesstraßen (singular: Landesstraße) may be translated as "state road". They are roads that cross the boundary of a rural or urban district (Landkreis or Kreisfreie Stadt). A Landesstraße is thus less important than a Bundesstraße or federal road, but more significant than a Kreisstraße or district road. Landesstraßen can be identified as rural collector roads, which are still part of the identified category of "rural highways". Geometrical, traffic, and accident data have been provided by Hessen Mobil. For all the stretches the accidents database refers to the period 2018-2020; however, the traffic data provided refers mainly to year 2015. In the accident database, one of the attributes is traffic (DTV), but this attribute is not always present. When present, the data are the same, or are very similar to those of year 2015, thus it has been decided to consider the year 2015 as reference for the analysis.

6.1.2.1 Roads description

B38

The stretch of the B38 analyzed ranges between km 1.200 after section 6118-001 and section 6118-036. The road develops through a plain and hilly terrain. The radii used are quite high and the operating speeds are high (between 80 km/h and 100 km/h). The road cross section is composed by two lanes of 3.75 m each and two paved shoulders of 1.50 m each. Many intersections are present along the road and some driveways. Most of the intersection are signalized intersections. Approaching the intersections, the speed limits are set to 70 km/h, but during the survey it appears that drivers do not comply much with them. An overview of the stretch on a satellite image is presented in Figure 6.4. Detailed statistics about the geometry of the stretch are provided in APPENDIX 6. Figure 6.5 shows two photos taken along the stretch. The photo on the left was taken in the south part of the stretch, northbound. The second photo was taken northbound too, but in the northern part, close to a signalized intersection. The direction of increasing km posts is northbound.

The high-speed hold by the driver is probably related to the geometry, but also to the available wide space perceptible around the driver: both ahead and beyond margins.

The traffic data used in the analysis refer to the year 2015 and are presented in Table 6.12. The southern part of the stretch (lower km posts) shows a lower level of traffic.

Figure 6.4 – The analyzed stretch of B38 on a satellite image

Figure 6.5 – Two photos taken along the B38

Table 6.12 – Traffic data considered in the analysis (year 2015), B38

Km post (from-to)	Km 1.0-2.5	Km 2.5-3.0	Km 3.0-4.2	Km 4.2-5.0	Km 5.0-6.5	Km 6.5-8.0	Km 8.0-9.0	Km 9.0-10	Km 10.0-10.8
AADT (veh/day)	7068	8058	11078	14098	10179	10456	10732	11377	12021

L3106

The L3106 road stretch analyzed runs from section 6218-045 to section 6118-005, for a total length of about 7.5 km. The road can be classified as an ECL3 road with reference to the German design standards. Its standard cross section is composed by two lanes of 3.50 m each and two paved shoulder of 0.50 m. When possible, the shoulders are widened with not-paved terrain. The road develops through a hilly terrain, maintains a curvy track. However, the CCR never reach the high level threshold. The road passes through two urban area (two villages), which have been excluded from the analysis. Outside the urban areas, the perceived environment is totally rural. In the central part, the road passes through a forest. Five major intersections are present, including the starting and ending points. Along the road are also present some driveways, bus stops, and one pedestrian crossing. An image of the stretch on a satellite image is provided in Figure 6.6, and two photos taken along the stretch are presented in Figure 6.7.

Figure 6.6 – The analyzed stretch of L3106 on a satellite image

Figure 6.7 - Two photos taken along the L3106

The traffic data used in the analysis refer to the year 2015 and are presented in Table 6.13.

Table 6.13 – Traffic data considered in the analysis (year 2015), L3106

Km post (from-to)	Km 1.0-2.5	Km 2.5-3.0	Km 3.0-4.2
AADT (veh/day)	3024	1783	2922

The very low traffic characterizing this road stretch, makes it very suitable for considerations about accidents caused mainly by road wrong perception, because when a high traffic volume is present, many accidents are due to the interaction between each vehicle and not to the interaction between single vehicles and the road.

L3408

The L3408 road stretch analyzed starts 1.600 km after section 6418-217 and ends 0.4 km before section 6418-207, for a total length of about 3.0 km. The road, like L3106, can be classified as an ECL3 road with reference to the German design standards. Its standard cross section is composed by two lanes of 3.50 m each and two paved shoulder of 0.50 m. The road develops mainly into the forest, with many curves of medium radius. The average CCR belongs to the medium level. The road goes up with a positive grade from start location (west) to the end (east). The grade is soft; thus, it is not well perceived. The road passes through two small groups of houses, which are less than 200 m long, that have been included in the analysis. Bus stops are present along the road, and in the villages' areas. Despite this, no pedestrian crossings are present (but pedestrian still need to cross to reach the bus stop). Finally, all the junction with minor roads can be considered as driveways. Indeed, minor roads serve mostly houses, very small residential areas, and other accesses to the woods. The road stretch is depicted on a satellite image in Figure 6.8 and two photos of the road are shown in Figure 6.9. The photo on the right shows the segment that passes close to one group of houses.

Even for this stretch, the traffic refers to the year 2015. The traffic along the whole stretch is 3311 vehicles/day. Thus, also for this stretch the volume of traffic is not high, and accident could be more likely related to road perception.

Figure 6.8 – The analyzed stretch of L3408 on a satellite image

Figure 6.9 - Two photos taken along the L3106

6.1.2.2 Accident database

The accident database considered to calculate the accident rate contains both severe and PDO accidents. The accident database has been provided by Hessen Mobil and refers to the period 2018-2020. Detailed information about the database is provided in APPENDIX 4. The database also contains the detailed description of accidents. Despite the large amount of information contained in the databases (mainly in the severe accidents database), only few data were considered, because many data were not relevant for the scopes of the analysis. The data used are presented in Table 6.14 and refers to the list presented in APPENDIX 4.

The analysis period contains data about the year 2020. The year 2020 is a very specific year since the Covid pandemic has struck hard in that year. Consequently, in many countries people drive less because of lockdowns. However, looking at the traffic data of all the three roads, the year 2020 has a very similar level of traffic to year 2018 and 2019, thus it has been decided to keep those data.

Table 6.14 – Severe accidents attributes considered for Italian stretches

#	Name	Description
1	STR	Road type and number
2	ABS	Node network section number
4	STAT	Station
5	DTV	AADT
7	OL	Urban or rural area
11	TO	Number of deads
12	SV	Number of serious injuries
13	LV	Number of slight injuries
14	U Art	Accident type
15	Char	Accident characteristics
19	Zust	Road conditions
21	Un kat	Accident category
22	U Typ	Accident typology
24	Urs 1	Definitive cause 1
25	Urs 2	Definitive cause 2
27	VBet1	Vehicle Type 1
28	VBet2	Vehicle Type 2
29	VBet3	Vehicle Type 3
30	COMVOR-Nr	Reference number

B38 accident statistics

An overview of the accidents occurred in the analysis period 2018-2020 on the B38 is presented. Table 6.15 shows the number of observed accidents divided by severity and years. A total of 137 accidents occurred in this period, among which 39 were severe accidents (fatal-injury accidents, FI) and 96 were PDO. Contrary to the Italian stretches, this stretch presents a standard relationship between FI and PDO accidents.

Table 6.15 – Number of accidents per severity and year, B38

Accident Severity	Year	Number of accidents
FI	2018	13
	2019	16
	2020	10
PDO	2018	33
	2019	36
	2020	27

The many options for each attribute have been grouped to few typologies as possible. The results are shown in Table 6.16 (accident location), Table 6.17 (surface condition), Table 6.18 (road user type), and Table 6.19 (alleged main contributing factor).

Table 6.16 – Number of accidents grouped by accident location and year, B38

Accident Location	2018	2019	2020	Total
Intersection/Driveways	19	24	15	58
Tangent	6	4	1	11
Curve	4	7	5	16
Not defined	19	17	16	52

Table 6.17 - Number of accidents grouped by surface conditions and year, B38

Surface conditions	2018	2019	2020	Total
Dry	33	36	25	94
Wet	13	16	12	41
Icy	2	0	0	2

Table 6.18 - Number of accidents grouped by vehicle type and year, B38

Vehicle Type	2018	2019	2020	Total
Passenger Car	45	48	33	126
Commercial vehicle	3	4	1	8
Powered Two-Wheeler	1	2	1	4
Cyclist	1	2	4	7
Pedestrian	0	0	0	0
Other	2	2	2	6

Table 6.19 - Number of accidents grouped by alleged main contributing factor and year, B38

Alleged main contributing/triggering factor	2018	2019	2020	Total
No information	0	0	0	0
Excessive Speed	5	3	2	10
Not give the right of way	7	4	5	16
Irregular maneuver/animal crossing	22	22	11	55
Falling from vehicle	0	0	0	0
Hard braking to turn/stop	9	14	11	34
Not clear	5	9	8	22

As depicted in Table 6.16, intersections and driveways play a crucial role in the safety of the stretch. Most of the accidents occurred there, even if many accidents are not classified (about 38%).

The results from Table 6.17 show only two accidents were caused by icy road. These accidents have been discarded as for the Italian roads.

Table 6.18 shows that passenger cars are the most involved vehicle type also in this road, with a very low number of other road users involved.

Table 6.19 shows the distribution of the alleged main contributing/triggering factors. Irregular maneuvers seem to be the leading contributing factor to the accident causation. A deeper analysis of those accidents highlights that 38 out of 55 of those accidents were caused by a collision with an animal. Some other were caused by irregular maneuvers from rescue vehicles and police vehicles. To this category belong also situations where the driver has drunk, has some specific physical deficiency, has been distracted by instruments inside the vehicles, and vehicles' breakdowns. Like this kind of accidents of the Italian dataset, it has been decided to discard these accidents as they are not derived from a wrong perception of the road. The second most relevant factor is the "hard braking maneuver" (about 25%). For this maneuver, the accident database was deeply analyzed too, and it was found that most of those accidents occurred close to intersections, mainly because of traffic, traffic lights, drivers' inattention, and a reduced distance from the preceding vehicle. All those accidents are classified in the German database as "the driver doesn't keep enough distance from the preceding vehicle". Many of those accidents are rear-end accidents that involve more than two cars. Driving too close to the preceding vehicles may be a problem of human factors, but not of road perception. However, abrupt braking actions could be linked to wrong road perceptions, thus it has been decided to keep those accidents.

The remaining accidents contributing factors are distributed among "excessive speed" (7%), "not give the right of way" (12%) and "not clear" (16%).

Because of the accidents screening, for the analysis of the B38 road stretch a total of 80 accidents have been considered.

L3106 accidents statistics

The period considered for the analysis is 2018-2020. Table 6.20 shows the number of observed accidents divided by severity and years. A total of 67 accidents occurred in this period, among which 1 was severe accidents (fatal-injury accidents, FI) and 66 were PDO. In this case, a very high number of PDO accidents is present compared to the FI accidents. This could indicate a general lower speed and/or safer margins.

Table 6.20 – Number of accidents per severity and year, L3106

Accident Severity	Year	Number of accidents
FI	2018	1
	2019	0
	2020	0
PDO	2018	26
	2019	27
	2020	13

Accidents have been grouped following the main groups also identified for B38. The results are shown in Table 6.21 (accident location), Table 6.22 (surface condition), Table 6.23 (road user type), and Table 6.24 (alleged main contributing factor).

Table 6.21 – Number of accidents grouped by accident location and year, L3106

Accident Location	2018	2019	2020	Total
Intersection/Driveways	2	3	0	5
Tangent	4	2	2	8
Curve	9	11	1	21
Not defined	12	11	10	33

Table 6.22 - Number of accidents grouped by surface conditions and year, L3106

Surface conditions	2018	2019	2020	Total
Dry	19	20	11	50
Wet	7	7	2	16
Icy	1	0	0	1

Table 6.23 - Number of accidents grouped by vehicle type and year, L3106

Vehicle Type	2018	2019	2020	Total
Passenger Car	24	26	13	63
Commercial vehicle	1	0	0	1
Powered Two-Wheeler	1	1	0	2
Cyclist	0	1	0	1
Pedestrian	0	0	1	1
Other	1	1	0	2

Table 6.24 - Number of accidents grouped by alleged main contributing factor and year, L3106

Alleged main contributing/triggering factor	2018	2019	2020	Total
No information	0	0	0	0
Excessive Speed	3	1	0	4
Not give the right of way	1	0	0	1
Irregular maneuver/animal crossing	20	19	12	51
Falling from vehicle	0	0	0	0
Hard braking to turn/stop	1	1	0	2
Not clear	2	6	1	9

Looking at the preceding tables, accidents characteristics differ from those of B38. Few accidents occurred at intersections, while many occurred along curves (Table 6.21).

Most of the accidents occurred under dry conditions (Table 6.22). The single accidents occurred because of ice on the road will be discarded.

In more than 90% of accidents, a passenger car is involved (Table 6.23), while the other road user's typologies involved are few.

The most relevant aspect of this stretch is depicted in Table 6.24. The 76% are due to animal crossing of the road (all the "irregular maneuver" accidents). Consequently, only 15 accidents will be included in the analysis. Among those the most relevant part (about 60%) occurred due to not clear factors, and about 25% because of speed.

L3408 accidents statistics

The same statistics presented for B38 and L3106 are also presented for L3408. The period considered for the analysis is 2018-2020. Table 6.25 shows the number of observed accidents divided by severity and years. A total of 22 accidents occurred in this period, among which 2 were severe accidents (fatal-injury accidents, FI) and 20 were PDO. Likewise, L3106, a very high number of PDO accidents is present compared to the FI accidents. This could indicate a general lower speed and/or safer margins.

Table 6.25 – Number of accidents per severity and year, L3408

Accident Severity	Year	Number of accidents
FI	2018	0
	2019	1
	2020	1
PDO	2018	8
	2019	6
	2020	6

Accidents have been grouped following the main groups also identified for the other stretches. The results are shown in Table 6.26 (accident location), Table 6.27 (surface condition), Table 6.28 (road user type), and Table 6.29 (alleged main contributing factor).

Table 6.26 – Number of accidents grouped by accident location and year, L3408

Accident Location	2018	2019	2020	Total
Intersection/Driveways	0	0	0	0
Tangent	2	3	0	5
Curve	0	2	1	3
Not defined	0	0	0	0

Table 6.27 - Number of accidents grouped by surface conditions and year, L3408

Surface conditions	2018	2019	2020	Total
Dry	4	5	5	14
Wet	4	2	2	8
Icy	0	0	0	0

Table 6.28 - Number of accidents grouped by vehicle type and year, L3408

Vehicle Type	2018	2019	2020	Total
Passenger Car	6	7	6	19
Commercial vehicle	0	0	0	0
Powered Two-Wheeler	1	0	1	2
Cyclist	0	0	0	0
Pedestrian	0	0	0	0
Other	1	0	0	1

Table 6.29 - Number of accidents grouped by alleged main contributing factor and year, L3408

Alleged main contributing/triggering factor	2018	2019	2020	Total
No information	0	0	0	0
Excessive Speed	0	2	1	3
Not give the right of way	0	0	0	0
Irregular maneuver/animal crossing	7	4	5	16
Falling from vehicle	0	0	0	0
Hard braking to turn/stop	0	0	0	0
Not clear	1	1	1	3

Looking at the preceding tables, accidents characteristics differ from those of other stretches. No accidents occurred at driveways/intersections (Table 6.26).

No accidents occurred because of icy (or slippery) road surface conditions (Table 6.27).

About 86% of accidents involve a passenger car (Table 6.28), 2 accidents involve PTWs and 1 involves one other not specified vehicle.

Considering the alleged main contributing/triggering factors shown in Table 6.29, 15 accidents have been due to animal crossing and 1 to irregular maneuver. These accidents have been excluded from the analysis. Among the remaining 6 accidents, 3 were caused because of excessive speed, and 3 because of not clear factors. Only those 6 accidents have been considered in the analysis.

6.1.3 Slovenian stretch

The Slovenian stretch has been analyzed in the phase three of the development of the procedure, thus it has been used to test the reliability of the final version of the procedure.

6.1.3.1 Road description

The 106 stretch develops from the southern part of Ljubljana for about 16 km. The road stretch analyzed corresponds to the section 261. The road 106 is an important road that connects the capital Ljubljana with the southern part of the country. Thus, many vehicles of different types travel the road. The road cross section in not always constant. On average, it can be assumed a lane width of 3.50 m and no or very narrow paved shoulder (from 0.25 m to 0.5 m). Many times, beyond the paved shoulders, a sub-horizontal strip of terrain is present, which provide an additional unpaved shoulder. From km post 3.200 to km post 5.200, the carriageway cross section is composed by a 2+1 lane, with a double lane in the south direction. These double lanes have the main scope of providing a climbing lane, because of the high grade. Figure 6.10 shows a graphical representation of the analyzed road stretch on a satellite image.

Figure 6.10 - The analyzed stretch of 106 on a satellite image

The road passes through two small villages located around km post 3.000 and km post 12.900. Nevertheless, because of the reduced length of these urban area and because a not well-defined urban environment, both the villages' areas have been included in the analysis. Moreover, some groups of housed are often present along the road margins. For this reason, along the road many driveways and some intersections are present.

At the beginning of the road a roundabout is present that has been built in August 2019, for this reason the accidents before that period has not been considered.

This is a fast stretch with speeds that often reach the value of 90 km/h[20]. The speeding is likely linked to the low curvature of the road's elements. The first part of the road has been classified as with low CCR, and the second part as medium; however, even in the second part, the CCR is very close to the threshold between low and medium level (see APPENDIX 6).

Figure 6.11 shows two photos from the road. The photo on the left shows the road while passes through one of the two cited urban areas. The second photo is taken in the central part of the road, completely into the woods.

Figure 6.11 – Two photos taken along the 106

Traffic data have been provided as a single data for each year in the period 2015-2019. Thus, no traffic data were provided for year 2020, which comprises accident data. Table 6.30 shows the traffic for each year of analysis.

Table 6.30 - Traffic data considered in the analysis, 106

Year	AADT
2015	7973
2016	8264
2017	8426
2018	8535
2019	8645

[20] It has been defined both during the inspection, both by the information provided by the road agencies.

6.1.3.2 *Accident database*

The accident database considered to calculate the accident rate contains both severe and PDO accidents. The accident database has been provided by Slovenian Infrastructure Agency and refers to the period 2015-2020. However, because in year 2020 the Covid pandemic struck and no traffic data have been provided about year 2020, it has been decided to not consider this year. Additional information about the database is provided in APPENDIX 4. All the provided accidents attributes have been used.

106 accidents statistics

An overview of the accidents occurred in the analysis period 2015-2019 on the 106 is presented. A total of 265 accidents occurred in this period, among which 64 were severe accidents (fatal-injury accidents, FI), 90 were PDO, and 110 were not classified.

Table 6.31 – Number of accidents per severity and year, 106

Accident Severity	Year	Number of accidents
FI	2015	11
	2016	18
	2017	10
	2018	10
	2019	16
PDO	2015	12
	2016	24
	2017	14
	2018	24
	2019	16
Not defined	2015	24
	2016	24
	2017	24
	2018	13
	2019	25

Based on accidents attributes, it was possible to analyze the accident distribution by means of surface conditions and alleged main contributing/triggering factor. No information about the vehicle types/road users involved has been provided, except only one accident where a pedestrian has been involved. The results from this grouping are shown in Table 6.32 (surface conditions), and Table 6.33 (alleged main contributing factor).

The results from Table 6.32 show that 15 accidents were caused by icy road. These accidents have been discarded as for the other stretches because the road conditions differ too much from standard conditions and these circumstances are not considered in the procedure.

Table 6.33 shows the distribution of the alleged main contributing/triggering factors. 86 accidents occurred because of animal crossing and 1 because of irregular maneuvers. Likewise other stretches, it has been decided to discard these accidents as they are not derived from a wrong perception of the road. Among the other factors, the most recurrent is "not clear", which means that accidents contributing/triggering factors are hardly explained by consider only what has been reported by the police. Those accidents, summed to those without information, are 121 (64% of accidents, excluding "irregular maneuver/animal crossing"). The third most influencing factor is "excessive speed" (25% of accidents, excluding "irregular maneuver/animal crossing"). Finally, few accidents occurred because of "not give the right of way" and "hard braking to turn/stop" (respectively 4% and 7% of accidents, excluding "irregular maneuver/animal crossing").

Consequently, a total of 169 accidents have been considered for the analysis period of 2015-2019.

Table 6.32 - Number of accidents grouped by surface conditions and year, 106

Surface conditions	2015	2016	2017	2018	2019	Total
Dry	33	46	38	29	40	186
Wet	13	16	12	18	17	76
Icy	3	5	4	3	0	15

Table 6.33 - Number of accidents grouped by alleged main contributing factor and year, 106

Alleged main contributing/triggering factor	2015	2016	2017	2018	2019	Total
No information	4	10	9	6	7	36
Excessive Speed	7	14	6	13	8	48
Not give the right of way	2	1	2	2	0	7
Irregular maneuver/animal crossing	21	15	18	10	23	87
Falling from vehicle	0	0	0	0	0	0
Hard braking to turn/stop	5	4	2	1	2	14
Not clear	10	23	17	18	17	85

6.2 Calculation of the accident rate

As in the first application of the HFET in its original form, the accident rate performance measure has been chosen as the most representative for a comparison with a network ranking based on the outcomes of the procedure. Indeed, accident rate is a safety performance that quantify the safety of a single-vehicle driving along a road stretch. As defined in Eq. 5 in 5.2.2.4, the accident rate for a road segment is defined as the number of accidents in a year (i.e., accident frequency), divided by the number of vehicles which pass through that segment yearly (in million vehicles), and divided by the length of the segment. In the calculation of the accident rate for the procedure test, it has been decided to calculate first the accident frequency in the whole analysis period, that is the yearly average of the observed number of accidents in the whole period. This value has been then considered as "n" in Eq. 5 (i.e., yearly number of accidents), and the AADT has been considered as the average AADT in the section among the different years[21].

Finally, one additional assumption made must be underlined about the use of accident rate. The calculation of accident rate for intersections do not account for the length of a segment and must consider the whole traffic entering the intersection.

Consequently, the accident rate for a road segment which include an intersection should account also for the specific accident rate of the intersection. However, in this study it has been decided to calculate the accidents rate only referring to the road segment equation (Eq. 5). The reason of this choice is because there are no or very few traffic data for minor roads intersecting the analyzed roads. Traffic data is crucial for the calculation of the accident rate. Calculating the accident rate only for some intersections will make hard the comparison between segments, because some segments will include "considered" intersection (by means of use their own accident rate) and some segments will include "not considered" intersection (because of unavailable traffic data). To make the comparison as more homogeneous as possible, it has been decided to not account for the specific calculation of intersections' accident rate. Moreover, on the analyzed road, in many cases the difference between intersection and driveway is very narrow, and this reflects also in the accident database in the definition of accident locations. Detailed description about accidents were not always available and thus it was not always possible to clearly define which information is relevant (located at intersection or not). This reinforces the choice made not to calculate the specific intersection-related accident rate.

To define the risk level based on accident rate, it has been decided to follow the procedure proposed by MIT (Ministero delle Infrastrutture e dei Trasporti, 2003) developed upon the proposal from Norde et al. (Norden et al., 1956). Two thresholds have been identified: T_{max} and T_{min}. The risk levels are assigned as follow:

$T_i < T_{min}$ = low risk level;

$T_{min} < T_i < T_{max}$ = medium risk level;

$T_i > T_{max}$ = high risk level.

T_i is the accident rate for section "i", calculated following Eq. 5. T_{min} and T_{max} can be calculated following Eq. 14 and Eq. 15.

$$T_{min} = T_m - K \times \sqrt{\frac{T_m}{M_i}} - \frac{1}{2 \times M_i} \qquad \textit{Eq. 14}$$

[21] This choice has been possible because of the very low variance of traffic in the same segment among different years.

$$T_{max} = T_m - K \times \sqrt{\frac{T_m}{M_i}} - \frac{1}{2 \times M_i} \qquad \text{Eq. 15}$$

Where:

K = constant of Poisson probability distribution function, taken as 1.282 (confidence interval of 90%) (Falconetti, 2012);

T_m = the average accident rate of the analyzed site (e.g., road stretch) calculated with Eq. 16;

$$T_m = \frac{n_p \times 10^6}{365 \times \sum_{i=1}^{t}\left(L_i \times AADT_{i,p}\right)} \qquad \text{Eq. 16}$$

M_i = the exposure momentum calculated with Eq. 17 for section "i".

$$M_i = 365 \times 10^{-6} \times L_i \times AADT_{i,p} \qquad \text{Eq. 17}$$

Where:

n_p = total number of accidents occurred in the considered period "p";

t = total number of sections in the analyzed site;

L_i = length of the "i" section;

$AADT_{i,p}$ = average annual daily traffic of section "i", in the whole considered period "p" (sum of the $AADT_i$ of each year).

It is clear that different samples will often lead to different thresholds values for the definition of accident rate risk level. As discussed in 5.2.4.4, this can be considered both a strength and a weakness. In order to account for this characteristic derived from the accident rate thresholds choice, it has been decided to evaluate the thresholds and to make the comparison between the risk level derived from the HFE procedure and the accident rate analysis, also for each road stretch.

6.3 Outcomes from the procedure

In phase three of the procedure development, the HFE procedure has been applied to these six road stretches: SR2, SR206, B38, L3106. L3408, and 106. Each intermediate result for each step of the procedure is presented and discussed (from paragraph 6.3.1 to 6.3.6). A comprehensive evaluation of the results is then presented. Finally, the results for a second application of the procedure to the SR2 stretch is presented to assess the repeatability of the procedure.

The results from the application of the HFE procedure and the outcomes from the accident rate calculation, are than discussed in CHAPTER 7. The results are analyzed comparing the risk level assigned to each NAS by means of Freeman-Halton extension of Fisher's test because of the low number of variables considered, and the ranking of each NAS by means of Kendall's coefficient of concordance (W). These two tests are described in 6.3.2.5.

The distance reference used in the following paragraphs considers the starting point of the stretch as 0.

6.3.1 SR2

6.3.1.1 First Step

Identification of potentially critical locations (PCLs)

A total of 161 PCLs has been identified in the analyzed stretch (excluding areas not considered in the analysis, e.g., urban areas). Among those, 59 are curves, 17 stopping areas, 14 crossings, 49 driveways, 19 intersections, and 3 lane changes. Figure 6.12 shows the distribution of the PCLs along the stretch. It can be noticed that along the road stretch, many PCLs are present. In the first part of the stretch (southern) the most recurrent PCLs are curve. In the remaining part, the PCLs are distributed quite homogeneously.

Figure 6.12 – Distribution of PCLs, SR2

Identification of expectation sections (EXSEs)

The EXSEs have been defined accounting for the winding level and for the PPI level. The CCR values and the CCR graph for SR2 are shown in APPENDIX 6. Concerning the PPI level, from km 280.600 to km 287.500 the road passes through a countryside area (from reference distance 0 km to 6.9 km). The PPI level along this section is low. From km 287.500 to km 292.200 (reference distance 6.9 km and 11.6 km), which includes the urban area, more houses, activities, driveways, and intersections are visible (and perceivable). The last part of the stretch (from km 9.350) can be considered as a suburban area. For this reason, the PPI level in this section has been judged as medium. Based on these evaluations, the EXSEs have been defined. The identified EXSEs are listed in Table 6.34. The table shows also the consequent expected speed level (V_E) and alertness level (AL).

Table 6.34 – EXSEs of SR2

Name	Starts [km]	End [km]	Length [km]	CCR [gon/km]	Winding level	PPI level	V_E	AL
EXSE 1	0	4.55	4.55	383	H	L	M	M
EXSE 2	4.55	6.9	2.35	89	L	L	H	L
EXSE 3	6.9	8.4	1.5	317	M	M	M	M
EXSE 5	9.35	11.6	2.25	109	L	M	M	M

The same EXSEs are also represented on a satellite image in Figure 6.13.

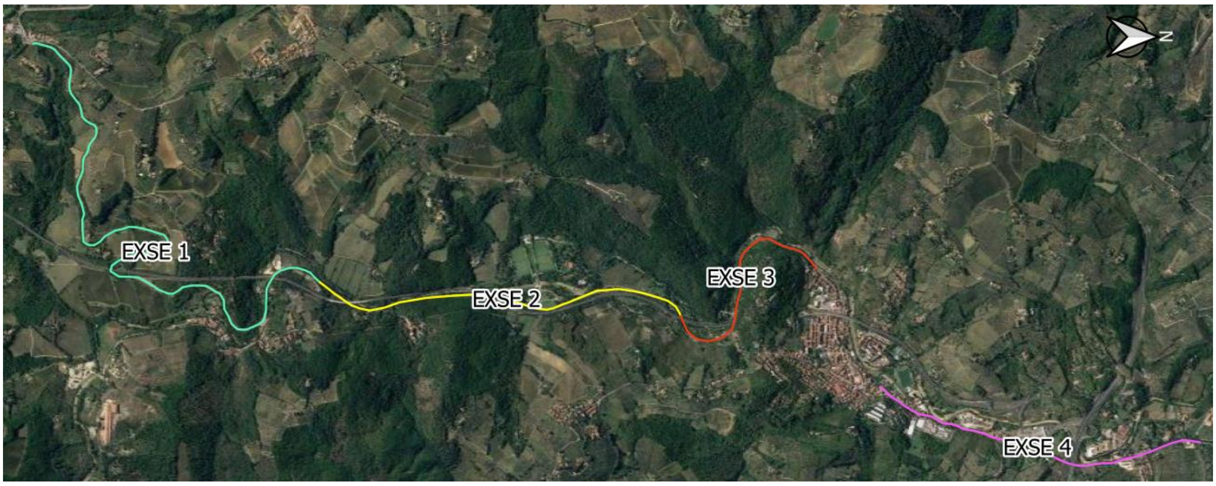

Figure 6.13 – EXSEs of SR2, representation on satellite image

Evaluation of potentially critical locations (PCLs)

Each PCL has been evaluated by means of VIS, PEX, and GEX. The results are summarized in Table 6.35. The results show that SR2 stretch has some visibility issues: about 2/3 of the total number of PCLs are at medium or high level of risk. PEX and GEX problems are few. About 1/4 of the total PCLs have a medium or a high risk level. Few differences are present concerning the two directions (INC = increasing km posts, DEC = decreasing km posts).

Table 6.35 – Overall results for SR2 PCLs evaluation

	VIS		PEX		GEX	
	INC	DEC	INC	DEC	INC	DEC
L	54	52	117	119	110	110
M	100	101	0	0	34	36
H	6	8	43	42	16	15
Tot	160	161	160	161	160	161

6.3.1.2 *Second Step*

Identification of challenging locations (CHLs)

Based on the results from the evaluation of the PCLs, the CHLs have been identified. PCLs are promoted to CHLs if they have been judged with at least one high level of risk and one medium level of risk by means of VIS, PEX, and GEX. A total of 61 PCLs has been promoted to CHLs. Among these, 29 are CHLs considering both directions, 19 are only in the increasing km post direction, and 13 in the decreasing km post direction. The distribution among the different types of PCLs is presented in Table 6.36. Driveways are the most critical locations, followed by at-grade intersections and curves. Moreover, many of the junctions classified as "at-grade intersections" have traffics similar to a driveway. The most recurrent issue concerning driveways is the low visibility. The GEX have a low influence on driveways. A graphical representation of the CHLs on a satellite image is provided in Figure 6.14.

Table 6.36 – Number of identified CHLs by type and direction, SR2

CHLs type	INC	DEC
Curve	10	8
At-grade intersection	9	10
Crossing	5	6
Driveway	19	15
Lane Change	0	1
Stopping area	5	2
TOTAL	***47***	***42***

Figure 6.14 – Identified CHLs, SR2

Identification of challenging transitions (CHTs) and Human Factors Evaluation Segments (HFESs)

CHTs are required to evaluate not only the point where the CHL is located but also the road 10-12 second before the CHL. This is crucial for judging the compliance of the road with all the Human Factors rules. As explained in 5.3.4.2, CHTs include the whole CHL itself and the preceding road segment travelled in about 10-12 seconds. If one or more CHTs overlap, they will be joined together. The obtained CHTs will be called HFESs and will be the segments to which apply the HFET.

The list of the obtained HFESs is presented in Table 6.37 for the increasing km post direction, and in Table 6.38 for the decreasing km post direction. The tables show also the EXSE to which the HFES belong. A total of 37 HFES have been identified: 19 for the increasing km post direction and 18 for the decreasing km post direction. This means that for this road stretch, the HFET will be applied 37 times. Figure 6.15 shows the position of the identified HFES by colored segments parallel to the road track on a satellite image. Light blue segments identified the HFES for the increasing km post direction, while red segments identified the HFES for the decreasing km post direction.

Table 6.37 – List of the HFES, SR2, increasing km post direction (INC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
INC0	EXSE 1	0.15	0.35	0.200
INC1	EXSE 1	0.800	0.950	0.150
INC2	EXSE 1	1.200	1.650	0.450
INC3	EXSE 1	1.750	2.250	0.500
INC4	EXSE 1	2.250	2.650	0.400
INC5	EXSE 1	2.700	3.150	0.450
INC6	EXSE 1	3.200	3.450	0.250
INC7	EXSE 1	3.550	4.050	0.500
INC8	EXSE 1	4.150	4.400	0.250
INC9	EXSE 1	4.450	4.700	0.250
INC10	EXSE 2	4.750	5.000	0.250
INC11	EXSE 2	5.600	6.100	0.500
INC12	EXSE 2	6.500	6.900	0.400
INC13	EXSE 3	6.950	7.500	0.550
INC14	EXSE 3	7.750	8.000	0.250
INC18	EXSE 5	9.500	9.700	0.200
INC19	EXSE 5	10.100	10.350	0.250
INC20	EXSE 5	10.400	10.600	0.200
INC21	EXSE 5	11.000	11.250	0.250

Table 6.38 – List of the HFES, SR2, decreasing km post direction (DEC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
DEC1	EXSE 1	0.900	1.100	0.200
DEC2	EXSE 1	1.400	1.800	0.400
DEC3	EXSE 1	2.050	2.950	0.900
DEC4	EXSE 1	3.350	3.600	0.250
DEC5	EXSE 1	3.700	3.950	0.250
DEC6	EXSE 2	4.650	4.900	0.250
DEC7	EXSE 2	4.950	5.250	0.300
DEC8	EXSE 2	5.800	6.200	0.400
DEC9	EXSE 2	6.750	7.000	0.250
DEC10	EXSE 3	7.150	7.500	0.350
DEC11	EXSE 3	7.600	7.800	0.200
DEC12	EXSE 3	7.950	8.150	0.200
DEC13	EXSE 3	8.150	8.400	0.250
DEC15	EXSE 4	9.350	9.550	0.200
DEC16	EXSE 5	9.550	9.700	0.150
DEC17	EXSE 5	9.800	10.000	0.200
DEC18	EXSE 5	10.350	10.800	0.450
DEC19	EXSE 5	11.200	11.450	0.250

Figure 6.15 – Obtained HFESs for increasing km post direction (light blue) and decreasing km post direction (red), SR2

Application of the Human Factors Evaluation Tool (HFET)

The HFET has been then applied to all the 37 HFESs. The outcomes are four different HFSs (Human Factors Scores) for each HFES: one score for the First Rule, one for the Second Rule, one for the Third Rule, and one considering all the rules together (i.e., Total HFS). The results are presented in Table 6.39 for the increasing km post direction and in Table 6.40 for the decreasing km post direction. The results considering only the Total HFS are graphically represented in Figure 6.16. Red segments identify high risk HFES (Total HFS < 0.40), while yellow segments identify medium risk HFES (0.40 ≤ Total HFS ≤ 0.60). Looking at Figure 6.16, it emerges that the road stretch presents many issues, so that no low risk segments are present. However, this result is also physiological, because in Step 1 of the procedure the PCLs judged as "less risky" have been discarded from the analysis.

One of the most recurrent issues is the low visibility. This partially emerges also from the first screening of Step 1, but becomes evident looking at the scores of the First Rule (4-6 seconds Rule) for each HFES in Table 6.39 and Table 6.40: 27 out of 37 (about 73%) HFESs have a First Rule HFS less than 0.40. The results are also presented by histogram in Figure 6.17. In the histogram, the HFSs have been grouped in three different bands: minor than 0.30, from 0.30 to 0.40, from 0.40 to 0.50, from 0.50 to 0.60, from 0.60 to 0.70, and above 0.70. From the histogram, the visibility issues are clearly visible. Concerning the Second Rule and the Third Rule, there are few results under the threshold of 0.40, and most of the results are in the 0.40-0.50 band. Globally, most of the evaluations are minor than 0.50. This confirms (even if not totally proves), the effectiveness of the first screening.

Table 6.39 – Results for each HFES from the application of the HFET, SR2, increasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
INC0	0.38	0.56	0.57	0.53
INC1	0.38	0.60	0.50	0.50
INC2	0.35	0.42	0.35	0.38
INC3	0.40	0.48	0.39	0.43
INC4	0.40	0.34	0.38	0.37
INC5	0.35	0.40	0.41	0.39
INC6	0.38	0.50	0.50	0.46
INC7	0.30	0.55	0.47	0.44
INC8	0.38	0.47	0.67	0.50
INC9	0.44	0.50	0.50	0.48
INC10	0.38	0.53	0.41	0.44
INC11	0.56	0.47	0.43	0.49
INC12	0.35	0.43	0.44	0.40
INC13	0.31	0.47	0.44	0.41
INC14	0.38	0.44	0.69	0.49
INC18	0.44	0.50	0.60	0.51
INC19	0.63	0.47	0.53	0.54
INC20	0.38	0.42	0.44	0.41
INC21	0.44	0.53	0.35	0.44

Table 6.40 – Results for each HFES from the application of the HFET, SR2, decreasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
DEC1	0.38	0.44	0.62	0.47
DEC2	0.35	0.46	0.41	0.41
DEC3	0.25	0.40	0.35	0.34
DEC4	0.31	0.65	0.40	0.46
DEC5	0.38	0.42	0.44	0.42
DEC6	0.38	0.63	0.46	0.49
DEC7	0.38	0.50	0.50	0.46
DEC8	0.44	0.33	0.59	0.45
DEC9	0.31	0.58	0.47	0.46
DEC10	0.25	0.50	0.45	0.40
DEC11	0.25	0.61	0.50	0.46
DEC12	0.30	0.48	0.69	0.47
DEC13	0.31	0.44	0.65	0.47
DEC15	0.38	0.50	0.40	0.43
DEC16	0.38	0.72	0.43	0.51
DEC17	0.44	0.58	0.45	0.49
DEC18	0.38	0.36	0.47	0.40
DEC19	0.44	0.44	0.33	0.40

Figure 6.16 – Total HFS results, SR2 (red = high risk HFES, yellow = medium risk HFES)

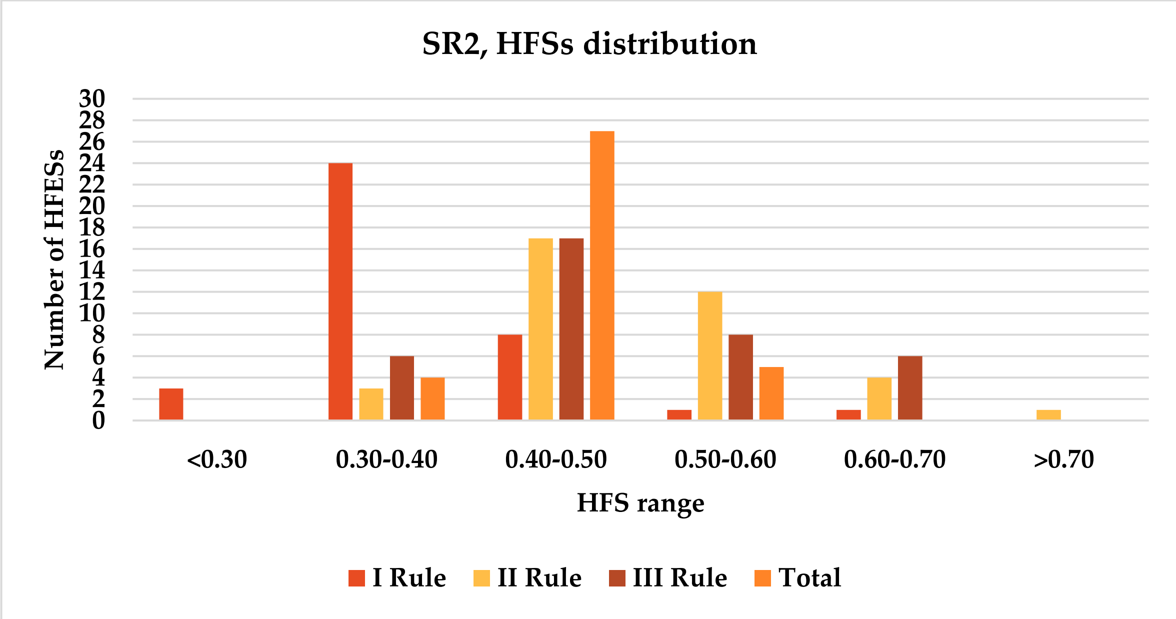

Figure 6.17 – Distribution of the HFSs for SR2

6.3.1.3 Third Step

The evaluation of the road stretch has been carried out in Step 2. However, to let the results to be suitable for road agency for identifying high risk location and planning interventions, longer sections should be considered ("iRAP Methodology fact sheets - iRAP," n.d.). These sections are called NASs.

Identification of network assessment sections (NASs)

For the purpose of this research, it has been decided to test the results for a chosen NAS fixed length of about 1 km. The NAS must include the HFES in full, thus HFES cannot be cut. Moreover, they must comprise both the direction (see 5.3.5.1 for further details). Thus, the analyzed road stretch has been sectioned as depicted in Figure 6.18. Details about each NAS are provided in Table 6.41. In this table both the length of the section, the sum of the lengths of each HFES, and the length of the NASs that are not part of HFES (i.e., Inconspicuous Segments, INCSs), are presented.

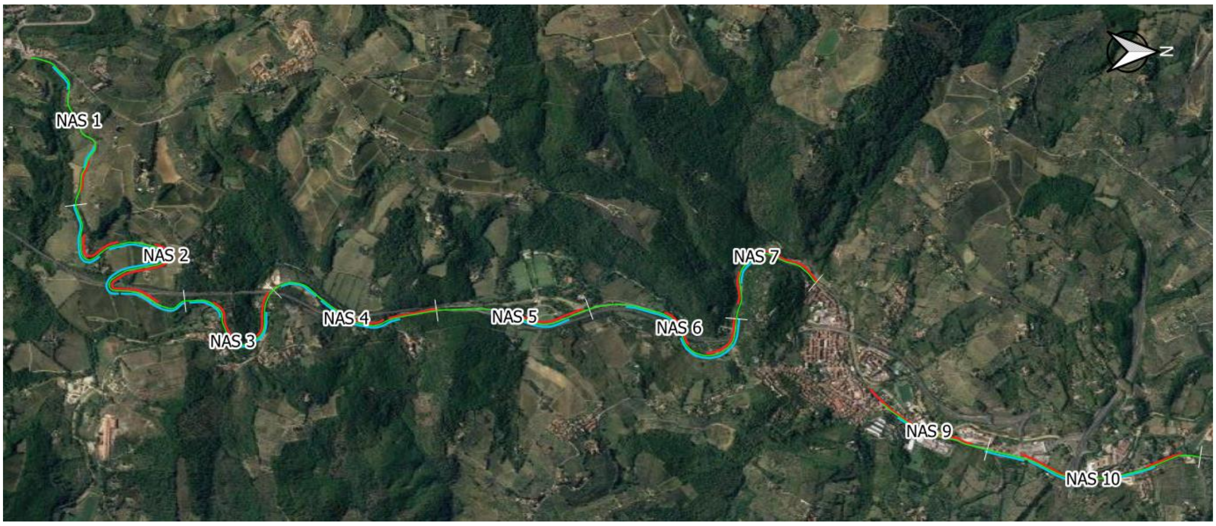

Figure 6.18 – NASs identification, SR2

Table 6.41 – Characteristics of the identified NASs, SR2

NAS ID	Start [km]	End [km]	Length [km]	HFES [km]	HFES [%]	INCS [km]	INCS [%]
NAS 1	0.000	1.200	1.200	0.350	15%	2.050	85%
NAS 2	1.200	3.150	1.950	3.100	79%	0.800	21%
NAS 3	3.150	4.100	0.950	1.250	66%	0.650	34%
NAS 4	4.100	5.250	1.150	1.300	57%	1.000	43%
NAS 5	5.250	6.250	1.000	0.900	45%	1.100	55%
NAS 6	6.250	7.500	1.250	1.550	62%	0.950	38%
NAS 7	7.500	8.400	0.900	0.900	50%	0.900	50%
NAS 9	9.350	10.100	0.750	0.200	13%	1.300	87%
NAS 10	10.100	11.600	1.500	0.700	23%	2.300	77%

Calculation of the risk code (RC)

After NASs have been identified, the RC (Risk Code) is calculated for each one. Considering the results from the application of the HFET to each HFES (Table 6.39 and Table 6.40), it is possible to identify the worst result for each rule and the Total HFS, considering the two different directions. Then, the worst result for each rule and for the Total HFS between the two directions, is taken to define the global (both directions) HFS for each rule and the Total. The results are presented in Table 6.42.

Table 6.42 – Definition of the worst result for each NAS, for each rule and the Total, SR2

	HFS, increasing km post				HFS, decreasing km post				Worst Results Both Directions			
NAS ID	I Rule	II Rule	III Rule	Total	I Rule	II Rule	III Rule	Total	I Rule	II Rule	III Rule	Total
NAS 1	38%	60%	50%	50%	38%	44%	62%	47%	38%	44%	50%	47%
NAS 2	35%	34%	35%	37%	25%	40%	35%	34%	25%	34%	35%	34%
NAS 3	30%	50%	47%	44%	31%	42%	40%	42%	30%	42%	40%	42%
NAS 4	38%	47%	41%	44%	38%	50%	46%	46%	38%	47%	41%	44%
NAS 5	56%	47%	43%	49%	44%	33%	59%	45%	44%	33%	43%	45%
NAS 6	31%	43%	44%	40%	25%	50%	45%	40%	25%	43%	44%	40%
NAS 7	38%	44%	69%	49%	25%	44%	50%	46%	25%	44%	50%	46%
NAS 9	44%	50%	60%	51%	38%	50%	40%	43%	38%	50%	40%	43%
NAS 10	38%	42%	35%	41%	38%	36%	33%	40%	38%	36%	33%	40%

The code will refer to the results from column "Worst Results Both Directions" of Table 6.42. The first part of the code will consider the worst risk level in the NAS. In the SR2 stretch, all NASs have at least one high risk level (every NASs have a high risk level for the First Rule, except NAS 5, which in turn has a high risk level for the Second Rule). For this reason, the letter of the first part of the code for each NAS will be "R" (red = high risk). Then, the number of high risk level HFSs obtained must be counted. For example, NAS 1 will be R1, while NAS2 will be R4. This will identify the risk level as explained in 5.3.5.2.

The second part of the code will be composed by the result of the Total HFS, taking out the percentage symbol (e.g., NAS 1 will have 47). Finally, the last part of the code will be calculated considering the weighted average of the Total HFSs (weighted on the HFESs' lengths) and the standard deviation (also considering the lengths of each HFES). It must be remembered that the average and the standard deviation are calculated accounting also for the INCSs, which have not been evaluated and are considered to have a Total HFS of 100% (as explained in 5.3.5.2). The outcomes from the application of the procedure to the SR2 road stretch are provided in Table 6.43.

Table 6.43 – Outcome from the application of the HFE procedure to the SR2 stretch (NAS of 1 km)

NAS ID	RC	Risk Level	Ranking
NAS 1	R1-47-92/18	Medium	9
NAS 2	R4-34-51/25	Very High	1
NAS 3	R1-42-63/27	Medium	4
NAS 4	R1-44-70/26	Medium	6
NAS 5	R1-45-76/26	Medium	7
NAS 6	R1-40-64/28	Medium	3
NAS 7	R1-46-74/26	Medium	8
NAS 9	R1-43-74/26	Medium	5
NAS 10	R3-40-74/29	High	2

The results identify one very high risk section, and one high risk section. The other sections are all considered ad medium risk. Among those sections, NAS 6 has a very low Total HFS, thus it is the third risky section in the stretch, and it is also very close to the high risk level. The results are also shown by means of colored segments on a satellite image in Figure 6.19 (dark red = very high risk, red = high risk, and yellow = medium risk).

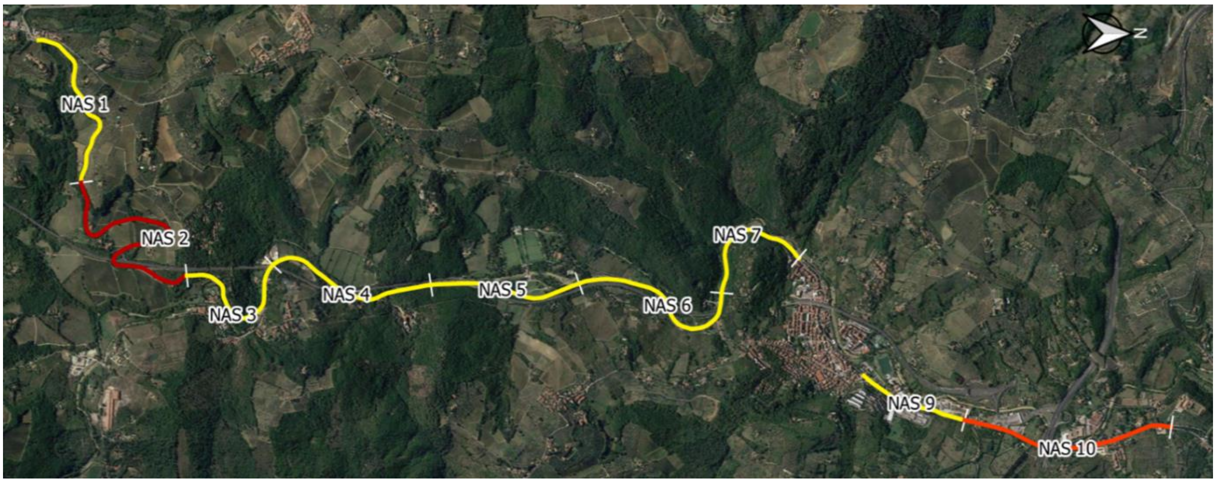

Figure 6.19 – NASs' risk level, SR2

6.3.2 SR206

6.3.2.1 First Step

Identification of potentially critical locations (PCLs)

A total of 94 PCLs has been identified in the analyzed stretch. Among those 13 are curves, 14 stopping areas, 4 crossings, 40 driveways, and 23 at-grade intersections. Figure 6.20 shows the distribution of the PCLs along the stretch. As already discussed, the road stretch is characterized by few curves and long tangents. Along the stretch many driveways and intersections are also present.

Figure 6.20 – Distribution of PCLs, SR206

Identification of expectation sections (EXSEs)

The EXSEs have been defined accounting for the winding level and for the PPI level. The CCR values are always below the thresholds of 160 gon/km, thus the winding level is always low. The CCR values and the CCR graph for SR206 are shown in APPENDIX 6. Concerning the PPI level, in many parts of the road the environment is composed by many houses. Many driveways and intersections are visible. For this reason, three EXSEs have been classified as having a medium PPI level. Two of these EXSEs are urban areas, but their environment is suburban (thus the medium level of PPI). Based on these evaluations, the EXSEs have been defined. The identified EXSEs are listed in Table 6.44. The table shows also the consequent expected speed level (V_E) and alertness level (AL). The same EXSEs are also represented on a satellite image in Figure 6.21.

Table 6.44 – EXSEs of SR206

Name	Starts [km]	End [km]	Length [km]	CCR [gon/km]	Winding level	PPI level	V_E	AL
EXSE 1	0	0.8	0.8	45	L	M	M	M
EXSE 2	0.8	3.6	2.8	56	L	L	H	L
EXSE 3	3.6	5.8	2.2	70	L	M	M	M
EXSE 4	5.8	8.7	2.9	41	L	L	H	L
EXSE 5	8.7	9.8	1.1	0	L	M	M	M
EXSE 6	9.8	10.8	1	0	L	L	H	L
EXSE 7	10.8	14.6	3.8	12	L	M	M	M

Figure 6.21 – EXSEs of SR206, representation on satellite image

Evaluation of potentially critical locations (PCLs)

Each PCL has been evaluated by means of VIS, PEX, and GEX. The results are summarized in Table 6.45. The results show that most of the PCLs do not present Human Factors deficiencies concerning VIS and GEX. On the other hand, PEX often present many critical aspects. Those judgement of a bad composition of the field of view (i.e., punctual expectations greatly differ from reality), are mainly due to the perceivable wider space. The plain environment and the long tangents lead drivers to speed up and to give less attention to the road, but many conflicts points are present. This may result in some wrong behaviors. Results are similar considering the two directions (INC = increasing km posts, DEC = decreasing km posts).

Table 6.45 – Overall results for SR206 PCLs evaluation

	VIS		PEX		GEX	
	INC	DEC	INC	DEC	INC	DEC
L	73	77	24	23	80	81
M	15	9	0	0	9	8
H	6	8	70	71	5	5
Tot	94	94	94	94	94	94

6.3.2.2 *Second Step*

Identification of challenging locations (CHLs)

Based on the results from the evaluation of the PCLs, the CHLs have been identified. A total of 32 PCLs has been promoted to CHLs. Among these, 13 are CHLs considering both directions, 11 are only in the increasing km post direction, and 8 in the decreasing km post direction. The distribution among the different types of PCLs is presented in Table 6.46. Intersections are the most critical locations, both considering increasing km post direction and decreasing km post direction. A graphical representation of the CHLs on a satellite image is provided in Figure 6.22. Looking at this representation, it appears that most of the CHLs are in the first part of the stretch (south). The last part comprises many driveways and stopping area, which are quite expected considering GEX and are generally highly visible, because they are located on a long tangent. Two road segments are composed by a series of intersections connecting to an oval shape (see Figure 5.8). For the purpose of the screening procedure (VIS, PEX, and GEX evaluation), those intersections have been classified as a single at-grade intersection with priority. This result in a classification of GEX as “low”. However, because of the particular and uncommon configuration of those intersections, the result has been set manually to “high risk level” of GEX. This choice let both the PCLs to be promoted to CHLs.

Table 6.46 – Number of identified CHLs by type and direction, SR206

CHLs type	INC	DEC
Curve	3	4
At-grade intersection	12	9
Crossing	4	3
Driveway	4	4
Lane Change	0	0
Stopping area	1	1
TOTAL	***24***	***21***

Figure 6.22 – Identified CHLs, SR206

Identification of challenging transitions (CHTs) and Human Factors Evaluation Segments (HFESs)

The list of the obtained HFESs is presented in Table 6.47 for the increasing km post direction, and in Table 6.48 for the decreasing km post direction. The tables show also the EXSE to which the HFES belong. A total of 22 HFESs have been identified: 12 for the increasing km post direction and 10 for the decreasing km post direction. Figure 6.23 shows the position of the identified HFES by colored segments parallel to the road track on a satellite image. Light blue segments identified the HFES for the increasing km post direction, while red segments identified the HFES for the decreasing km post direction.

Table 6.47 – List of the HFES, SR206, increasing km post direction (INC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
INC0	EXSE 1	0.150	0.500	0.350
INC1	EXSE 2	1.300	2.450	1.150
INC2	EXSE 2	2.450	2.650	0.200
INC3	EXSE 2	2.850	3.200	0.350
INC4	EXSE 3	3.800	4.050	0.250
INC5	EXSE 3	4.600	5.750	1.150
INC6	EXSE 4	6.250	6.700	0.450
INC7	EXSE 4	7.100	8.100	1.000
INC8	EXSE 5	9.100	9.600	0.500
INC9	EXSE 6	10.600	10.950	0.350
INC10	EXSE 7	12.450	12.800	0.350
INC11	EXSE 7	13.850	14.100	0.250

Table 6.48 – List of the HFES, SR206, decreasing km post direction (DEC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
DEC0	EXSE 2	0.800	0.400	0.400
DEC1	EXSE 2	1.600	1.300	0.300
DEC2	EXSE 2	2.600	1.700	0.900
DEC3	EXSE 3	5.000	4.800	0.200
DEC4	EXSE 4	5.900	5.150	0.750
DEC5	EXSE 4	6.850	6.350	0.500
DEC6	EXSE 4	8.100	7.200	0.900
DEC7	EXSE 6	9.800	9.300	0.500
DEC8	EXSE 7	11.150	10.750	0.400
DEC9	EXSE 7	13.100	12.800	0.300

Figure 6.23 – Obtained HFESs for increasing km post direction (light blue) and decreasing km post direction (red), SR206

Application of the Human Factors Evaluation Tool (HFET)

The HFET has been then applied to all the 22 HFESs. The outcomes are four different HFSs (Human Factors Scores) for each HFES: one score for the First Rule, one for the Second Rule, one for the Third Rule, and one considering all the rules together (i.e., Total HFS). The results are presented in Table 6.49 for the increasing km post direction and in Table 6.50 for the decreasing km post direction. The results considering only the Total HFS are also presented in Figure 6.24. Red segments identify high risk HFES (Total HFS < 0.40), while yellow segments identify medium risk HFES (0.40 ≤ Total HFS ≤ 0.60).

Table 6.49 – Results for each HFES from the application of the HFET, SR206, increasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
INC0	0.50	0.44	0.38	0.44
INC1	0.50	0.43	0.42	0.45
INC2	0.53	0.50	0.60	0.53
INC3	0.47	0.47	0.50	0.48
INC4	0.33	0.65	0.40	0.46
INC5	0.40	0.41	0.40	0.40
INC6	0.43	0.47	0.40	0.43
INC7	0.38	0.43	0.44	0.42
INC8	0.56	0.43	0.38	0.46
INC9	0.33	0.47	0.40	0.41
INC10	0.47	0.50	0.38	0.45
INC11	0.44	0.44	0.53	0.47

Table 6.50 – Results for each HFES from the application of the HFET, SR206, decreasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
DEC1	0.44	0.44	0.36	0.41
DEC2	0.53	0.50	0.86	0.62
DEC3	0.40	0.39	0.56	0.44
DEC4	0.46	0.67	0.55	0.54
DEC5	0.31	0.45	0.50	0.43
DEC6	0.50	0.42	0.47	0.46
DEC7	0.40	0.45	0.42	0.43
DEC8	0.47	0.44	0.54	0.48
DEC9	0.40	0.50	0.42	0.44
DEC10	0.55	0.44	0.36	0.44

Figure 6.24 – Total HFS results, SR206 (yellow = medium risk HFES, green =low risk HFES)

Looking at Figure 6.24, it emerges that like in SR2, most of the segments result in a medium risk level concerning the Total HFS. This result confirms again the effectiveness of the

Step 1 of the procedure, where PCLs judged as "less risky" have been discarded from the analysis. On the other hand, while in Step 1 many fields of view issues (II Rule) have been identified, the detailed analysis implemented using the HFET, only partially confirm this evaluation. Indeed, only one HFES has a Second Rule HFS lower than 0.40. Most of the HFESs has a Second Rule HFS comprised between 0.40 and 0.50, as shown in Figure 6.25. In Step 1 PCLs can be judged only as high risk or low risk considering PEX. PCLs which present some issues, even if not big issues, must be judged as high risk. Thus, the results seem to confirm again the effectiveness of the fast evaluation based on expectation that was carried out in Step 1.

Looking at the results of the other rules, in this stretch, visibility is not a big issue, even if two HFESs present four results below 0.40. A lack of consistent driving logic (Third Rule) is instead present in some HFESs. This is mainly due to an ambiguous environment, that appear as suburban, with few perceivable conflicts points and a geometry that allows for a high speed, but with many real conflict points (they are not completely perceivable).

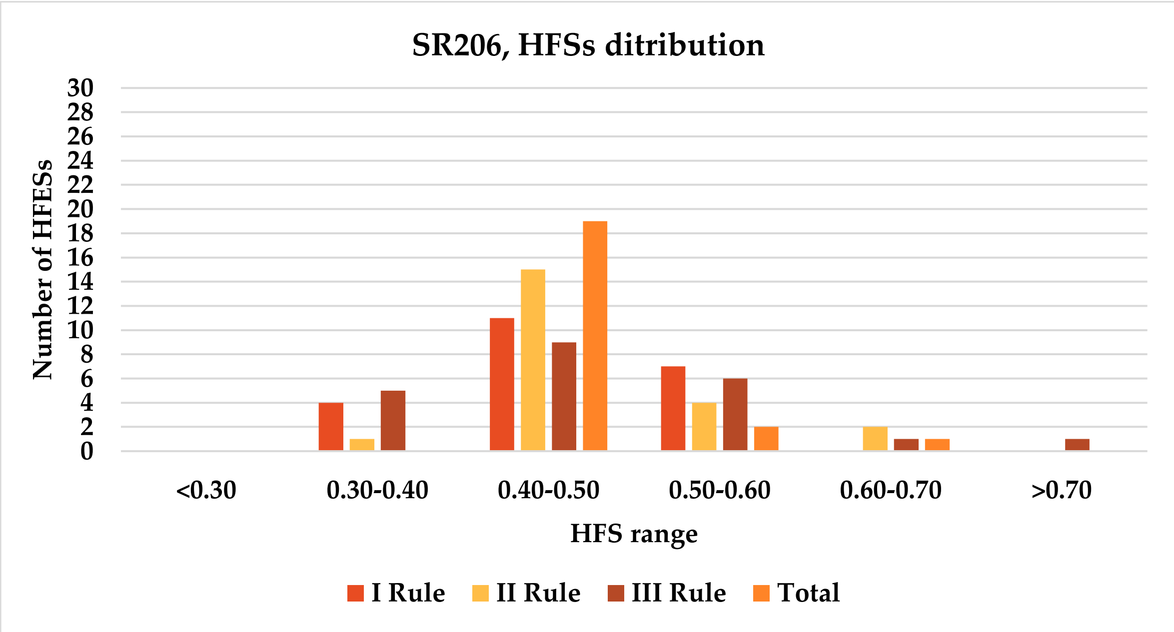

Figure 6.25 – Distribution of the HFSs for SR206

6.3.2.3 *Third Step*

Identification of network assessment sections (NASs)

The analyzed road stretch has been sectioned as depicted in Figure 6.26, considering a NAS fixed length of about 1 km. Details about each NAS are provided in Table 6.51. In this table both the length of the section, the sum of the lengths of each HFES, and the length of the sections that are not part of HFES (i.e., INCSs), are presented.

Figure 6.26 – NASs identification, SR206

Table 6.51 – Characteristics of the identified NASs, SR206

NAS ID	Start [km]	End [km]	Length [km]	HFES [km]	HFES [%]	INCS [km]	INCS [%]
NAS 1	0.000	1.300	1.300	1.050	40%	1.550	60%
NAS 2	1.300	2.650	1.350	2.250	83%	0.450	17%
NAS 3	2.650	3.600	0.950	0.350	18%	1.550	82%
NAS 4	3.600	4.600	1.000	0.250	13%	1.750	88%
NAS 5	4.600	5.900	1.300	2.100	81%	0.500	19%
NAS 6	5.900	7.000	1.100	0.950	43%	1.250	57%
NAS 7	7.000	8.100	1.100	1.900	86%	0.300	14%
NAS 8	8.100	9.100	1.000	0.000	0%	2.000	100%
NAS 9	9.100	10.100	1.000	1.000	50%	1.000	50%
NAS 10	10.100	11.150	1.050	0.750	36%	1.350	64%
NAS 11	11.150	12.300	1.150	0.000	0%	2.300	100%
NAS 12	12.300	13.400	1.100	0.650	30%	1.550	70%
NAS 13	13.400	14.600	1.200	0.250	10%	2.150	90%

Calculation of the risk code (RC)

After NASs have been identified, the RC is calculated following the procedure defined in 5.3.5.2. The worst results for each direction and for both the direction together are presented in Table 6.52. The final calculated RC for each NAS is presented in Table 6.53.

Table 6.52 – Definition of the worst result for each NAS, for each rule and the Total, SR206

	HFS, increasing km post				HFS, decreasing km post				Worst Results Both Directions			
NAS ID	I Rule	II Rule	III Rule	Total	I Rule	II Rule	III Rule	Total	I Rule	II Rule	III Rule	Total
NAS 1	50%	44%	38%	44%	44%	44%	36%	41%	44%	44%	36%	41%
NAS 2	50%	43%	42%	45%	40%	39%	56%	44%	40%	39%	42%	44%
NAS 3	47%	47%	50%	48%	100%	100%	100%	100%	47%	47%	50%	48%
NAS 4	33%	65%	40%	46%	100%	100%	100%	100%	33%	65%	40%	46%
NAS 5	40%	41%	40%	40%	31%	45%	50%	43%	31%	41%	40%	40%
NAS 6	43%	47%	40%	43%	50%	42%	47%	46%	43%	42%	40%	43%
NAS 7	38%	43%	44%	42%	40%	45%	42%	43%	38%	43%	42%	42%
NAS 8	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
NAS 9	56%	43%	38%	46%	47%	44%	54%	48%	47%	43%	38%	46%
NAS 10	33%	47%	40%	41%	40%	50%	42%	44%	33%	47%	40%	41%
NAS 11	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
NAS 12	47%	50%	38%	45%	55%	44%	36%	44%	47%	44%	36%	44%
NAS 13	44%	44%	53%	47%	100%	100%	100%	100%	44%	44%	53%	47%

Table 6.53 – Outcome from the application of the HFE procedure to the SR2 stretch (NAS of 1 km)

NAS ID	RC	Risk Level	Ranking
NAS 1	R1-41-79/26	Medium	2
NAS 2	R1-44-55/20	Medium	5
NAS 3	Y4-48-90/20	Medium	11
NAS 4	R1-46-93/18	Medium	8
NAS 5	R1-40-54/23	Medium	1
NAS 6	Y4-43-76/27	Medium	9
NAS 7	R1-42-50/20	Medium	4
NAS 8	G4-100-100/00	Low	12
NAS 9	R1-46-73/27	Medium	7
NAS 10	R1-41-80/27	Medium	3
NAS 11	G4-100-100/00	Low	13
NAS 12	R1-44-84/25	Medium	6
NAS 13	Y4-47-94/16	Medium	10

11 medium risk sections and 2 low risk sections are identified. The most critical sections (NAS 1 and NAS 5) are characterized by a suburban environment, where the risk perception from the road and its environment is different from the real risk of the road. The results are also shown by means of colored segments on a satellite image in Figure 6.27 (red = high risk, yellow = medium risk, green = low risk).

Figure 6.27 – NASs' risk level, SR206

6.3.3 B38

6.3.3.1 First Step

Identification of potentially critical locations (PCLs)

A total of 30 PCLs has been identified in the analyzed stretch. Among those 14 are curves, 4 driveways, and 12 at-grade intersections. The relative low number of driveways demonstrates that this rural highway has the primary function of connection and movements, not for access. However, some of these types of locations are present. Figure 6.28 shows the distribution of the PCLs along the stretch. The road stretch is characterized by fast sections and signalized intersections. The PCLs are homogeneously distributed with a low density. Consequently, the PPI level will result in a low level.

Figure 6.28 – Distribution of PCLs, B38

Identification of expectation sections (EXSEs)

The EXSEs have been defined accounting for the winding level and for the PPI level. The CCR values are always below the thresholds of 160 gon/km, thus the winding level is always low. The CCR values and the CCR graph for B38 are shown in APPENDIX 6. Concerning the PPI level, the environment is not complex, and few PCLs are present along the whole stretch. Thus, the PPI level is low for the entire stretch. A single EXSE has been identified. Its characteristics are reported in Table 6.54. The table shows also the consequent expected speed level (V_E) and alertness level (AL).

Table 6.54 – EXSE of B38

Name	Starts [km]	End [km]	Length [km]	CCR [gon/km]	Winding level	PPI level	V_E	AL
EXSE 1	1.0	10.89	10.89	32	L	L	H	L

Evaluation of potentially critical locations (PCLs)

Each PCL has been evaluated by means of VIS, PEX, and GEX. The results are summarized in Table 6.55. The results show that PCLs of this stretch have overall good VIS characteristics, but PEXs and GEXs present some problems. The road environment has a great influence of PEXs, because the wide available space along the whole stretch, the few marginal elements, and long tangents, induce the drivers to speed up. GEXs issues concern mainly the presence of many signalized intersections along the stretch. This type of intersections is generally quite uncommon along those type of road, mainly when they develop in a completely rural area. However, if well signalized and clearly recognizable, they will likely not be an issue. Still, they must be judged as high risk level concerning GEXs.

Table 6.55 – Overall results for B38 PCLs evaluation

	VIS		PEX		GEX	
	INC	DEC	INC	DEC	INC	DEC
L	21	15	13	18	11	11
M	8	14	0	0	8	8
H	1	1	17	12	11	11
Tot	30	30	30	30	30	30

6.3.3.2 *Second Step*

Identification of challenging locations (CHLs)

Based on the results from the evaluation of the PCLs, the CHLs have been identified. A total of 19 PCLs has been promoted to CHLs. Among these, 7 are CHLs considering both directions, 6 are only in the increasing km post direction, and 6 in the decreasing km post direction. The distribution among the different types of PCLs is presented in Table 6.56. At-grade intersections are the most critical locations, both considering increasing km post direction and decreasing km post direction. A graphical representation of the CHLs on a satellite image is provided in Figure 6.29.

Table 6.56 – Number of identified CHLs by type and direction, B38

CHLs type	INC	DEC
Curve	4	4
At-grade intersection	8	7
Crossing	0	0
Driveway	1	2
Lane Change	0	0
Stopping area	0	0
TOTAL	***13***	***13***

Figure 6.29 – Identified CHLs, B38

Identification of challenging transitions (CHTs) and Human Factors Evaluation Segments (HFESs)

The list of the obtained HFESs is presented in Table 6.57 for the increasing km post direction, and in Table 6.58 for the decreasing km post direction. The tables show also the EXSE to which the HFES belong. A total of 22 HFESs have been identified: 11 for the increasing km post direction and 11 for the decreasing km post direction. Figure 6.30 shows the position of the identified HFES by colored segments parallel to the road track on a satellite image. Light blue segments identified the HFES for the increasing km post direction, while red segments identified the HFES for the decreasing km post direction.

Table 6.57 – List of the HFES, B38, increasing km post direction (INC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
INC1	EXSE 1	1.000	1.300	0.300
INC2	EXSE 1	1.900	2.300	0.400
INC3	EXSE 1	2.600	3.300	0.700
INC4	EXSE 1	3.700	4.100	0.400
INC5	EXSE 1	4.700	5.300	0.600
INC6	EXSE 1	5.500	6.200	0.700
INC7	EXSE 1	6.350	6.650	0.300
INC8	EXSE 1	6.950	7.300	0.350
INC9	EXSE 1	9.100	9.400	0.300
INC10	EXSE 1	9.700	10.000	0.300
INC11	EXSE 1	10.600	10.880	0.280

Table 6.58 – List of the HFES, B38, decreasing km post direction (DEC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
DEC1	EXSE 1	1.500	1.150	0.350
DEC2	EXSE 1	3.500	2.750	0.750
DEC3	EXSE 1	5.500	5.100	0.400
DEC4	EXSE 1	6.400	5.900	0.500
DEC5	EXSE 1	7.450	7.050	0.400
DEC6	EXSE 1	7.900	7.500	0.400
DEC7	EXSE 1	8.500	8.100	0.400
DEC8	EXSE 1	9.000	8.600	0.400
DEC9	EXSE 1	9.700	9.300	0.400
DEC10	EXSE 1	10.200	9.900	0.300
DEC11	EXSE 1	10.800	10.400	0.400

Figure 6.30 – Obtained HFESs for increasing km post direction (light blue) and decreasing km post direction (red), B38

Application of the Human Factors Evaluation Tool (HFET)

The HFET has been then applied to all the 22 HFESs. The results are presented in Table 6.59 for the increasing km post direction and in Table 6.60 for the decreasing km post direction. The results considering only the Total HFS are also presented in Figure 6.31. Red segments identify high risk HFES (Total HFS < 0.40), while yellow segments identify medium risk HFES (0.40 ≤ Total HFS ≤ 0.60).

Table 6.59 – Results for each HFES from the application of the HFET, B38, increasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
INC1	0.75	0.42	0.71	0.60
INC2	0.42	0.42	0.59	0.47
INC3	0.54	0.58	0.64	0.58
INC4	0.91	0.37	0.83	0.64
INC5	0.44	0.37	0.59	0.45
INC6	0.33	0.41	0.45	0.40
INC7	0.53	0.52	0.56	0.54
INC8	0.39	0.27	0.50	0.38
INC9	0.75	0.44	0.69	0.61
INC10	0.63	0.41	0.50	0.51
INC11	0.45	0.48	0.38	0.44

Table 6.60 – Results for each HFES from the application of the HFET, B38, decreasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
DEC1	0.45	0.41	0.75	0.53
DEC2	0.85	0.43	0.86	0.60
DEC3	0.36	0.48	0.50	0.46
DEC4	0.92	0.43	0.57	0.59
DEC5	0.35	0.31	0.53	0.38
DEC6	0.82	0.39	0.69	0.60
DEC7	0.40	0.43	0.56	0.46
DEC8	0.55	0.45	0.44	0.48
DEC9	0.58	0.41	0.71	0.57
DEC10	0.63	0.38	0.57	0.52
DEC11	0.63	0.41	0.50	0.51

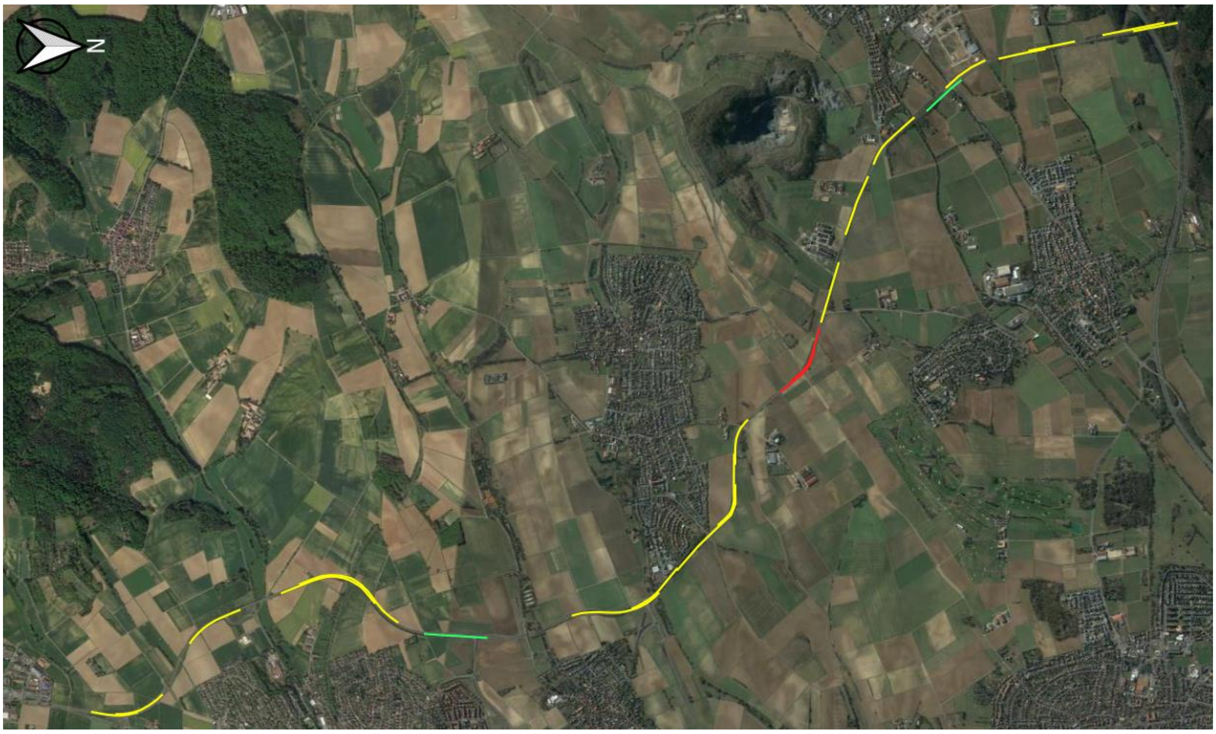

Figure 6.31 – Total HFS results, B38 (red = high risk HFES, yellow = medium risk HFES, green =low risk HFES)

Looking at Figure 6.31, the outcomes are like those of the previous stretches, with most of the segments resulting in a medium risk level (considering the Total HFS). This is mainly due to the application of the Step 1 of the procedure, where PCLs judged as "less risky" have been discarded from the analysis. Figure 6.32 illustrates the distribution of the HFSs among the HFESs. The Second Rules seems to be the less respected, with also one HFES below 0.30. The most recurrent bad conditions concerning the Second Rule, are the perceived available space, both ahead and in the lateral part of the field of view, and the composition of the field of view itself. For example, some trees' lines are present, mainly in the central part of the stretch, which are not symmetric.

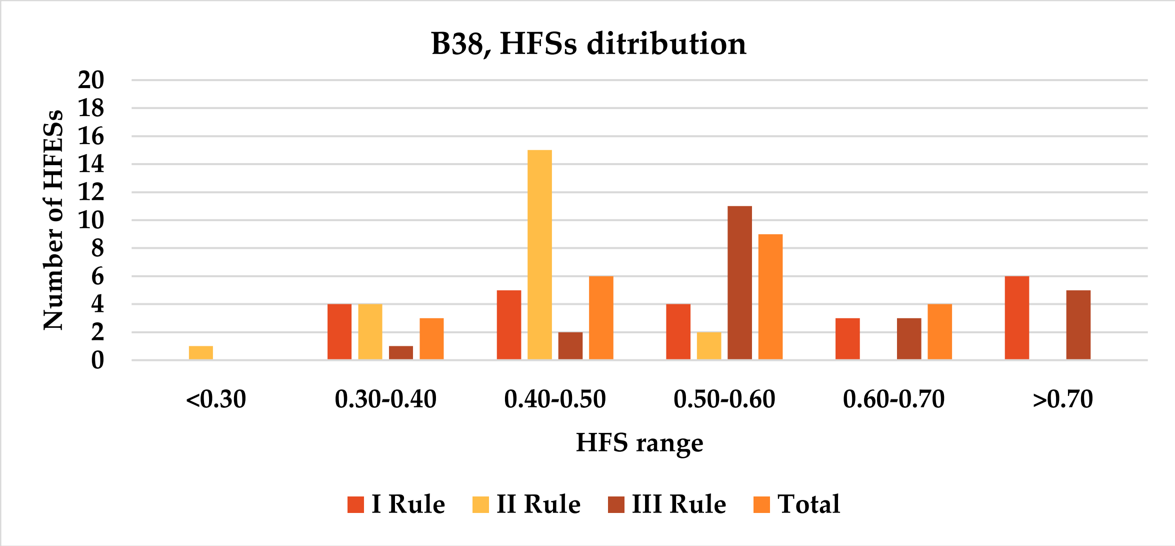

Figure 6.32 – Distribution of the HFSs for B38

6.3.3.3 *Third Step*

Identification of network assessment sections (NASs)

The analyzed road stretch has been sectioned as depicted in Figure 6.33, considering a NAS fixed length of about 1 km. Details about each NAS are provided in Table 6.61. In this table both the length of the section, the sum of the lengths of each HFES, and the length of the sections that are not part of HFES (i.e., INCSs), are presented.

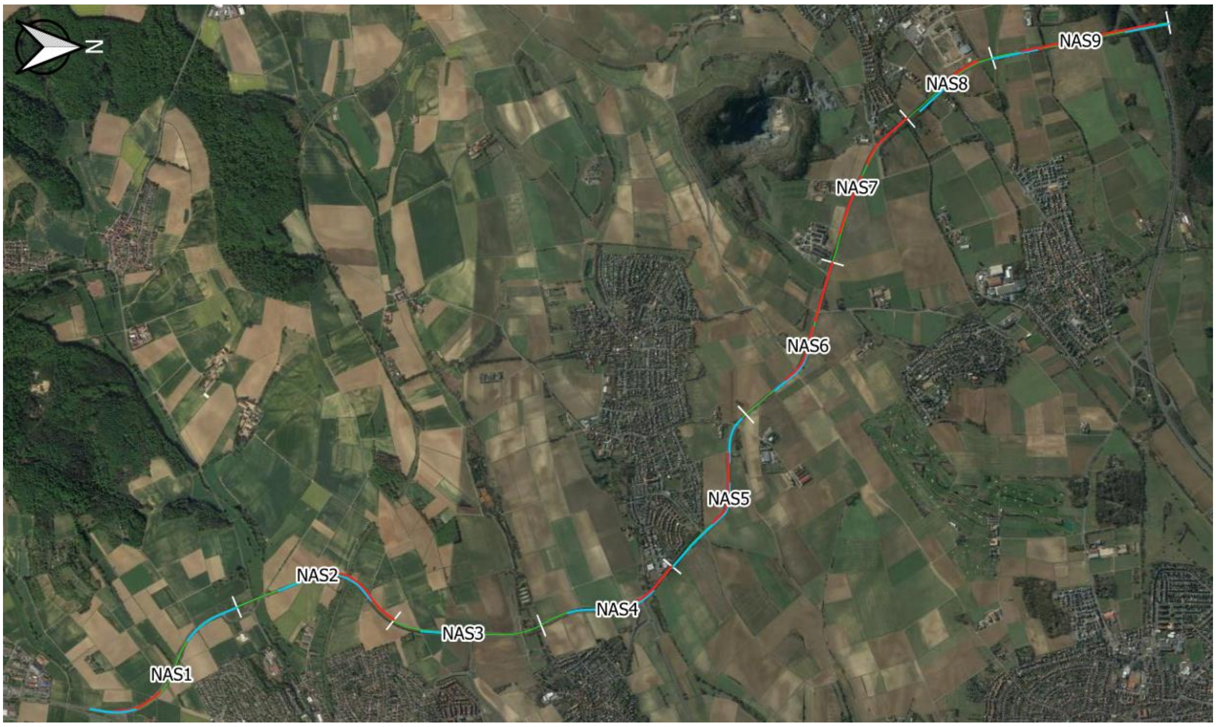

Figure 6.33 – NASs identification, B38

Table 6.61 – Characteristics of the identified NASs, B38

NAS ID	Start [km]	End [km]	Length [km]	HFES [km]	HFES [%]	INCS [km]	INCS [%]
NAS 1	1.000	2.300	1.300	1.050	40%	1.550	60%
NAS 2	2.300	3.500	1.200	1.450	60%	0.950	40%
NAS 3	3.500	4.500	1.000	0.400	20%	1.600	80%
NAS 4	4.500	5.500	1.000	1.000	50%	1.000	50%
NAS 5	5.500	6.700	1.200	1.500	63%	0.900	38%
NAS 6	6.700	7.900	1.200	1.150	48%	1.250	52%
NAS 7	7.900	9.000	1.100	0.800	36%	1.400	64%
NAS 8	9.000	9.700	0.700	0.700	50%	0.700	50%
NAS 9	9.700	10.890	1.190	1.280	54%	1.100	46%

Calculation of the risk code (RC)

The worst results considering all the HFESs belonging to each NAS, for each single direction and for both the direction together, are presented in Table 6.62. The final calculated RC for each NAS is presented in Table 6.63.

Table 6.62 – Definition of the worst result for each NAS, for each rule and the Total, B38

	HFS, increasing km post				HFS, decreasing km post				Worst Results Both Directions			
NAS ID	I Rule	II Rule	III Rule	Total	I Rule	II Rule	III Rule	Total	I Rule	II Rule	III Rule	Total
NAS 1	42%	42%	59%	47%	45%	41%	75%	53%	42%	41%	59%	47%
NAS 2	54%	58%	64%	58%	85%	43%	86%	60%	54%	43%	64%	58%
NAS 3	91%	37%	83%	64%	100%	100%	100%	100%	91%	37%	83%	64%
NAS 4	44%	37%	59%	45%	36%	48%	50%	46%	36%	37%	50%	45%
NAS 5	33%	41%	45%	40%	92%	43%	57%	59%	33%	41%	45%	40%
NAS 6	39%	27%	50%	38%	35%	31%	53%	38%	35%	27%	50%	38%
NAS 7	100%	100%	100%	100%	40%	43%	44%	46%	40%	43%	44%	46%
NAS 8	75%	44%	69%	61%	58%	41%	71%	57%	58%	41%	69%	57%
NAS 9	45%	41%	38%	44%	63%	41%	50%	51%	45%	41%	38%	44%

Table 6.63 – Outcome from the application of the HFE procedure to the B38 stretch (NAS of 1 km)

NAS ID	RC	Risk Level	Ranking
NAS 1	Y4-47-81/23	Medium	7
NAS 2	Y3-58-75/20	Low	9
NAS 3	R1-64-93/14	Medium	5
NAS 4	R2-45-73/27	High	2
NAS 5	R1-40-68/26	Medium	3
NAS 6	R3-38-74/28	High	1
NAS 7	Y4-46-81/25	Medium	6
NAS 8	Y3-57-79/21	Low	8
NAS 9	R1-44-73/25	Medium	4

2 high risk sections, 5 medium risk sections, and 2 low risk sections have been identified. The most critical section comprises an at-grade intersection with priority and a curve, which have both visibility issues and a bad composition of the field of view. The results are also shown by means of colored segments on a satellite image in Figure 6.34 (red = high risk, yellow = medium risk, green = low risk).

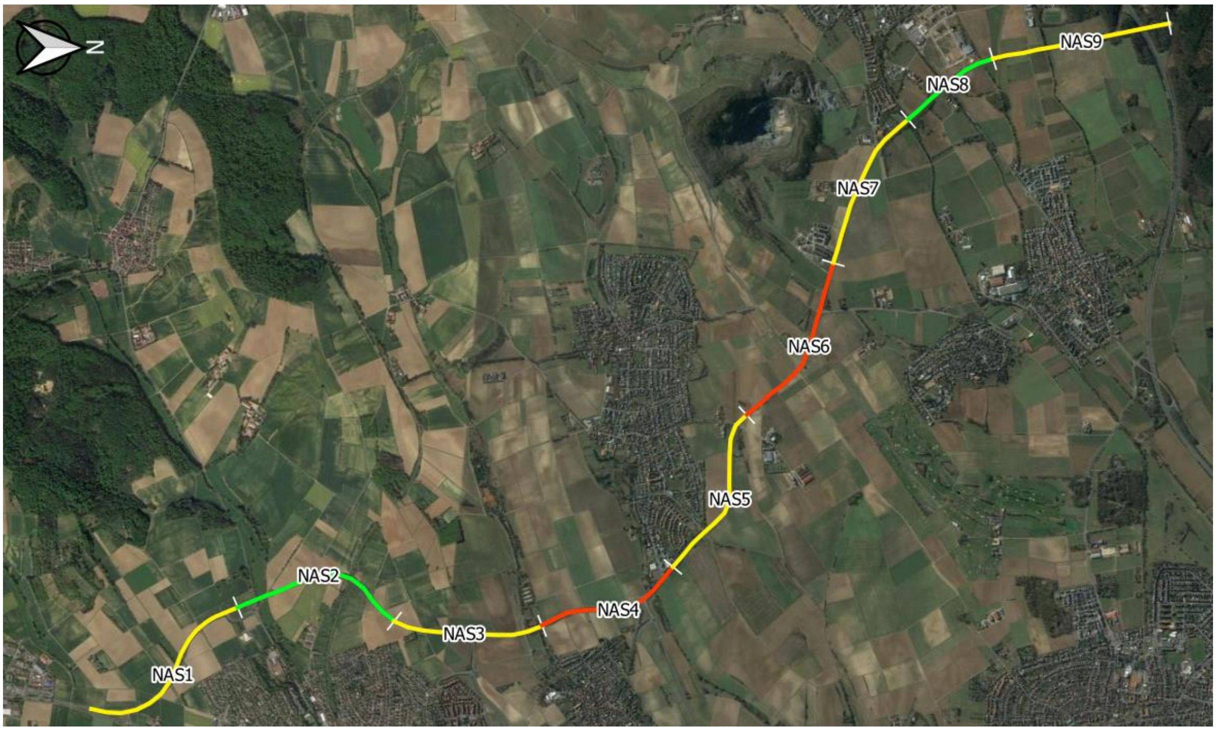

Figure 6.34 – NASs' risk level, B38

6.3.4 L3106

6.3.4.1 First Step

Identification of potentially critical locations (PCLs)

A total of 64 PCLs has been identified in the analyzed stretch. Among those 29 are curves, 23 driveways, 6 at-grade intersections, 1 crossing, and 5 stopping areas. The L3106, even if a rural highway, is of minor rank comparing to the B38. This is clear while looking at the number of possible conflict points present, mainly driveways. Figure 6.35Figure 6.20 shows the distribution of the PCLs along the stretch. The road stretch is characterized by fast sections and signalized intersections.

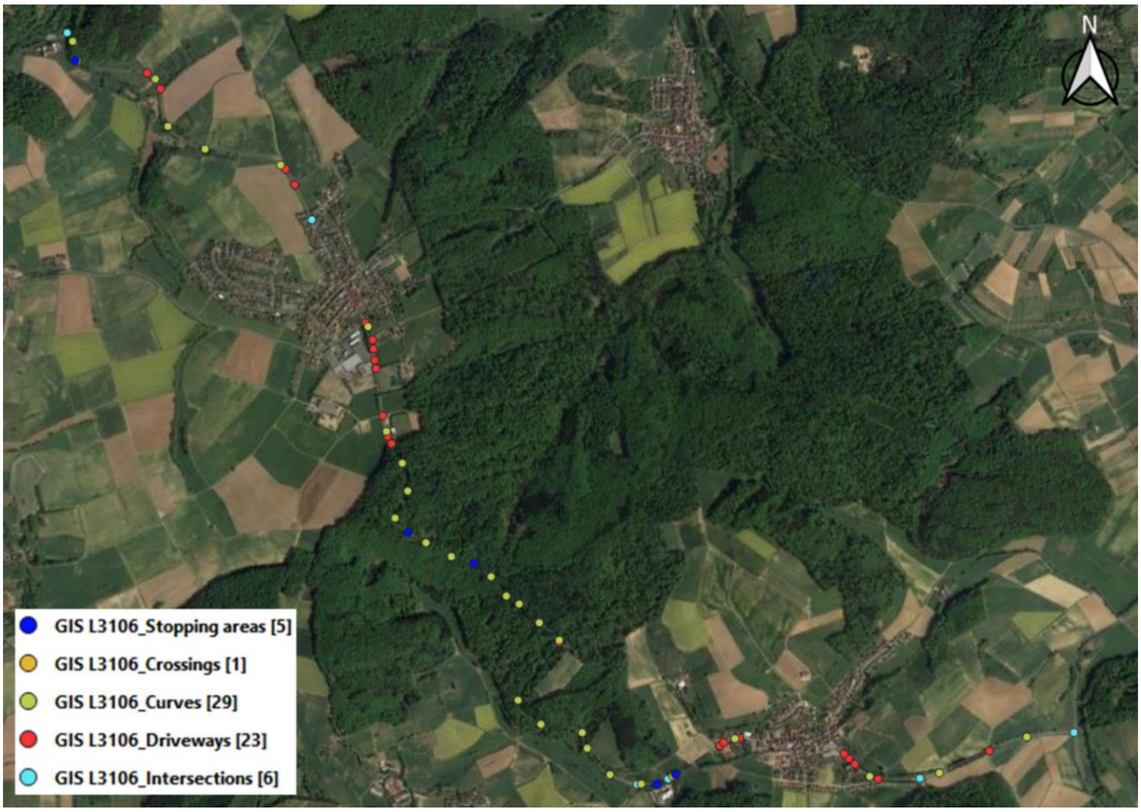

Figure 6.35 – Distribution of PCLs, L3106

Identification of expectation sections (EXSEs)

The EXSEs have been defined accounting for the winding level and for the PPI level. The CCR values and the CCR graph are shown in APPENDIX 6. The PPI level is low for the entire stretch. Two urban areas have been excluded from the analysis. The identified EXSEs' characteristics are reported in Table 6.64. The table shows also the consequent expected speed level (V_E) and alertness level (AL).

Table 6.64 – EXSE of L3106

Name	Starts [km]	End [km]	Length [km]	CCR [gon/km]	Winding level	PPI level	V_E	AL
EXSE 1	0	1.6	1.6	194	M	L	H	L
EXSE 2	2.1	5.7	3.6	239	M	L	H	L
EXSE 3	6.15	7.34	1.19	103	L	L	H	L

Evaluation of potentially critical locations (PCLs)

Each PCL has been evaluated by means of VIS, PEX, and GEX. The results are summarized in Table 6.65. The results show that the PCLs are all quite expected for this road type (most of the GEX levels of risk are low), but there are some issues concerning VIS and PEX.

Table 6.65 – Overall results for L3106 PCLs evaluation

	VIS		PEX		GEX	
	INC	**DEC**	**INC**	**DEC**	**INC**	**DEC**
L	42	41	45	42	56	56
M	16	14	0	0	5	5
H	6	9	19	22	3	3
Tot	64	64	64	64	64	64

6.3.4.2 Second Step

Identification of challenging locations (CHLs)

Based on the results from the evaluation of the PCLs, the CHLs have been identified. A total of 29 PCLs has been promoted to CHLs. Among these, 9 are CHLs considering both directions, 10 are only in the increasing km post direction, and 10 in the decreasing km post direction. The distribution among the different types of PCLs is presented in Table 6.66. Curves and driveways are the most critical locations, both considering increasing km post direction and decreasing km post direction. A graphical representation of the CHLs on a satellite image is provided in Figure 6.36.

Table 6.66 – Number of identified CHLs by type and direction, L3106

CHLs type	INC	DEC
Curve	6	8
At-grade intersection	4	3
Crossing	1	1
Driveway	7	6
Lane Change	0	0
Stopping area	1	1
TOTAL	***19***	***19***

Figure 6.36 – Identified CHLs, L3106

Identification of challenging transitions (CHTs) and Human Factors Evaluation Segments (HFESs)

The list of the obtained HFESs is presented in Table 6.67 for the increasing km post direction, and in Table 6.68 for the decreasing km post direction. The tables show also the EXSE to which the HFES belong. A total of 24 HFESs have been identified: 12 for the increasing km post direction and 12 for the decreasing km post direction. Figure 6.37 shows the position of the identified HFES by colored segments parallel to the road track on a satellite image. Light blue segments identified the HFES for the increasing km post direction, while red segments identified the HFES for the decreasing km post direction.

Table 6.67 – List of the HFES, L3106, increasing km post direction (INC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
INC1	EXSE 1	0.250	0.600	0.350
INC2	EXSE 1	1.000	1.400	0.400
INC3	EXSE 1	1.400	1.600	0.200
INC4	EXSE 2	2.450	2.750	0.300
INC5	EXSE 2	2.850	3.300	0.450
INC6	EXSE 2	3.850	4.100	0.250
INC7	EXSE 2	4.100	4.500	0.400
INC8	EXSE 2	4.950	5.350	0.400
INC9	EXSE 2	5.400	5.700	0.300
INC10	EXSE 3	6.300	6.700	0.400
INC11	EXSE 3	6.700	6.950	0.250
INC12	EXSE 3	7.000	7.200	0.200

Table 6.68 – List of the HFES, L3106, decreasing km post direction (DEC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
DEC1	EXSE 1	0.000	0.400	0.400
DEC2	EXSE 1	0.400	0.750	0.350
DEC3	EXSE 1	1.200	1.550	0.350
DEC4	EXSE 2	2.100	2.550	0.450
DEC5	EXSE 2	3.050	3.300	0.250
DEC6	EXSE 2	3.700	3.900	0.200
DEC7	EXSE 2	4.000	4.250	0.250
DEC8	EXSE 2	4.300	4.600	0.300
DEC9	EXSE 2	4.950	5.500	0.550
DEC10	EXSE 3	6.150	6.450	0.300
DEC11	EXSE 3	6.500	6.900	0.400
DEC12	EXSE 3	6.900	7.100	0.200

Figure 6.37 – Obtained HFESs for increasing km post direction (light blue) and decreasing km post direction (red), L3106

Application of the Human Factors Evaluation Tool (HFET)

The HFET has been then applied to all the 22 HFESs. The results are presented in Table 6.69 for the increasing km post direction and in Table 6.70 for the decreasing km post direction. The results considering only the Total HFS are also presented in Figure 6.38. Red segments identify high risk HFES (Total HFS < 0.40), while yellow segments identify medium risk HFES (0.40 ≤ Total HFS ≤ 0.60).

Looking at the results, no high risk HFES is present considering the Total HFS. However, some HFESs present some high risk results concerning the First Rule and the Third Rule. Looking at the graph in Figure 6.39, most of the HFSs ranges between 0.40 and 0.60, thus the medium level, with a slight shift to 0.40.

Table 6.69 – Results for each HFES from the application of the HFET, L3106, increasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
INC1	0.92	0.52	0.62	0.64
INC2	0.61	0.41	0.42	0.49
INC3	0.44	0.41	0.40	0.42
INC4	0.40	0.44	0.54	0.45
INC5	0.47	0.50	0.42	0.47
INC6	0.42	0.43	0.42	0.43
INC7	0.58	0.45	0.64	0.54
INC8	0.44	0.48	0.50	0.47
INC9	0.38	0.44	0.43	0.42
INC10	0.33	0.44	0.55	0.43
INC11	0.56	0.41	0.38	0.46
INC12	0.47	0.47	0.43	0.46

Table 6.70 – Results for each HFES from the application of the HFET, L3106, decreasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
DEC1	0.32	0.48	0.40	0.40
DEC2	0.53	0.53	0.71	0.58
DEC3	0.75	0.55	0.63	0.63
DEC4	0.38	0.47	0.39	0.41
DEC5	0.50	0.53	0.44	0.50
DEC6	0.17	0.58	0.43	0.42
DEC7	0.67	0.50	0.54	0.56
DEC8	0.42	0.65	0.78	0.61
DEC9	0.53	0.47	0.53	0.51
DEC10	0.45	0.59	0.41	0.49
DEC11	0.44	0.60	0.56	0.53
DEC12	0.53	0.40	0.57	0.49

Figure 6.38 – Total HFS results, L3106 (red = high risk HFES, yellow = medium risk HFES, green =low risk HFES)

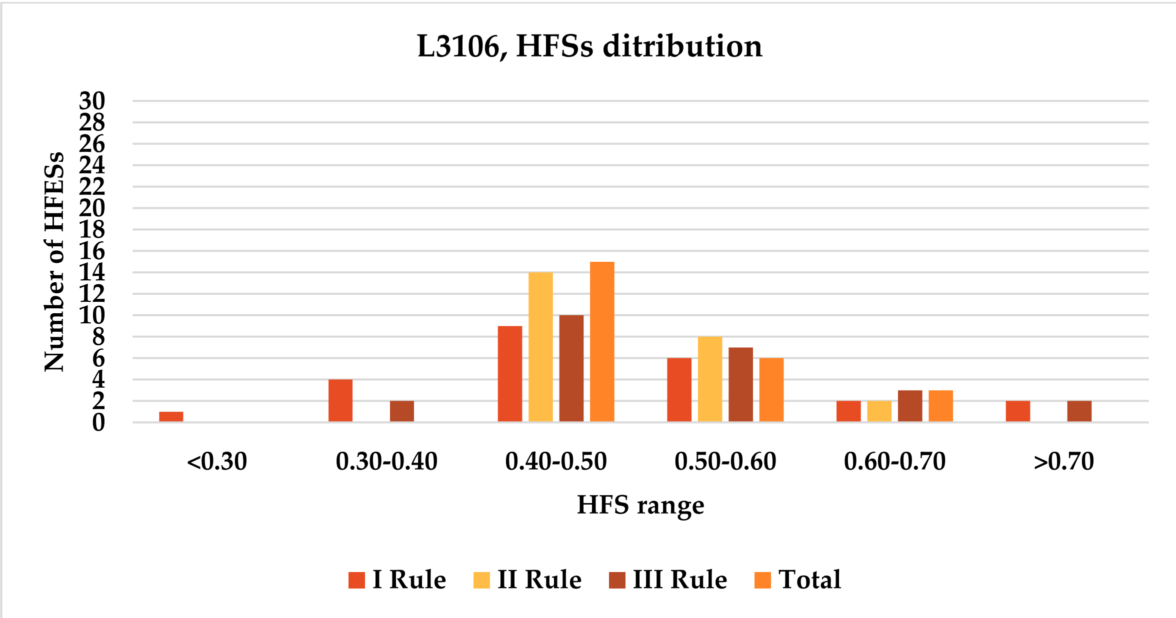

Figure 6.39 – Distribution of the HFSs for L3106

6.3.4.3 Third Step

Identification of network assessment sections (NASs)

The identified NASs are depicted in Figure 6.40. Details about each NAS are provided in Table 6.71. In this table both the length of the section, the sum of the lengths of each HFES, and the length of the sections that are not part of HFES (i.e., INCSs), are presented.

Figure 6.40 – NASs identification, L3106

Table 6.71 – Characteristics of the identified NASs, L3106

NAS ID	Start [km]	End [km]	Length [km]	HFES [km]	HFES [%]	INCS [km]	INCS [%]
NAS 1	0.000	0.800	0.800	1.100	69%	0.500	31%
NAS 2	0.800	1.600	0.800	0.950	59%	0.650	41%
NAS 3	2.100	3.350	1.250	1.450	58%	1.050	42%
NAS 4	3.350	4.600	1.250	1.400	56%	1.100	44%
NAS 5	4.600	5.650	1.050	0.950	45%	0.950	55%
NAS 6	6.200	7.340	1.140	1.450	64%	0.630	36%

Calculation of the risk code (RC)

The worst results considering all the HFESs belonging to each NAS, for each direction and for both the direction together are presented in Table 6.72. The final calculated RC for each NAS is presented in Table 6.73. The RC is calculated following the procedure defined in 5.4.5.2. Two high risk NASs have been identified, while others are all classified as medium risk. The results are also shown by means of colored segments on a satellite image in Figure 6.41 (red = high risk, yellow = medium risk, green = low risk).

Table 6.72 – Definition of the worst result for each NAS, for each rule and the Total, L3106

	HFS, increasing km post				HFS, decreasing km post				Worst Results Both Directions			
NAS ID	I Rule	II Rule	III Rule	Total	I Rule	II Rule	III Rule	Total	I Rule	II Rule	III Rule	Total
NAS 1	92%	52%	62%	64%	32%	48%	40%	40%	32%	48%	40%	40%
NAS 2	44%	41%	40%	42%	75%	55%	63%	63%	44%	41%	40%	42%
NAS 3	40%	44%	42%	45%	38%	47%	39%	41%	38%	44%	39%	41%
NAS 4	42%	43%	42%	43%	17%	50%	43%	42%	17%	43%	42%	42%
NAS 5	38%	44%	43%	42%	53%	47%	53%	51%	38%	44%	43%	42%
NAS 6	33%	41%	38%	43%	44%	40%	41%	49%	33%	40%	38%	43%

Table 6.73 – Outcome from the application of the HFE procedure to the L3106 stretch (NAS of 1 km)

NAS ID	RC	Risk Level	Ranking
NAS 1	R1-40-68/23	Medium	3
NAS 2	Y4-42-72/24	Medium	6
NAS 3	R2-41-68/27	High	1
NAS 4	R1-42-73/24	Medium	5
NAS 5	R1-42-70/26	Medium	4
NAS 6	R2-43-62/23	High	2

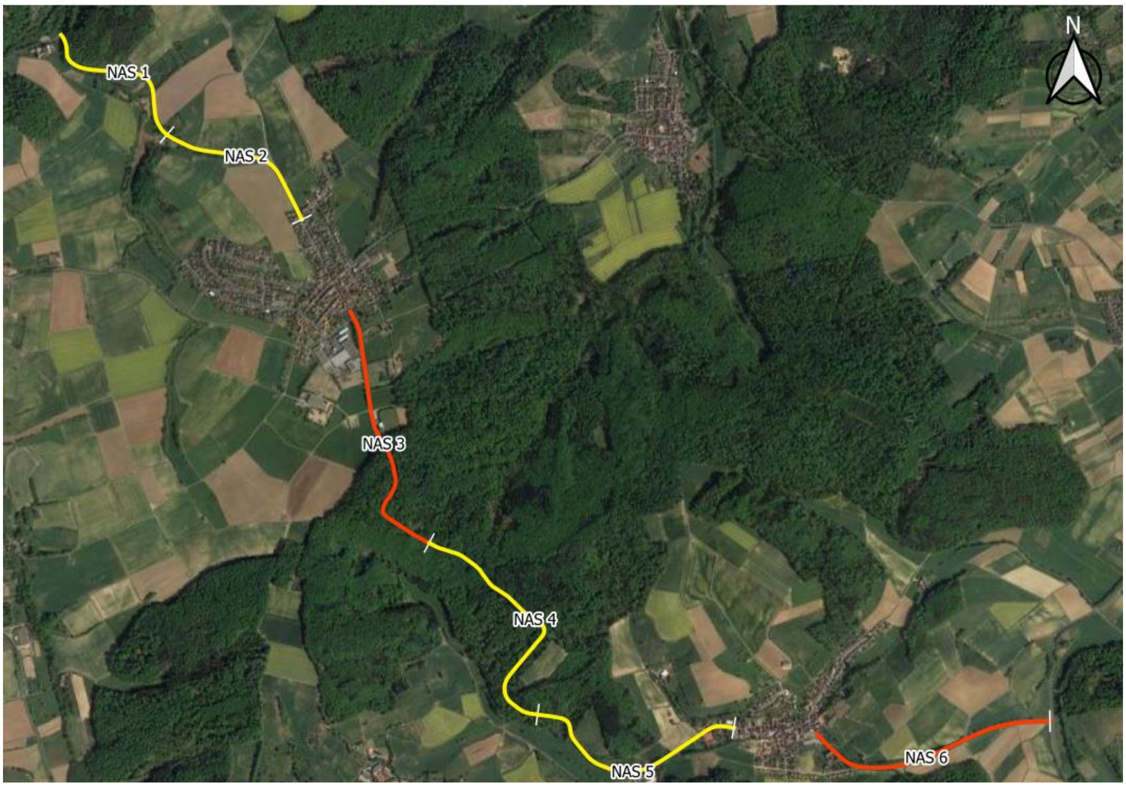

Figure 6.41 – NASs' risk level, L3106

6.3.5 L3408

6.3.5.1 First Step

Identification of potentially critical locations (PCLs)

A total of 35 PCLs has been identified in the analyzed stretch. Among those 24 are curves, 8 driveways, and 3 stopping areas. The L3408 has a similar function as L3106. Figure 6.42 shows the distribution of the PCLs along the stretch. The road stretch is characterized by fast sections and signalized intersections.

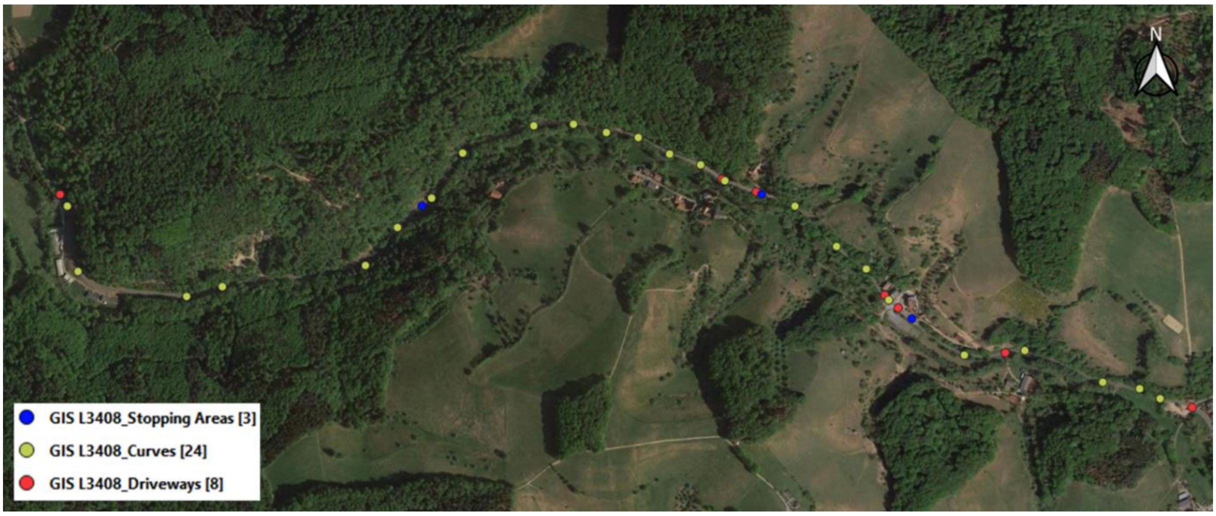

Figure 6.42 – Distribution of PCLs, L3408

Identification of expectation sections (EXSEs)

The EXSEs have been defined accounting for the winding level and for the PPI level. The CCR values and the CCR graph are shown in APPENDIX 6. The consequent winding level is medium. The PPI level is low for the entire stretch. Thus, a single EXSE has been identified. The identified EXSE's characteristics are reported in Table 6.74. The table shows also the consequent expected speed level (V_E) and alertness level (AL).

Table 6.74 – EXSE of L3408

Name	Starts [km]	End [km]	Length [km]	CCR [gon/km]	Winding level	PPI level	V_E	AL
EXSE 1	0	2.91	2.91	283	M	L	H	L

Evaluation of potentially critical locations (PCLs)

Each PCL has been evaluated by means of VIS, PEX, and GEX. The results are summarized in Table 6.75. Similar to L3106, the results show that the PCLs are all quite expected for this road type (most of the GEX levels of risk are low), but there are some issues concerning VIS and PEX.

Table 6.75 – Overall results for L3408 PCLs evaluation

	VIS		PEX		GEX	
	INC	DEC	INC	DEC	INC	DEC
L	24	22	25	22	33	33
M	6	10	0	0	0	0
H	5	3	10	13	2	2
Tot	35	35	35	35	35	35

6.3.5.2 *Second Step*

Identification of challenging locations (CHLs)

Based on the results from the evaluation of the PCLs, the CHLs have been identified. A total of 14 PCLs has been promoted to CHLs. Among these, 9 are CHLs considering both directions, 1 is in the increasing km post direction, and 4 in the decreasing km post direction. The distribution among the different types of PCLs is presented in Table 6.76. Curves and driveways are the most critical locations, both considering increasing km post direction and decreasing km post direction. A graphical representation of the CHLs on a satellite image is provided in Figure 6.43.

Table 6.76 – Number of identified CHLs by type and direction, L3408

CHLs type	INC	DEC
Curve	4	6
At-grade intersection	0	0
Crossing	0	0
Driveway	4	5
Lane Change	0	0
Stopping area	2	2
TOTAL	***10***	***13***

Figure 6.43 – Identified CHLs, L3408

Identification of challenging transitions (CHTs) and Human Factors Evaluation Segments (HFESs)

The list of the obtained HFESs is presented in Table 6.77 for the increasing km post direction, and in Table 6.78 for the decreasing km post direction. The tables show also the EXSE to which the HFES belong. A total of 13 HFESs have been identified: 7 for the increasing km post direction and 6 for the decreasing km post direction. Figure 6.44 shows the position of the identified HFES by colored segments parallel to the road track on a satellite image. Light blue segments identified the HFES for the increasing km post direction, while red segments identified the HFES for the decreasing km post direction.

Table 6.77 – List of the HFES, L3408, increasing km post direction (INC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
INC1	EXSE 1	0.000	0.300	0.300
INC2	EXSE 1	0.300	0.500	0.200
INC3	EXSE 1	0.900	1.100	0.200
INC4	EXSE 1	1.600	1.900	0.300
INC5	EXSE 1	1.850	2.050	0.200
INC6	EXSE 1	2.100	2.300	0.200
INC7	EXSE 1	2.700	2.900	0.200

Table 6.78 – List of the HFES, L3408, decreasing km post direction (DEC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
DEC1	EXSE 1	0.000	0.600	0.600
DEC2	EXSE 1	1.000	1.200	0.200
DEC3	EXSE 1	1.700	1.950	0.250
DEC4	EXSE 1	2.050	2.250	0.200
DEC5	EXSE 1	2.150	2.350	0.200
DEC6	EXSE 1	2.450	2.700	0.250

Figure 6.44 – Obtained HFESs for increasing km post direction (light blue) and decreasing km post direction (red), L3408

Application of the Human Factors Evaluation Tool (HFET)

The HFET has been then applied to all the 13 HFESs. The results are presented in Table 6.79 for the increasing km post direction and in Table 6.80 for the decreasing km post direction. The results considering only the Total HFS are also presented in Figure 6.45. Red segments identify high risk HFES (Total HFS < 0.40), while yellow segments identify medium risk HFES (0.40 ≤ Total HFS ≤ 0.60).

Looking at the results, no high risk HFES is present considering the Total HFS. However, some HFESs present some high risk results concerning the First Rule and the Second Rule. Looking at the graph in Figure 6.46, most of the HFSs ranges between 0.40 and 0.60.

Table 6.79 – Results for each HFES from the application of the HFET, L3408, increasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
INC1	0.67	0.65	0.77	0.69
INC2	0.42	0.43	0.62	0.48
INC3	0.67	0.50	0.83	0.63
INC4	0.38	0.43	0.42	0.41
INC5	0.33	0.60	0.71	0.57
INC6	0.38	0.52	0.47	0.46
INC7	0.44	0.64	0.45	0.53

Table 6.80 – Results for each HFES from the application of the HFET, L3408, decreasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
DEC1	0.43	0.39	0.42	0.41
DEC2	0.58	0.48	0.86	0.62
DEC3	0.40	0.40	0.52	0.44
DEC4	0.42	0.64	0.58	0.57
DEC5	0.44	0.47	0.42	0.44
DEC6	0.55	0.54	0.46	0.53

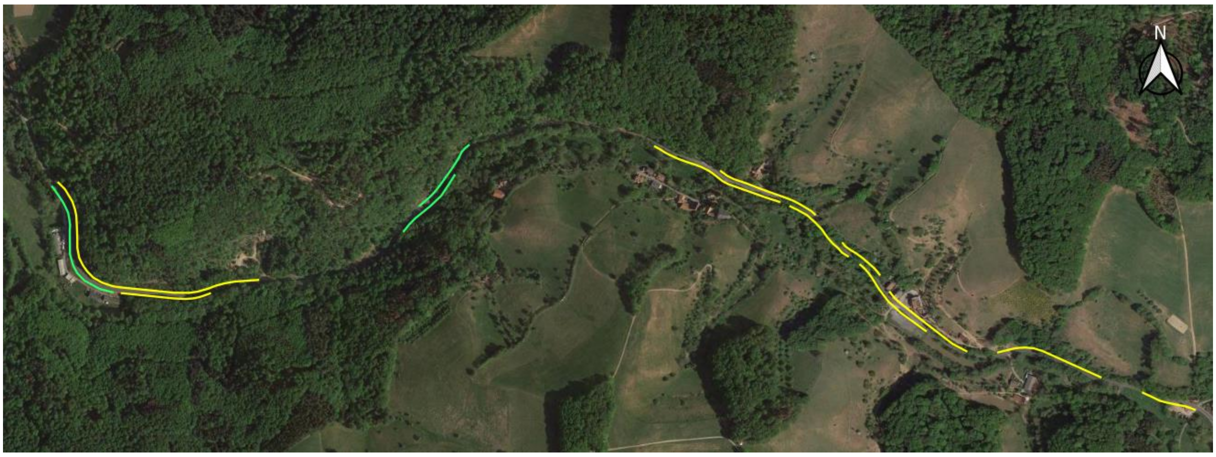

Figure 6.45 – Total HFS results, L3408 yellow = medium risk HFES, green =low risk HFES)

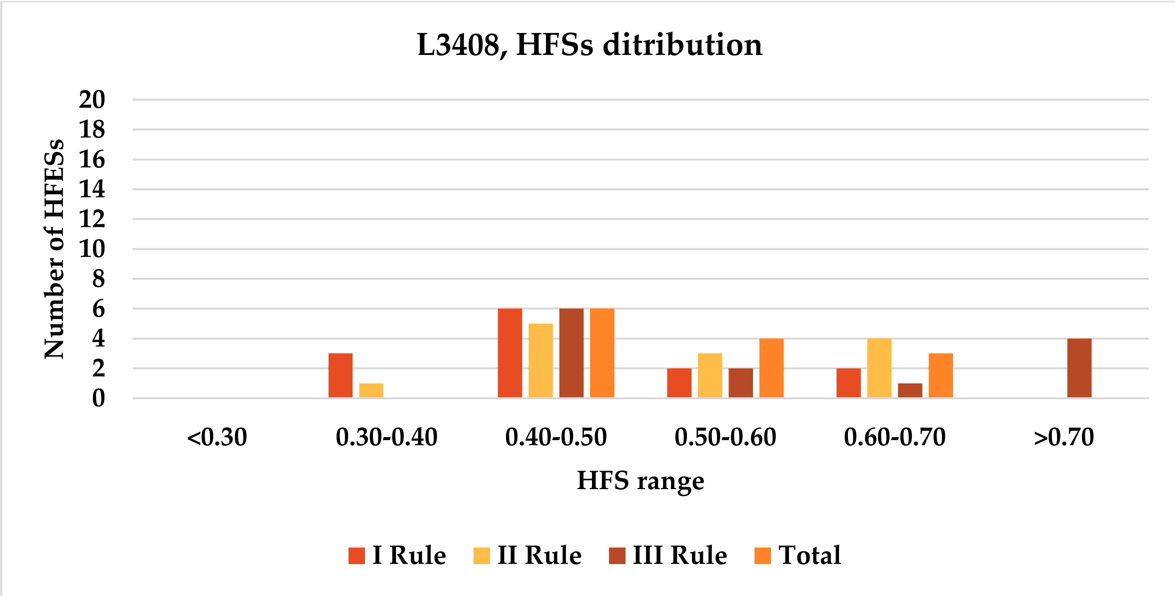

Figure 6.46 – Distribution of the HFSs for L3408

6.3.5.3 Third Step

Identification of network assessment sections (NASs)

Only two NASs have been identified for this road stretch. The identified NASs are depicted in Figure 6.47. Details about each NAS are provided in Table 6.81. In this table both the length of the section, the sum of the lengths of each HFES, and the length of the sections that are not part of HFES (i.e., INCSs), are presented.

Figure 6.47 – NASs identification, L3408

Table 6.81 – Characteristics of the identified NASs, L3408

NAS ID	Start [km]	End [km]	Length [km]	HFES [km]	HFES [%]	INCS [km]	INCS [%]
NAS 1	0.000	1.500	1.500	1.500	50%	1.500	50%
NAS 2	1.500	2.910	1.410	1.800	64%	1.020	36%

Calculation of the risk code (RC)

After NASs have been identified, the RC (Risk Code) is calculated following the procedure defined in 5.3.5.2. The worst results for each direction and for both the direction together are presented in Table 6.82. The final calculated RC for each NAS is presented in Table 6.83.

Table 6.82 – Definition of the worst result for each NAS, for each rule and the Total, L3408

	HFS, increasing km post				HFS, decreasing km post				Worst Results Both Directions			
NAS ID	I Rule	II Rule	III Rule	Total	I Rule	II Rule	III Rule	Total	I Rule	II Rule	III Rule	Total
NAS 1	42%	43%	62%	48%	43%	39%	42%	41%	42%	39%	42%	41%
NAS 2	33%	43%	42%	41%	40%	40%	42%	44%	33%	40%	42%	41%

Table 6.83 – Outcome from the application of the HFE procedure to the L3408 stretch (NAS of 1 km)

NAS ID	RC	Risk Level	Ranking
NAS 1	R1-41-77/25	Medium	2
NAS 2	R1-41-67/25	Medium	1

Two high risk NASs have been identified, while others are all classified as medium risk. The results are also shown by means of colored segments on a satellite image in Figure 6.48 (red = high risk, yellow = medium risk, green = low risk).

Figure 6.48 – NASs' risk level, L3408

6.3.6 106

6.3.6.1 First Step

Identification of potentially critical locations (PCLs)

A total of 123 PCLs has been identified in the analyzed stretch. Among those 60 are curves, 33 driveways, 2 crossings, 2 lane changes, 14 at-grade intersections, and 12 stopping areas. Figure 6.49 shows the distribution of the PCLs along the stretch. The road stretch is characterized by fast sections and signalized intersections.

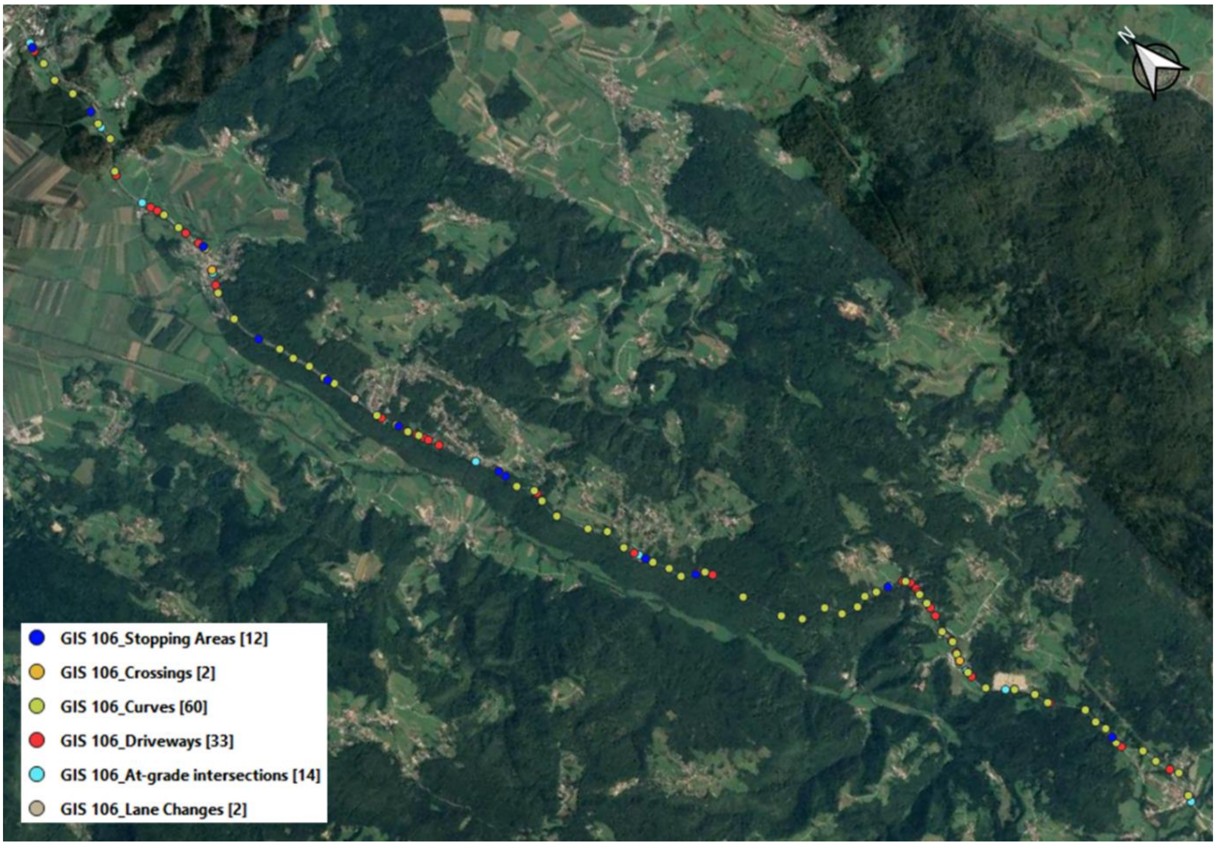

Figure 6.49 – Distribution of PCLs, 106

Identification of expectation sections (EXSEs)

The EXSEs have been defined accounting for the winding level and for the PPI level. The CCR values and the CCR graph are shown in APPENDIX 6. A medium level PPI is present along three EXSEs that pass through some small villages and residential areas. The identified EXSEs' characteristics are reported in Table 6.84. The table shows also the consequent expected speed level (V_E) and alertness level (AL).

Table 6.84 – EXSE of 106

Name	Starts [km]	End [km]	Length [km]	CCR [gon/km]	Winding level	PPI level	V_E	AL
EXSE 1	0	3.2	3.2	88	L	M	M	M
EXSE 2	3.2	5.1	1.9	64	L	L	H	L
EXSE 3	5.1	6.7	1.6	40	L	M	M	M
EXSE 4	6.7	12.1	5.4	142	L	L	H	L
EXSE 5	12.1	13.2	1.1	205	M	M	M	M
EXSE 6	13.2	16	2.8	160	M	L	H	L

Evaluation of potentially critical locations (PCLs)

Each PCL has been evaluated by means of VIS, PEX, and GEX. The results are summarized in Table 6.85. The main issues identified concern VIS and PEX.

Table 6.85 – Overall results for 106 PCLs evaluation

	VIS		PEX		GEX	
	INC	**DEC**	**INC**	**DEC**	**INC**	**DEC**
L	86	83	70	83	111	115
M	24	22	0	0	5	4
H	13	18	53	40	6	4
Tot	123	123	123	123	122	123

6.3.6.2 Second Step

Identification of challenging locations (CHLs)

A total of 47 PCLs has been promoted to CHLs. Among these, 14 are CHLs considering both directions, 18 is in the increasing km post direction, and 15 in the decreasing km post direction. The distribution among the different types of PCLs is presented in Table 6.86. Curves and driveways are the most critical locations, both considering increasing km post direction and decreasing km post direction. A graphical representation of the CHLs on a satellite image is provided in Figure 6.50.

Table 6.86 – Number of identified CHLs by type and direction, 106

CHLs type	INC	DEC
Curve	11	9
At-grade intersection	5	6
Crossing	1	2
Driveway	12	9
Lane Change	0	1
Stopping area	3	2
TOTAL	***32***	***29***

Figure 6.50 – Identified CHLs, 106

Identification of challenging transitions (CHTs) and Human Factors Evaluation Segments (HFESs)

The list of the obtained HFESs is presented in Table 6.87 for the increasing km post direction, and in Table 6.88 for the decreasing km post direction. The tables show also the EXSE to which the HFES belong. A total of 34 HFESs have been identified: 17 for the increasing km post direction and 17 for the decreasing km post direction. Figure 6.51 shows the position of the identified HFES by colored segments parallel to the road track on a satellite image. Light blue segments identified the HFES for the increasing km post direction, while red segments identified the HFES for the decreasing km post direction.

Table 6.87 – List of the HFES, 106, increasing km post direction (INC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
INC1	EXSE 1	0.200	0.450	0.250
INC2	EXSE 1	0.600	0.900	0.300
INC3	EXSE 1	1.000	1.900	0.900
INC4	EXSE 1	2.500	3.200	0.700
INC5	EXSE 2	4.400	4.750	0.350
INC6	EXSE 3	5.100	5.300	0.200
INC7	EXSE 3	5.650	6.450	0.800
INC8	EXSE 4	6.850	7.200	0.350
INC9	EXSE 4	8.200	8.450	0.250
INC10	EXSE 4	8.700	9.300	0.600
INC11	EXSE 4	10.000	10.800	0.800
INC12	EXSE 4	10.900	11.300	0.400
INC13	EXSE 4	11.650	12.050	0.400
INC14	EXSE 5	12.150	12.350	0.200
INC15	EXSE 5	12.800	13.200	0.400
INC16	EXSE 6	14.700	15.050	0.350
INC17	EXSE 6	15.350	16.000	0.650

Table 6.88 – List of the HFES, 106, decreasing km post direction (DEC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
DEC1	EXSE 1	0.400	0.650	0.250
DEC2	EXSE 1	1.100	1.500	0.400
DEC3	EXSE 1	1.600	1.900	0.300
DEC4	EXSE 1	1.950	2.300	0.350
DEC5	EXSE 1	3.000	3.600	0.600
DEC6	EXSE 3	5.500	5.850	0.350
DEC7	EXSE 3	5.900	6.600	0.700
DEC8	EXSE 4	7.000	7.400	0.400
DEC9	EXSE 4	8.400	8.700	0.300
DEC10	EXSE 4	9.050	9.550	0.500
DEC11	EXSE 4	10.200	10.500	0.300
DEC12	EXSE 4	10.850	11.400	0.550
DEC13	EXSE 4	11.600	12.200	0.600
DEC14	EXSE 5	12.950	13.300	0.350
DEC15	EXSE 6	13.350	13.800	0.450
DEC16	EXSE 6	14.300	15.100	0.800
DEC17	EXSE 6	15.500	15.700	0.200

Figure 6.51 – Obtained HFESs for increasing km post direction (light blue) and decreasing km post direction (red), 106

Application of the Human Factors Evaluation Tool (HFET)

The HFET has been then applied to all the 34 HFESs. The results are presented in Table 6.89 for the increasing km post direction and in Table 6.90 for the decreasing km post direction. The results considering only the Total HFS are also presented in Figure 6.52. Red segments identify high risk HFES (Total HFS < 0.40), while yellow segments identify medium risk HFES (0.40 ≤ Total HFS ≤ 0.60).

The graph in Figure 6.53 shows the distribution of the results within the analyzed stretch. The most critical aspects concern the First Rule, followed by the Second Rule, and the Third. Many HFESs are present which have at one HFS below 0.40 for one rule, but only three have a HFS less than 0.40 for more than one rule. Indeed, only one HFES has a Total HFS below 0.40. However, most of the HFESs have a Total HFS ranging between 0.40 and 0.50.

Table 6.89 – Results for each HFES from the application of the HFET, 106, increasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
INC1	0.44	0.50	0.69	0.54
INC2	0.44	0.60	0.80	0.64
INC3	0.35	0.39	0.63	0.44
INC4	0.44	0.50	0.52	0.49
INC5	0.46	0.45	0.71	0.53
INC6	0.44	0.63	0.71	0.61
INC7	0.50	0.39	0.50	0.46
INC8	0.36	0.36	0.50	0.41
INC9	0.38	0.50	0.53	0.47
INC10	0.40	0.48	0.38	0.43
INC11	0.50	0.47	0.38	0.45
INC12	0.69	0.52	0.62	0.60
INC13	0.45	0.50	0.33	0.43
INC14	0.50	0.61	0.57	0.56
INC15	0.44	0.39	0.54	0.45
INC16	0.63	0.47	0.50	0.53
INC17	0.40	0.43	0.48	0.43

Table 6.90 – Results for each HFES from the application of the HFET, 106, decreasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
DEC1	0.38	0.50	0.53	0.47
DEC2	0.42	0.38	0.75	0.49
DEC3	0.38	0.44	0.56	0.46
DEC4	0.50	0.40	0.56	0.48
DEC5	0.44	0.50	0.43	0.45
DEC6	0.38	0.53	0.46	0.46
DEC7	0.44	0.41	0.46	0.43
DEC8	0.58	0.37	0.60	0.50
DEC9	0.38	0.43	0.75	0.51
DEC10	0.40	0.40	0.47	0.42
DEC11	0.38	0.44	0.46	0.42
DEC12	0.58	0.43	0.60	0.52
DEC13	0.40	0.57	0.41	0.47
DEC14	0.44	0.40	0.40	0.41
DEC15	0.44	0.50	0.65	0.53
DEC16	0.25	0.47	0.40	0.39
DEC17	0.38	0.48	0.56	0.47

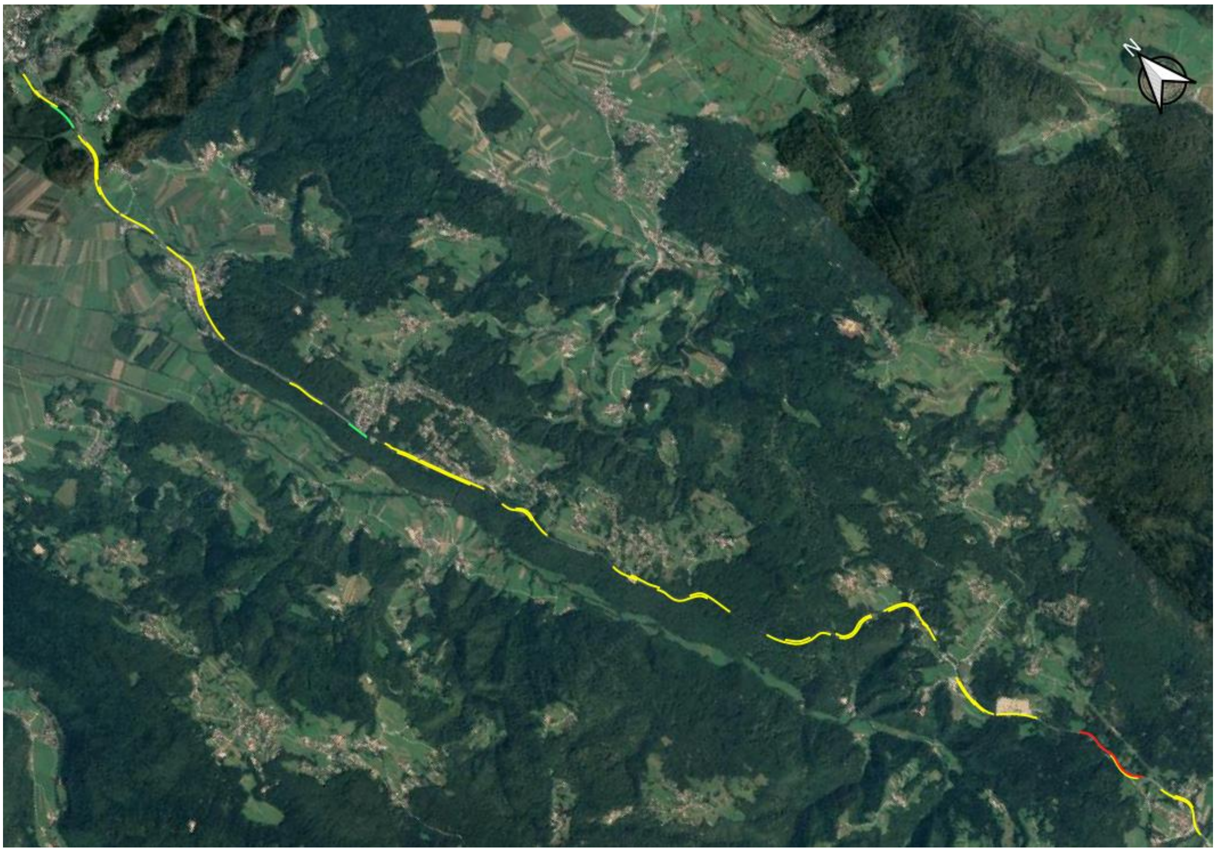

Figure 6.52 – Total HFS results, 106 (red = high risk HFES, yellow = medium risk HFES, green =low risk HFES)

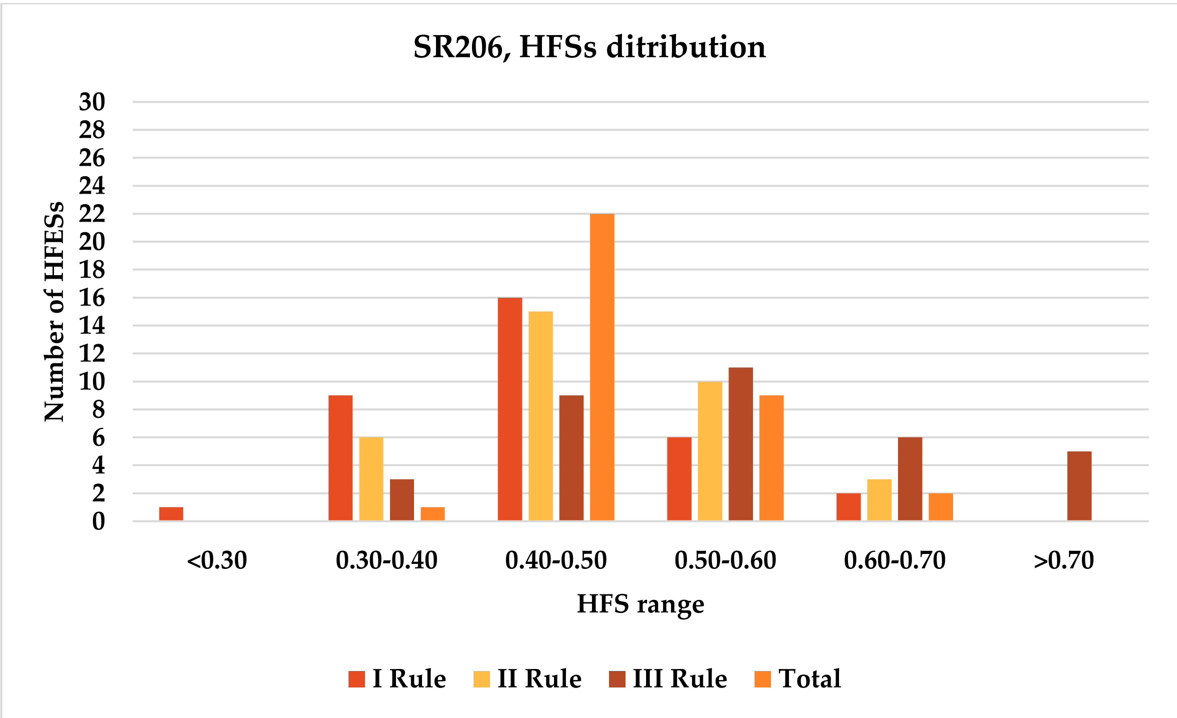

Figure 6.53 – Distribution of the HFSs for 106

6.3.6.3 Third Step

Identification of network assessment sections (NASs)

identified NASs are depicted in Figure 6.54. Details about each NAS are provided in Table 6.91. In this table both the length of the section, the sum of the lengths of each HFES, and the length of the sections that are not part of HFES (i.e., INCSs), are presented.

Figure 6.54 – NASs identification, 106

Table 6.91 – Characteristics of the identified NASs, 106

NAS ID	Start [km]	End [km]	Length [km]	HFES [km]	HFES [%]	INCS [km]	INCS [%]
NAS 1	0.000	1.000	1.000	0.800	40%	1.200	60%
NAS 2	1.000	2.300	1.300	1.950	75%	0.650	25%
NAS 3	2.300	3.600	1.300	1.300	50%	1.300	50%
NAS 4	3.600	4.800	1.200	0.350	15%	2.050	85%
NAS 5	4.800	5.500	0.700	0.200	14%	1.200	86%
NAS 6	5.500	6.600	1.100	1.850	84%	0.350	16%
NAS 7	6.600	7.600	1.000	0.750	38%	1.250	63%
NAS 8	7.600	8.700	1.100	0.550	25%	1.650	75%
NAS 9	8.700	9.700	1.000	1.100	55%	0.900	45%
NAS 10	9.700	10.800	1.100	1.100	50%	1.100	50%
NAS 11	10.800	11.600	0.800	0.950	59%	0.650	41%
NAS 12	11.600	12.700	1.100	1.200	55%	1.000	45%
NAS 13	12.700	13.900	1.200	1.200	50%	1.200	50%
NAS 14	13.900	15.100	1.200	1.150	48%	1.250	52%
NAS 15	15.100	16.000	0.900	0.850	47%	0.950	53%

Calculation of the risk code (RC)

The worst results considering all the HFESs belonging to each NAS, for each direction and for both the direction together are presented in Table 6.92. The final calculated RC for each NAS is presented in Table 6.93. The RC (Risk Code) is calculated following the procedure defined in 5.3.5.2.

Table 6.92 – Definition of the worst result for each NAS, for each rule and the Total, 106

	HFS, increasing km post				HFS, decreasing km post				Worst Results Both Directions			
NAS ID	I Rule	II Rule	III Rule	Total	I Rule	II Rule	III Rule	Total	I Rule	II Rule	III Rule	Total
NAS 1	44%	50%	69%	54%	38%	50%	53%	47%	38%	50%	53%	47%
NAS 2	35%	39%	63%	44%	38%	38%	56%	46%	35%	38%	56%	44%
NAS 3	44%	50%	52%	49%	44%	50%	43%	45%	44%	50%	43%	45%
NAS 4	46%	45%	71%	53%	100%	100%	100%	100%	46%	45%	71%	53%
NAS 5	44%	63%	71%	61%	100%	100%	100%	100%	44%	63%	71%	61%
NAS 6	50%	39%	50%	46%	38%	41%	46%	43%	38%	39%	46%	43%
NAS 7	36%	36%	50%	41%	58%	37%	60%	50%	36%	36%	50%	41%
NAS 8	38%	50%	53%	47%	38%	43%	75%	51%	38%	43%	53%	47%
NAS 9	40%	48%	38%	43%	40%	40%	47%	42%	40%	40%	38%	42%
NAS 10	50%	47%	38%	45%	38%	44%	46%	42%	38%	44%	38%	42%
NAS 11	69%	52%	62%	60%	58%	43%	60%	52%	58%	43%	60%	52%
NAS 12	45%	50%	33%	43%	40%	57%	41%	47%	40%	50%	33%	43%
NAS 13	44%	39%	54%	45%	44%	40%	40%	41%	44%	39%	40%	41%
NAS 14	63%	47%	50%	53%	25%	47%	40%	39%	25%	47%	40%	39%
NAS 15	40%	43%	48%	43%	38%	48%	56%	47%	38%	43%	48%	43%

Table 6.93 – Outcome from the application of the HFE procedure to the 106 stretch (NAS of 1 km)

NAS ID	RC	Risk Level	Ranking
NAS 1	R1-47-82/22	Medium	10
NAS 2	R2-44-60/23	High	5
NAS 3	Y4-45-74/26	Medium	12
NAS 4	Y3-53-93/17	Low	14
NAS 5	Y1-61-94/14	Low	15
NAS 6	R2-43-54/20	High	4
NAS 7	R2-41-80/26	High	2
NAS 8	R1-47-87/22	Medium	11
NAS 9	R1-42-68/29	Medium	7
NAS 10	R2-42-72/28	High	3
NAS 11	Y3-52-73/22	Low	13
NAS 12	R1-43-71/27	Medium	8
NAS 13	R1-41-73/27	Medium	6
NAS 14	R2-39-73/29	High	1
NAS 15	R1-43-74/28	Medium	9

Five high risk, seven medium risk, and 3 low risk NASs have been identified. The results are also shown by means of colored segments on a satellite image in Figure 6.55 (red = high risk, yellow = medium risk, green = low risk).

Figure 6.55 – NASs' risk level, 106

6.3.7 SR2 –application of the procedure from another inspection team

The SR2 stretch has been analyzed a second time, about five months after the first analysis. This second analysis has been carried out by two different inspectors that have been instructed about the use of the procedure and about the HFET. The analysis is part of a Master Degree thesis from Di Michele and Lanuza (Di Michele and Lanuza, 2022). The detailed results of this second analysis are discussed in the cited thesis (Di Michele and Lanuza, 2022). The summary of the results is here presented.

The students follow the same procedure presented in this PhD thesis.

The first difference occurred has been the identification of the stretch to analyze. In fact, the procedure focuses on rural roads, but also suggest including urban areas if they appear to be more similar to rural or suburban. Even if some references are provided to determine whether to consider an urban area or not, (e.g., the density of PCLs in the area, see 5.3.3), some situations may be ambiguous and thus the choices from different inspectors can be slightly different, as in this case. In this analysis Di Michele and Lanuza excluded the road segments between km 289.950 and 290.550, and those between 291.650 and 292.200. This choice influences many aspects of the subsequent procedure's step; nevertheless, the main scope is to identify the most critical road sections and in the first analysis of SR2 (that one described in this thesis) no particularly critical conditions have been found in the suburban areas. Thus, this choice must not heavily influence the results.

6.3.7.1 *First Step*

Concerning the definition of EXSEs, the results are very similar. This is a crucial point for the repeatability of the procedure. The results from the first application presented in Table 6.34 are included in Table 6.94 for comparison. Four EXSEs have been identified on both applications, with approximately the same length, excluding the last EXSE, which partially includes the urban area for the first application, and does not include any urban areas for the second application.

The major difference here is the evaluation of PPI. In this second analysis EXSE 3's PPI has been judged as low (L), while in the first analysis it has been judged as medium (M).

This results in minor differences concerning the GEXs evaluation because the only differences are in roundabouts, pedestrian crossings, and cycling crossings (see Table 5.27). A pedestrian crossing is present in the section, which has been evaluated as high risk level in the second analysis and as medium risk level in the first analysis. Nevertheless, this does not heavily influence the subsequent analysis.

Instead, this different classification leads to a greater difference in the definition of V_E and AL, which in turn influence VIS evaluation. As a result of this combination, some changes concerning VIS in the evaluation of EXSE 3's PCLs occurred.

Table 6.94 – EXSEs of SR2, first and second application of the HFE procedure

Run	Name	Starts [km]	End [km]	Length [km]	CCR [gon/km]	Winding level	PPI level	V_E	AL
1st	EXSE 1	0.00	4.55	4.55	383	H	L	M	M
1st	EXSE 2	4.55	6.90	2.35	89	L	L	H	L
1st	EXSE 3	6.90	8.40	1.50	317	M	M	M	M
1st	EXSE 5	9.35	11.60	2.25	109	L	M	M	M
2nd	EXSE 1	0.00	3.80	3.80	405	H	L	M	M
2nd	EXSE 2	3.8	6.57	2.77	135	L	L	H	L
2nd	EXSE 3	6.57	8.20	1.64	281	M	L	H	L
2nd	EXSE 5	9.90	10.90	1.00	105	L	M	M	M

6.3.7.2 *Second Step*

The PCLs in the analyzed stretch were 127 (34 less than the previous analysis). Among those 127 PCLs, Di Michele and Lanuza identified a total of 69 CHLs. In the previous analysis 61 CHLs have been identified. This difference is mainly due to the judgments of the PEX, which are subjective, and to some differences in the evaluation of VIS in EXSE 3.

Looking at Table 6.95, some additional considerations can be drafted. Crossings and stopping areas are quite the same number. In the stretch analyzed in the second run, three pedestrian crossings have been excluded from the analysis. Those pedestrian crossings were all promoted to be CHLs in the first run. Thus, the evaluation for the remaining pedestrian crossings were the same in both the applications.

Table 6.95 – Comparison between the number of identified CHLs by type, SR2, first and second application

CHLs' type	1st		2nd	
	INC	DEC	INC	DEC
Curve	10	8	15	14
At-grade intersection	9	10	5	4
Crossing	5	6	4	4
Driveway	19	15	26	23
Lane Change	0	1	0	1
Stopping area	5	2	5	3
TOTAL	***47***	***42***	***55***	***49***

A greater difference is present in the number of considered curves. This occurred mainly because of PEXs evaluation. However, a couple of curves have been also considered as CHLs because of VIS. These two curves belong to EXSE 3.

The different results between at-grade intersections and driveways occurred because of two reasons. The first is because in the two runs, the inspectors judged some intersections as driveways and some driveways as intersections. This may occur when junctions are ambiguous, and its classification not defined or not updated from road agencies. This condition often occurs in this type of roads and the SR2 stretch is a great example. Two driveways have been judged as at-grade intersections. Both have been promoted to CHLs (in the increasing direction). The remaining differences were mostly because of PEX. Only two difference was because of VIS.

Therefore, some differences occurred in the identification of EXSEs, CHLs and HFESs, which is preliminary to the application of the HFET. Those differences are physiological because some judgments are up to inspectors. If the procedure is robust against subjectivity, and if those differences are few, then the final result will likely be not influenced.

From the 69 CHLs, a total of 31 HFESs have been derived, 16 for the increasing km posts direction, and 15 for the decreasing km posts direction. The characteristics of each HFESs are reported in Table 6.96 and Table 6.97. Even if a higher number of CHLs has been identified, the HFESs are less than the HFESs identified in the first application of the procedure (where 37 HFESs were identified). This result is quite expected: the shorter the stretch analyzed, the less the HFESs identified. On the opposite, the longer the stretch analyzed, the higher the number of HFESs, because longer stretches means more possibilities to found CHLs.

Table 6.96 – List of the HFES, SR2, second application, increasing km post direction (INC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
INC1	EXSE 1	0.155	0.375	0.220
INC2	EXSE 1	0.422	0.928	0.506
INC3	EXSE 1	1.101	1.613	0.512
INC4	EXSE 1	1.745	2.207	0.462
INC5	EXSE 1	2.317	2.820	0.503
INC6	EXSE 1	2.831	3.129	0.299
INC7	EXSE 1	3.303	3.488	0.185
INC8	EXSE 1	3.768	4.455	0.687
INC9	EXSE 2	4.615	4.997	0.381
INC10	EXSE 2	5.273	5.665	0.392
INC11	EXSE 2	5.715	6.051	0.336
INC12	EXSE 3	6.594	6.803	0.209
INC13	EXSE 3	7.060	7.649	0.589
INC14	EXSE 3	7.773	8.007	0.234
INC15	EXSE 5	9.977	10.228	0.251
INC16	EXSE 5	10.245	10.801	0.556

Table 6.97 – List of the HFES, SR2, second application, decreasing km post direction (DEC)

HFES ID	EXSE	Start [km]	End [km]	Length [km]
DEC1	EXSE 1	0.410	1.078	0.668
DEC2	EXSE 1	1.405	1.813	0.408
DEC3	EXSE 1	2.069	2.826	0.757
DEC4	EXSE 1	3.011	3.329	0.319
DEC5	EXSE 1	3.333	3.548	0.215
DEC6	EXSE 2	3.968	4.595	0.627
DEC7	EXSE 2	4.660	4.926	0.266
DEC8	EXSE 2	4.970	5.194	0.224
DEC9	EXSE 2	5.473	5.676	0.203
DEC10	EXSE 2	5.830	6.249	0.419
DEC11	EXSE 3	6.600	7.024	0.424
DEC12	EXSE 3	7.075	7.849	0.774
DEC13	EXSE 3	7.973	8.207	0.234
DEC14	EXSE 5	10.120	10.428	0.308
DEC15	EXSE 5	10.445	11.001	0.556

The HFET has been then applied to all the 31 HFESs. The results are presented in Table 6.98 for the increasing km post direction and in Table 6.99 for the decreasing km post direction.

Table 6.98 – Results for each HFES from the application of the HFET, SR2, second application, increasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
INC0	0.38	0.56	0.57	0.53
INC1	0.38	0.60	0.50	0.50
INC2	0.35	0.42	0.35	0.38
INC3	0.40	0.48	0.39	0.43
INC4	0.40	0.34	0.38	0.37
INC5	0.35	0.40	0.41	0.39
INC6	0.38	0.50	0.50	0.46
INC7	0.30	0.55	0.47	0.44
INC8	0.38	0.47	0.67	0.50
INC9	0.44	0.50	0.50	0.48
INC10	0.38	0.53	0.41	0.44
INC11	0.56	0.47	0.43	0.49
INC12	0.35	0.43	0.44	0.40
INC13	0.31	0.47	0.44	0.41
INC14	0.38	0.44	0.69	0.49
INC18	0.44	0.50	0.60	0.51
INC19	0.63	0.47	0.53	0.54
INC20	0.38	0.42	0.44	0.41
INC21	0.44	0.53	0.35	0.44

Table 6.99 – Results for each HFES from the application of the HFET, SR2, second application decreasing km post direction

HFES ID	I Rule	II Rule	III Rule	Total
DEC1	0.38	0.44	0.62	0.47
DEC2	0.35	0.46	0.41	0.41
DEC3	0.25	0.40	0.35	0.34
DEC4	0.31	0.65	0.40	0.46
DEC5	0.38	0.42	0.44	0.42
DEC6	0.38	0.63	0.46	0.49
DEC7	0.38	0.50	0.50	0.46
DEC8	0.44	0.33	0.59	0.45
DEC9	0.31	0.58	0.47	0.46
DEC10	0.25	0.50	0.45	0.40
DEC11	0.25	0.61	0.50	0.46
DEC12	0.30	0.48	0.69	0.47
DEC13	0.31	0.44	0.65	0.47
DEC15	0.38	0.50	0.40	0.43
DEC16	0.38	0.72	0.43	0.51
DEC17	0.44	0.58	0.45	0.49
DEC18	0.38	0.36	0.47	0.40
DEC19	0.44	0.44	0.33	0.40

The results from the application of the HFET are also presented by graphical representation in Figure 6.56 (right side). The colors identified medium risk level HFESs (yellow) and high risk level HFESs (red). The risk level is related only to the results of the Total HFS. In the same figure the results from the first application of the procedure are also presented (left side) to better compare each other. The comparison of these results serves to prove both the effectiveness and the repeatability of the procedure (until this step) and of the updated version of the HFET.

Looking at in Figure 6.56, the results are very similar. Along the whole stretch many medium level HFESs are present. The most critical segment identified in both the applications are in the southern part of the stretch, in the hilly terrain, when the road is very curvy. Some differences are also present: above all, in the first application some more critical HFESs have been identified in the southern area, while in the second application a high risk level HFES has been identified in the northern part.

Looking at the distributions of the results among the single rules in Figure 6.57, similar results can be also observed to those described in Figure 6.17. From the two graphs it can be observed that the most critical aspect of the stretch concerns the First Rule, that means some visibility issues are present. Concerning the Second and the Third Rules and comparing the results of the second application to those of the first application, the HFSs below 0.40 are quite the same number, but a shift from the range 0.40-0.50 to 0.50-0.60 is present moving from the first to the second application. This consequently involves the Total. Nevertheless, it must be noticed that a HFS between 0.40 and 0.60 is considered always as a “medium risk level”. Another important difference is that the Second Rules results are very shifted to the right of the graph (higher values of the HFS). The maximum number of HFES are comprised between 0.60 and 0.70, which means low risk level. This result is interesting, because during the Step 1 of the procedure, many PCLs have been judged as having possible issues concerning PEXs (thus, issues related to the Second Rule). Consequently, more PCLs have been promoted to CHLs in the second application compared to the first one. After the detailed analysis with the HFET, the results from the second application shows that most of the CHLs do not have problems concerning the Second Rule. This suggest that in the Step 1 of the second application, the dangerousness of the PCLs has been overestimated. Therefore, also in this case, the structure of the procedure helps reducing some evaluations errors. The cost is more time expended applying the HFET to more CHLs, but the results converge to the same solution.

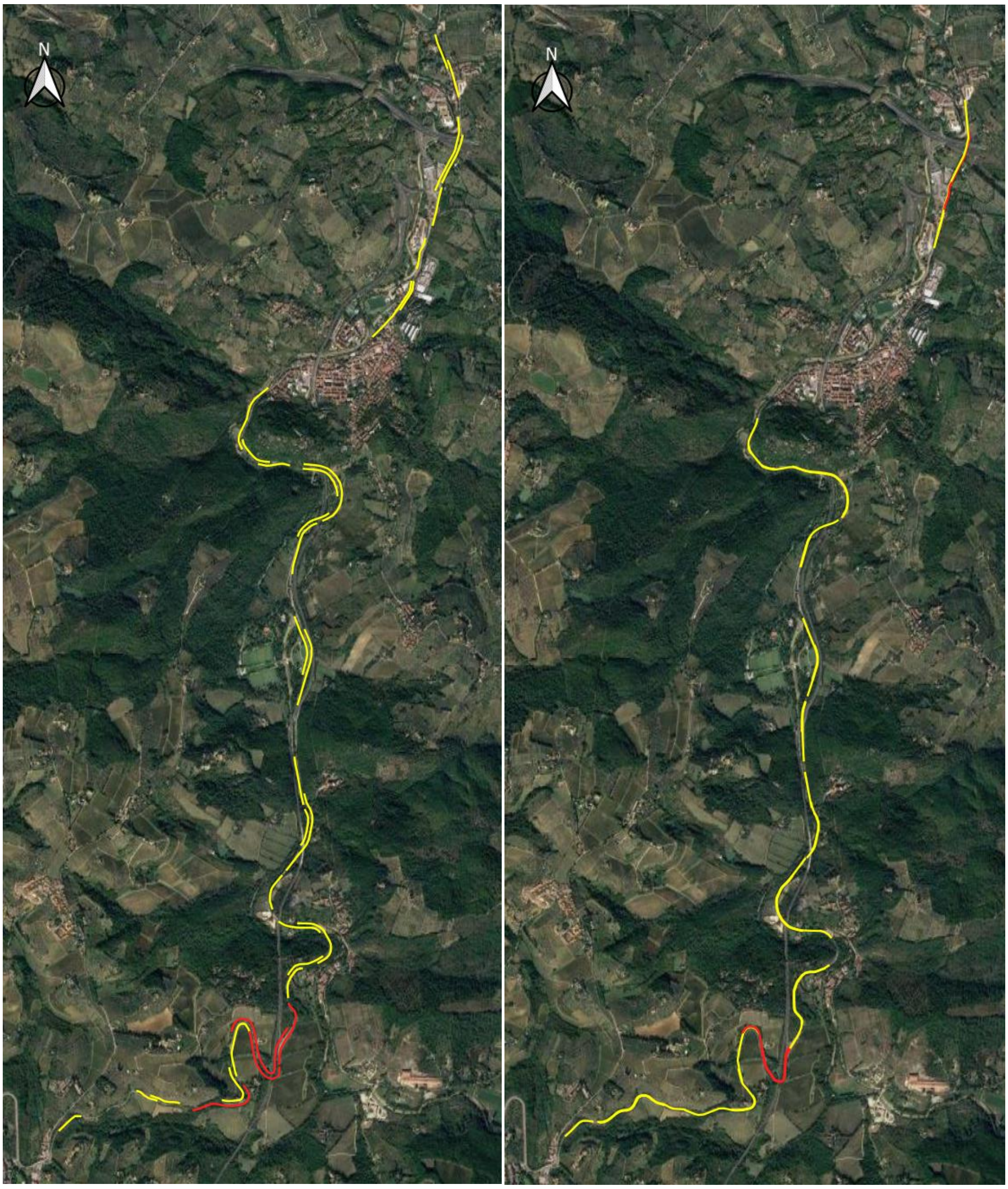

Figure 6.56 – Total HFS results, SR2 (red = high risk HFES, yellow = medium risk HFES)

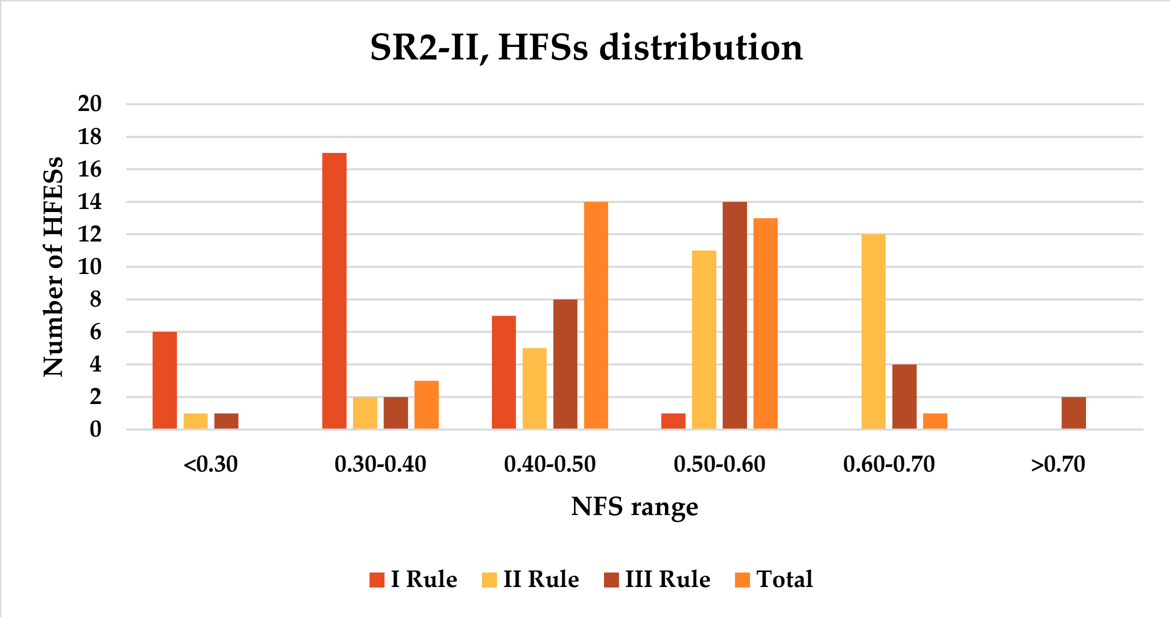

Figure 6.57 – Distribution of the HFSs for SR2, second application

6.3.7.3 Third Step

Finally, NASs have been defined and the RC for each NAS has been calculated. Table 6.100 shows the identified NASs' characteristics, while Table 6.101 show the calculated RC for each NAS, their risk level, and their ranking. The NAS segmentation presents some differences, even if the reference length chosen was in both cases of 1 km. In the second application, a shorter stretch has been analyzed and some difference in the HFESs occurred. These induce a difference in the NASs segmentation.

Despite some differences in the segmentation, the HFE procedure identifies the same risky areas in both cases. Indeed, a strict correspondence is present between the two results: the most critical section is located at the same point of the stretch (south) and has been classified as "very high risk", and the second most critical section is also located at the same point of the stretch (north) and has been classified as "high risk".

Table 6.100 – Characteristics of the identified NASs, SR2, second application

NAS ID	Start [km]	End [km]	Length [km]	HFES [km]	HFES [%]	INCS [km]	INCS [%]
NAS 1	0.000	1.080	1.080	1.394	65%	0.766	35%
NAS 2	1.080	2.830	1.750	2.642	75%	0.858	25%
NAS 3	2.830	3.700	0.870	1.017	58%	0.723	42%
NAS 4	3.700	4.600	0.900	1.313	73%	0.487	27%
NAS 5	4.600	5.700	1.100	1.466	67%	0.734	33%
NAS 6	5.700	7.025	1.325	1.388	52%	1.262	48%
NAS 7	7.025	8.250	1.225	1.831	75%	0.619	25%
NAS 8	9.950	11.050	1.100	1.671	76%	0.529	24%

Table 6.101 – Outcome from the application of the HFE procedure to the SR2 stretch (NAS of 1 km)

NAS ID	RC	Risk Level	Ranking
NAS 1	R1-51-72/21	Medium	8
NAS 2	R4-34-56/26	Very High	1
NAS 3	R1-45-69/26	Medium	6
NAS 4	R1-45-61/24	Medium	4
NAS 5	R1-47-67/23	Medium	7
NAS 6	R1-42-73/26	Medium	3
NAS 7	R1-45-62/22	Medium	5
NAS 8	R3-35-58/25	High	2

The other sections are all classified as "medium risk level". The results are easily understandable looking at Figure 6.58, where both the results of the two applications are graphically represented on a satellite image (dark red = very high risk, red = high risk, and yellow = medium risk). The results show a very high correspondence.

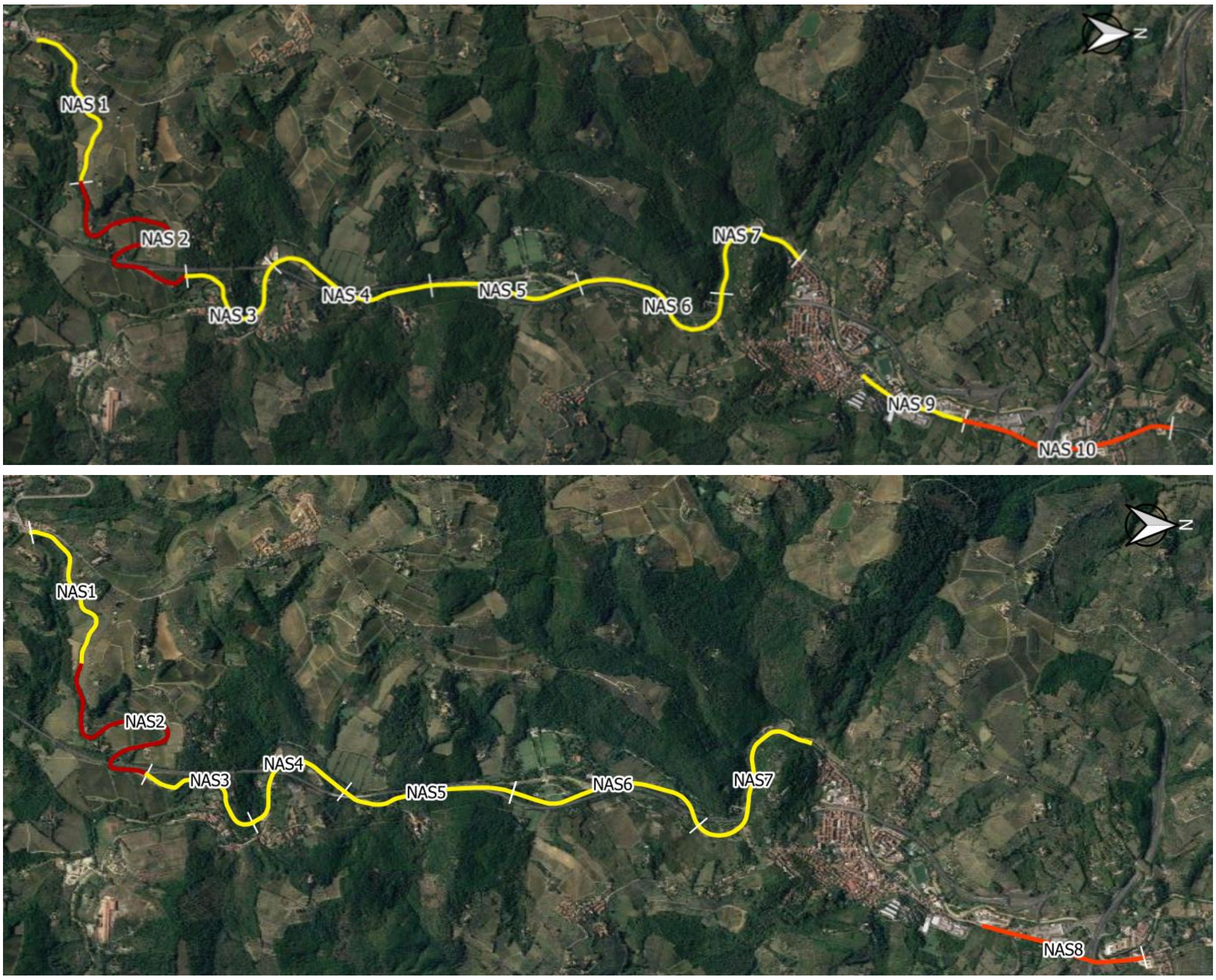

Figure 6.58 – NASs' risk level, SR2, first application (top) and second application (bottom)

6.4 Summary of the results

The outcomes from the application of the procedure are presented in Table 6.102 (the number of high risk NASs includes also the very high risk NAS).

Table 6.102 – Procedure results summary

	Number of NASs			
Road	**Total**	**Low Risk**	**Medium Risk**	**High Risk**
SR2	9	0	8	2
SR206	13	2	9	2
B38	9	2	5	2
L3106	6	0	4	2
L3408	2	0	2	0
106	15	3	7	5
All roads	**54**	**7**	**34**	**13**
Percentage	**100%**	**13%**	**63%**	**24%**

Table 6.102 shows that most of the identified NASs have been classified as medium risk (64%) and about 13% have been classified as low risk. Those sections do not require specific urgent improvements. However, about a quarter of the total NASs are classified as high risk. Those sections require an intervention as soon as possible to improve their safety level.

CHAPTER 7 ANALYSIS AND DISCUSSION OF THE RESULTS

Chapter abstract

The results presented in CHAPTER 6 will be here discussed, evaluating the effectiveness, the repeatability, and the consistency of the procedure. Effectiveness will be evaluated comparing the results of the procedure with those based on observed accident rate. Two comparison types have been considered: comparing the risk level associated to each network assessment section (NAS) and comparing the rank assigned to each NAS. The results were calculated considering both each separate road stretch and all the NASs of all the stretches together. The ranking results have been compared Kendall's coefficient of concordance, and the risk level results by the Freeman-Halton extension of Fisher's test. Results from the comparison demonstrate an overall good correspondence for all the statistics indices considered. The results highlight that the more dangerous the section, the higher the correspondence between risk code (RC) and accident rate (average correspondence of 56%). Indeed, while considering only "sections that require intervention", which are the high risk level sections, and "section that do not require intervention", which are the low and medium risk sections, the correspondence is of 81%.

Repeatability has been analyzed and discussed comparing the results of two applications of the procedures by different inspectors to the same road stretch, that is the SR2 stretch. Results demonstrate that the procedure is repeatable: the obtained safety level for each NAS are the same. The results regarding consistency among different NASs show that the semi-fixed length about 1 km show the best results.

Overall, the intended procedure demonstrates to be a useful instrument within the road safety analysis. The implementation of the HFE procedure doesn't require specific road data, thus it can be immediately applied to all existing rural highways. The introduction in the procedure of a first screening process of potentially critical locations (PCLs), helps to drastically reduce the application time of the procedure without affecting the reliability of the results (about 80 minutes for each km analyzed). It has been estimated an average time to apply the procedure of less than 2 hours/km.

Moreover, the results show a high consistency with all previous studies that reported a rate of about 75% consistency between Human Factors Score (HFS) and accident rate (Birth and Pflaumbaum, 2006) (Birth et al., 2015). So, the conclusion is valid that the procedure and Human Factors Evaluation Tool (HFET) are very efficient instruments in predicting accidents and treating accidents spots. This is possible because the road related deficiencies in space perception, expectations, and repsponse of drivers are clearly identified and can be treated with specific countermeasures. This is a great step forward in the field of road safety.

Chapter list of acronyms

AADT	Average Annual Daily Traffic
CHL	Challenging Location
EXSE	Expectation Section
GEX	General Expectation
HFE	Human Factors Evaluation

HFES	Human Factors Evaluation Segment
HFET	Human Factors Evaluation Tool
HFS	Human Factors Score
ID	Identification
NAS	Network Assessment Section
PCL	Potentially Critical Location
PEX	Punctual Expectation
PPI	Perception of Possible Interaction
RC	Risk Code
RSI	Road Safety Inspection
VIS	Visibility

7.1 Effectiveness: comparison with accident rate

7.1.1 General discussion

Overall, the results obtained from the HFE procedure and the accident rate calculation, show a medium to high correspondence. The most important result is that a well-defined correlation is present considering high risk level sections. Indeed, low risk levels and mostly medium risk levels may likely change their ranking both considering HFE procedure and accident rate. In the first case, minor flows may occur because of different judgments from the inspectors; in the second case, because of accident randomness. In sections that are very dangerous, these flows have minor influence. The high-risk level is reached only when many issues are identified during the HFE procedure, and only when many accidents occurred in that section (accidents in that section are so much that also if some fluctuations occurred over the analysis period, they would not influence the classification). For this reason, having a good correspondence of high risk sections is better than having good correspondence of medium and low risk level sections.

When considering the comparison between the risk levels, it must be noted that the thresholds value for the accident rate are strictly related to the accidents rate values obtained for the considered dataset, while the risk level from the HFE procedure is an absolute value, independently from the stretch. Thus, if the stretch has a very low T_m (average accident rate), the risk level considering accident rate will be higher compared to another stretch of higher T_m. Thus, more stress should be put on this index when analyzing the whole NASs of all roads together, than in the analysis of the single stretches.

Moreover, the accident rate of the single sections is also highly influenced by length. The choice of a fixed length of approximately 1 km, has partially fixed this problem.

Finally, a numerical correlation between RC and accident rate has been investigated considering all the roads together. Because RC is a qualitative variable, it has been translated in number considering the different combination of the first part of the RC as number. The results show a low correlation when all the NASs are considered separated, but the results are quite good while considering the average value of accident rate for NASs with the same RC. These results are discussed in 7.1.8.

7.1.2 SR2

The results from the application of the HFE procedure and the accident rate calculation are summarized in Table 7.1.

Table 7.1 – Summary of the results from the application of the HFE procedure and accident rate calculation, SR2

Name	Length [km]	AADT [veh./day]	HFE Proc. RC	HFE Proc. Risk Level	RC Rank	Acc. Rate*	Acc. Rate Risk Level	Acc. Rate Rank
NAS 1	1.200	4247	R1-47-92/18	Medium	9	0.11	Medium	8
NAS 2	1.950	4247	R4-34-51/25	Very High	1	1.32	High	1
NAS 3	0.950	4247	R1-42-63/27	Medium	4	0.27	Medium	6
NAS 4	1.150	4247	R1-44-70/26	Medium	6	0.34	Medium	5
NAS 5	1.000	4247	R1-45-76/26	Medium	7	0.52	Medium	3
NAS 6	1.250	4247	R1-40-64/28	Medium	3	0.21	Medium	7
NAS 7	0.900	4247	R1-46-74/26	Medium	8	0.00	Low	9
NAS 9	0.750	12395	R1-43-74/26	Medium	5	0.41	Medium	4
NAS 10	1.500	12395	R3-40-74/29	High	2	0.59	High	2

*[acc./(km·Mvehicles·year)]

The results from the statistic tests are:

- Freeman-Halton extension of Fisher's test: p-value significance of 0.028 < 0.05, thus the null hypothesis that the variables assume these risk level by chance, can be rejected;
- Kendall'W of 0.833, with a p-value of 0.03 < 0.05, thus the null hypothesis that the variables assume this ranking by chance, can be rejected;

The two statistics tests demonstrate a strong correlation between the results.

Overall, the outcomes from the two procedures are very similar for this stretch, both considering high risk location, medium risk location and low risk location. In this stretch, the most critical section has been identified within all the analyzed stretch (it has been classified as very high-risk level), namely NAS 2.

NAS 2 is composed by many HFES and develops for about 2 kms. This is also the longest identified NAS. This condition suggests that the higher the HFESs within the NAS, the higher the possibilities for that NAS to become riskier, because the process of RC calculation consider primarily the worst results. This implicitly also show that the length of a section may have some influence in the results, even if the length is not considered in any calculation. Additional considerations about NAS length and its influence of the results are provided in 7.3.

Despite its length, NAS 2 will be classified as a high risk section even if divided in two different parts, because it is characterized by two critical HFESs. Most of the accidents recorded in this section, occurred exactly within these two HFESs. A detailed analysis of NAS

2 is provided in APPENDIX 11, highlighting which deficiencies have been identified as the most influencing on road safety by the application of the HFE procedure.

7.1.3 SR206

The results from the application of the HFE procedure and the accident rate calculation are summarized in Table 7.2.

Table 7.2 – Summary of the results from the application of the HFE procedure and accident rate calculation, SR206

Name	Length [km]	AADT [veh./day]	HFE Proc. RC	HFE Proc. Risk Level	RC Rank	Acc. Rate*	Acc. Rate Risk Level	Acc. Rate Rank
NAS 1	1.300	11799	R1-41-79/26	Medium	2	0.21	Medium	5
NAS 2	1.350	11799	R1-44-55/20	Medium	5	0.14	Medium	9
NAS 3	0.950	11799	Y4-48-90/20	Medium	11	0.00	Low	12
NAS 4	1.000	11799	R1-46-93/18	Medium	8	0.23	Medium	4
NAS 5	1.300	11799	R1-40-54/23	Medium	1	0.43	High	1
NAS 6	1.100	11799	Y4-43-76/27	Medium	9	0.00	Low	13
NAS 7	1.100	11799	R1-42-50/20	Medium	4	0.21	Medium	6
NAS 8	1.000	11799	G4-100-100/00	Low	12	0.14	Medium	8
NAS 9	1.000	11799	R1-46-73/27	Medium	7	0.09	Medium	10
NAS 10	1.050	11799	R1-41-80/27	Medium	3	0.40	High	2
NAS 11	1.150	15335	G4-100-100/00	Low	13	0.03	Low	11
NAS 12	1.100	15335	R1-44-84/25	Medium	6	0.39	High	3
NAS 13	1.200	15335	Y4-47-94/16	Medium	10	0.18	Medium	7

*[acc./(km·Mvehicles·year)]

The results from the statistic tests are:

- Freeman-Halton extension of Fisher's test: p-value significance of 0.46 > 0.05, thus the null hypothesis that the variables assume these risk level by chance, must be accepted;
- Kendall'W of 0.849, with a p-value of 0.02 < 0.05, thus the null hypothesis that the variables assume this ranking by chance, can be rejected;

The Freeman-Halton extension of Fisher's test shows low significance. However, this result can be due to the definition of thresholds value considering the accident rate of this single stretch, and also to the general low values of the accident rate between the stretch (see 7.1.1).

Concerning the ranking, the results from the comparison are good. A good correspondence is present considering the most critical sections too.

Overall, the accident rate results are very low compared to those of the other stretch, thus it can be expected that the HFE procedure result show no high risk level sections. This suggests some thinking. On one hand it is possible that the HFE procedure cannot clearly analyze the safety level of the sections, overestimating some minor problems. On the other hand, it could be that some other factors occurred that reduce the possibilities of accident occurrence.

Analyzing in detail the two critical sections (see APPENDIX 11), the presence of some Human Factors-related issues is confirmed. Considering all the NASs, a common characteristic is that they have a remarkably high level of traffic comparing to other analyzed stretch. Moreover, the southern part of the stretch lack of any traffic monitoring station. This part is where the bigger urban area is located, thus it could be expected that a higher traffic volume will be present. This suggest that traffic may influence the risk of an accident (not by simply increase the exposure).

7.1.4 B38

The results from the application of the HFE procedure and the accident rate calculation are summarized in Table 7.3.

Table 7.3 – Summary of the results from the application of the HFE procedure and accident rate calculation, B38

Name	Length [km]	AADT [veh./day]	HFE Proc. RC	HFE Proc. Risk Level	RC Rank	Acc. Rate*	Acc. Rate Risk Level	Acc. Rate Rank
NAS 1	1.300	7068	Y4-47-81/23	Medium	7	0.20	Low	9
NAS 2	1.200	8058	Y3-58-75/20	Low	9	0.47	Medium	7
NAS 3	1.000	11078	R1-64-93/14	Medium	5	0.49	Medium	6
NAS 4	1.000	14098	R2-45-73/27	High	2	0.97	Medium	3
NAS 5	1.200	10179	R1-40-68/26	Medium	3	0.82	Medium	4
NAS 6	1.200	10456	R3-38-74/28	High	1	1.31	High	1
NAS 7	1.100	10732	Y4-46-81/25	Medium	6	0.46	Medium	8
NAS 8	0.700	11377	Y3-57-79/21	Low	8	1.03	Medium	2
NAS 9	1.190	12021	R1-44-73/25	Medium	4	0.51	Medium	5

*[acc./(km·Mvehicles·year)]

The results from the statistic tests are:

- Freeman-Halton extension of Fisher's test: p-value significance of 0.16 > 0.05, thus the null hypothesis that the variables assume these risk level by chance, must be accepted;
- Kendall'W of 0.783, with a p-value of 0.04 < 0.05, thus the null hypothesis that the variables assume this ranking by chance, can be rejected;

Overall, also in this stretch, the correspondence between the two indices is good. However, a great difference is present in NAS 8, that has been classified concerning HFE procedure as low risk, with the 8th position in the rank, and concerning the accident rate as medium risk, with the 2nd position in the rank. This difference also influence the Kendall's coefficient calculation. This difference seems related to the specific accident type occurred in the section, which are rear-end accidents and are only partially related to Human Factors aspects. Moreover, the accidents' descriptions also provide the description of the last moment of the accidents, without specific details about the preceding conditions. Thus, it is not easy to determine whether the accident occurred because of a wrong perception of the road, or because some other human mistakes. Nevertheless, a deeper analysis of NAS 8 is provided in APPENDIX 11.

7.1.5 L3106

The results from the application of the HFE procedure and the accident rate calculation are summarized in Table 7.4.

Table 7.4 – Summary of the results from the application of the HFE procedure and accident rate calculation, L3106

Name	Length [km]	AADT [veh./day]	HFE Proc. RC	HFE Proc. Risk Level	RC Rank	Acc. Rate*	Acc. Rate Risk Level	Acc. Rate Rank
NAS 1	0.800	7068	R1-40-70/26	Medium	3	1.51	Medium	2
NAS 2	0.800	8058	Y4-42-71/25	Medium	6	0.00	Low	6
NAS 3	1.250	11078	R2-41-68/26	High	1	2.05	High	1
NAS 4	1.250	14098	R1-42-73/25	Medium	5	0.41	Medium	5
NAS 5	1.050	10179	Y4-47-84/22	Medium	4	0.60	Medium	4
NAS 6	1.140	10456	R2-42-58/22	High	2	0.82	Medium	3

*[acc./(km·Mvehicles·year)]

The results from the statistic tests are:

- Freeman-Halton extension of Fisher's test: p-value significance of 0.33 > 0.05, thus the null hypothesis that the variables assume these risk level by chance, must be accepted;
- Kendall'W of 0.971, with a p-value of 0.03 < 0.05, thus the null hypothesis that the variables assume this ranking by chance, can be rejected;

Overall, the correspondence between the two indices is very good, mainly considering ranking. The only difference in the ranking between the two indices is in NAS 1 and NAS 6. The first is more critical concerning the accident rate, while the second is more critical concerning the RC. Looking in details at the RC value, it appears that NAS 1 has the first part of the code as R1, but a minimum Total HFS as 40. NAS 6 is an R2 section with a Total HFS of 42. This means that R1 is very close to become an R2 section and, if that would the case, it will jump before NAS 6, because the Total HFS value is minor. This highlights that sometimes, few differences in the inspector judgments may also change the risk level of a section. However, even if NAS 1 has not been considered as a high-risk section, it is ranked immediately after the high-risk sections, because of its very low Total HFS.

7.1.6 L3408

The results from the application of the HFE procedure and the accident rate calculation are summarized in Table 7.5.

Table 7.5 – Summary of the results from the application of the HFE procedure and accident rate calculation, L3408

Name	Length [km]	AADT [veh./day]	HFE Proc. RC	HFE Proc. Risk Level	RC Rank	Acc. Rate*	Acc. Rate Risk Level	Acc. Rate Rank
NAS 1	1.500	3311	R1-41-77/25	Medium	2	0.74	Medium	1
NAS 2	1.410	3311	R1-41-67/25	Medium	1	0.39	Medium	2

*[acc./(km·Mvehicles·year)]

The statistic tests have not been considered for this stretch, because only two sections are present. The results of the two NASs are very similar and both of medium level.

7.1.7 106

The results from the application of the HFE procedure and the accident rate calculation are summarized in Table 7.6.

Table 7.6 – Summary of the results from the application of the HFE procedure and accident rate calculation, 106

Name	Length [km]	AADT [veh./day]	HFE Proc. RC	HFE Proc. Risk Level	RC Rank	Acc. Rate*	Acc. Rate Risk Level	Acc. Rate Rank
NAS 1	1.000	8369	R1-47-82/22	Medium	10	0.46	Medium	12
NAS 2	1.300	8369	R2-44-60/23	High	5	0.65	Medium	9
NAS 3	1.300	8369	Y4-45-74/26	Medium	12	0.76	High	8
NAS 4	1.200	8369	Y3-53-93/17	Low	14	0.22	Low	15
NAS 5	0.700	8369	Y1-61-94/14	Low	15	0.47	Medium	11
NAS 6	1.100	8369	R2-43-54/20	High	4	0.77	High	6
NAS 7	1.000	8369	R2-41-80/26	High	2	1.11	High	1
NAS 8	1.100	8369	R1-47-87/22	Medium	11	0.54	Medium	10
NAS 9	1.000	8369	R1-42-68/29	Medium	7	1.05	High	2
NAS 10	1.100	8369	R2-42-72/28	High	3	0.95	High	3
NAS 11	0.800	8369	Y3-52-73/22	Low	13	0.41	Medium	13
NAS 12	1.100	8369	R1-43-71/27	Medium	8	0.83	High	5
NAS 13	1.200	8369	R1-41-73/27	Medium	6	0.76	High	7
NAS 14	1.200	8369	R2-39-73/29	High	1	0.87	High	4
NAS 15	0.900	8369	R1-43-74/28	Medium	9	0.36	High	14

*[acc./(km·Mvehicles·year)]

The results from the statistic tests are:

- Freeman-Halton extension of Fisher's test: p-value significance of 0.08 > 0.05, thus the null hypothesis that the variables assume these risk level by chance, must be accepted;
- Kendall’W of 0.886, with a p-value of 0.01 < 0.05, thus the null hypothesis that the variables assume this ranking by chance, can be rejected;

The Freeman-Halton extension of Fisher's test shows low significance. Moreover, 8 sections have been classified as high-risk level concerning accident rate, while only 5 have been considered as high risk by the HFE procedure. The good result is that 4 out of 5 of the high-risk sections identified by the HFE procedure, are classified as high risk also for the accident rate.

A very good correlation is instead present considering the section ranking. A good correspondence is present considering the most critical sections too.

NAS 7 and NAS14 are the most critical sections identified for both the HFE procedure and the accident rate analysis. NAS 9 shows some difference among the two results.

It must be noted that in this case traffic data may contain not negligible bias, because many intersections are present along the whole stretch, with also some villages and traffic variance is expected. Changing in traffic will likely produce a change also in the accident rate.

7.1.8 Comprehensive results

The comparison of all NASs together has been made. The results are shown in Table 7.7. The results are ordered from the worst section to the better one, considering the RC derived from the application of the HFE procedure. The ranking columns for both RC and accident rate are colored to better identify differences. The colors range from red (most critical) to green (less critical). The gradient is based on the rank itself.

Considering all the NASs together implies new accident rate thresholds, thus new accident rate risk levels, and a new ranking both for the HFE procedure and for the accident rate results. The different road stretch and the different countries to which they belong, may lead to some bias judging all the NASs together. This can be due to peculiarities of roads designs or drivers' habits. However, this procedure has as objective to be a worldwide procedure, which allows to analyze different two-lane two-way road networks from different countries. Thus, an evaluation of all the NASs together must be carried out.

Table 7.7 - Summary of the results from the application of the HFE procedure and accident rate calculation, all NASs analyzed

Road	Name	Length [km]	AADT [veh./day]	HFE Proc. RC	HFE Proc. Risk Level	RC Rank	Acc. Rate*	Acc. Rate Risk Level	Acc. Rate Rank
SR2	NAS 2	1.950	4247	R4-34-51/25	Very High	1	1.32	High	3
B38	NAS 6	1.200	10456	R3-38-74/28	High	2	1.31	High	4
SR2	NAS 10	1.500	12395	R3-40-74/29	High	3	0.59	Medium	20
106	NAS 14	1.200	8369	R2-39-73/29	High	4	0.87	High	10
L3106	NAS 3	1.250	1783	R2-41-68/26	High	5	2.05	High	1
106	NAS 7	1.000	8369	R2-41-80/26	High	6	1.11	High	5
L3106	NAS 6	1.140	2922	R2-42-58/22	High	7	0.82	Medium	12
106	NAS 10	1.100	8369	R2-42-72/28	High	8	0.95	High	9
106	NAS 6	1.100	8369	R2-43-54/20	High	9	0.77	High	14
106	NAS 2	1.300	8369	R2-44-60/23	High	10	0.65	Medium	18
B38	NAS 4	1.000	14098	R2-45-73/27	High	11	0.97	High	8
SR206	NAS 5	1.300	11799	R1-40-54/23	Medium	12	0.43	Medium	29
SR2	NAS 6	1.250	4247	R1-40-64/28	Medium	13	0.21	Medium	43
B38	NAS 5	1.200	10179	R1-40-68/26	Medium	14	0.82	High	13
L3106	NAS 1	0.800	3024	R1-40-70/26	Medium	15	1.51	High	2
L3408	NAS 2	1.410	3311	R1-41-67/25	Medium	16	0.39	Medium	34

106	NAS 13	1.200	8369	R1-41-73/27	Medium	17	0.76	High	15
L3408	NAS 1	1.500	3311	R1-41-77/25	Medium	18	0.74	Medium	17
SR206	NAS 1	1.300	11799	R1-41-79/26	Medium	19	0.21	Low	41
SR206	NAS 10	1.050	11799	R1-41-80/27	Medium	20	0.40	Medium	33
SR206	NAS 7	1.100	11799	R1-42-50/20	Medium	21	0.21	Low	42
SR2	NAS 3	0.950	4247	R1-42-63/27	Medium	22	0.27	Medium	38
106	NAS 9	1.000	8369	R1-42-68/29	Medium	23	1.05	High	6
L3106	NAS 4	1.250	1783	R1-42-73/25	Medium	24	0.41	Medium	31
106	NAS 12	1.100	8369	R1-43-71/27	Medium	25	0.83	High	11
106	NAS 15	0.900	8369	R1-43-74/28	Medium	26	0.36	Medium	36
SR2	NAS 9	0.750	12395	R1-43-74/26	Medium	27	0.41	Medium	30
SR206	NAS 2	1.350	11799	R1-44-55/20	Medium	28	0.14	Low	47
SR2	NAS 4	1.150	4247	R1-44-70/26	Medium	29	0.34	Medium	37
B38	NAS 9	1.190	12021	R1-44-73/25	Medium	30	0.51	Medium	23
SR206	NAS 12	1.100	15335	R1-44-84/25	Medium	31	0.39	Medium	35
SR2	NAS 5	1.000	4247	R1-45-76/26	Medium	32	0.52	Medium	22
SR206	NAS 9	1.000	11799	R1-46-73/27	Medium	33	0.09	Low	49
SR2	NAS 7	0.900	4247	R1-46-74/26	Medium	34	0.00	Low	52
SR206	NAS 4	1.000	11799	R1-46-93/18	Medium	35	0.23	Low	39
106	NAS 1	1.000	8369	R1-47-82/22	Medium	36	0.46	Medium	28
106	NAS 8	1.100	8369	R1-47-87/22	Medium	37	0.54	Medium	21
SR2	NAS 1	1.200	4247	R1-47-92/18	Medium	38	0.11	Low	48
B38	NAS 3	1.000	11078	R1-64-93/14	Medium	39	0.49	Medium	24
L3106	NAS 2	0.800	3024	Y4-42-71/25	Medium	40	0.00	Low	53
SR206	NAS 6	1.100	11799	Y4-43-76/27	Medium	41	0.00	Low	54
106	NAS 3	1.300	8369	Y4-45-74/26	Medium	42	0.76	High	16
B38	NAS 7	1.100	10732	Y4-46-81/25	Medium	43	0.46	Medium	27
B38	NAS 1	1.300	7068	Y4-47-81/23	Medium	44	0.20	Medium	44
L3106	NAS 5	1.050	2922	Y4-47-84/22	Medium	45	0.60	Medium	19
SR206	NAS 13	1.200	15335	Y4-47-94/16	Medium	46	0.18	Low	45
SR206	NAS 3	0.950	11799	Y4-48-90/20	Medium	47	0.00	Low	51
106	NAS 11	0.800	8369	Y3-52-73/22	Low	48	0.41	Medium	32
106	NAS 4	1.200	8369	Y3-53-93/17	Low	49	0.22	Low	40
B38	NAS 8	0.700	11377	Y3-57-79/21	Low	50	1.03	High	7
B38	NAS 2	1.200	8058	Y3-58-75/20	Low	51	0.47	Medium	25
106	NAS 5	0.700	8369	Y1-61-94/14	Low	52	0.47	Medium	26
SR206	NAS 11	1.150	15335	G4-100-100/00	Low	53	0.03	Low	50
SR206	NAS 8	1.000	11799	G4-100-100/00	Low	54	0.14	Low	46

*[acc./(km·Mvehicles·year)]

The same statistic tests applied for the single stretches, have been also considered for all NASs. The outcomes from the statistical analysis are:

- Freeman-Halton extension of Fisher's test: p-value significance of $0.004 < 0.05$, thus the null hypothesis that the variables assume these risk level by chance, can be rejected;
- Kendall'W of 0.78, with a p-value of $0.001 < 0.05$, thus the null hypothesis that the variables assume this ranking by chance, can be rejected;

The larger dataset (compared to those of each stretch) allows for more reliable statistics analysis. All the statistics confirm a good correspondence, and the null hypothesis can be rejected for all the statistics.

Moreover, the thresholds values of accident rate risk levels are different from those of the single road stretches, and because of the larger sample used they can be expected to be more reliable (however, this cannot be stated with certainty). One example are the risk levels of SR206's sections. Considering the whole dataset, SR206 has no more accident-based high risk sections.

Considering much "stable" and uniform risk thresholds, allows for the definition of common risk intervals. Therefore, it is possible to build the contingency table for risk levels comparison, which is shown in Table 7.8. The greater the values on the matrix diagonal, the better the correspondence between the two classifications. From the table it can be observed a very good correspondence of the medium levels and a good correspondence of the high levels. Moreover, Table 7.8 also shows that medium and high levels are far more than the low levels. This is because in Step 1 of the procedure the PCLs have been evaluated and in Step 2 only the most critical have been chosen to become CHLs.

Table 7.8 – Contingency table, all NASs

Contingency Table		Accident Rate				
		Low	**Medium**	**High**	**Tot.**	**Tot. [%]**
HFE Procedure	**Low**	3	3	1	**7**	**13%**
	Medium	11	19	6	**36**	**67%**
	High	0	3	8	**11**	**20%**
	Tot. [-]	**14**	**25**	**15**	**54**	**100%**
	Tot. [%]	**26%**	**46%**	**28%**	**100%**	

The contingency table leads to the cited result of the Freeman-Halton extension of Fisher's test p-value of $0.004 < 0.05$, thus the null hypothesis that the variables assume these risk level by chance, can be rejected. Table 7.9 shows the percentage of concordance for each risk level considering the ratio between the number of NASs classified with the same risk level within the results of the HFE procedure (second column of the table) and the accident rate procedure (third column of the table). The overall concordance is 56%. The results shows that a better correspondence is present considering high risk level (as also visible in Table 7.7). It must be also noted that only in one NAS the difference among the results is of "two levels", that means that the section is classified as high risk for one index and as low risk for the other. In all other cases if the risk level is not the same, is the immediately preceding one (or immediately following one). Indeed, while considering only "sections that require intervention", which are the high risk level sections, and "section that do not require intervention", which are the low and medium risk sections, the correspondence is of 81%.

Table 7.9 – Percentage of concordance for each risk level considering the number of NAS of the same level

	Percentage on the total of NAS of	
Risk level	**the same RC risk level**	**the same Acc. Rate risk level**
Low	43%	21%
Medium	53%	76%
High	73%	53%

Despite an overall good concordance between the results, some sections shown a high difference in the evaluation. Those sections may differ from those analyzed while considering each stretch separately. Thus, a detailed analysis of those sections must be carried out to understand if the different results may have been occurred by chance, or because the HFE procedure cannot identify some issues (or may have identified more than those present).

As previously discussed (7.1.1), if the difference between sections classification is between low and medium, this difference it is not much relevant. However, if the difference includes one high risk level sections, this specific situation must be addressed.

The NASs that shown some great differences and include one high risk level section for one index, are:

- NAS 1 from L3106 (high level for accident rate classification, medium level for HFE procedure);
- NAS 9 and NAS 12 from 106 (high level for accident rate classification, medium level for HFE procedure);
- NAS 8 from B38 (low level for HFE procedure, high level for accident rate classification).

The most relevant of these NASs are deeply described and analyzed in APPENDIX 11.

Finally, a regression analysis of RC values vs. accident rate has been performed to test the existence also of a numerical correlation. Because RC is a qualitative variable, it has been translated in number considering the different combination of the first part of the RC as number (see Table 7.10). The used scale is linear and the difference between each different RC has been set to 1.

Table 7.10 – Relationship between the RC index and the value considered for the regression analysis

Code	Associated value
R4	8
R3	7
R2	6
R1	5
Y4	4
Y3	3
Y2	2
Y1	1
Z4	0

Looking at the distribution of the points in a scatter plot (see Figure 7.1), it has been decided to evaluate if a linear correlation was present. The results are presented in Figure 7.1.

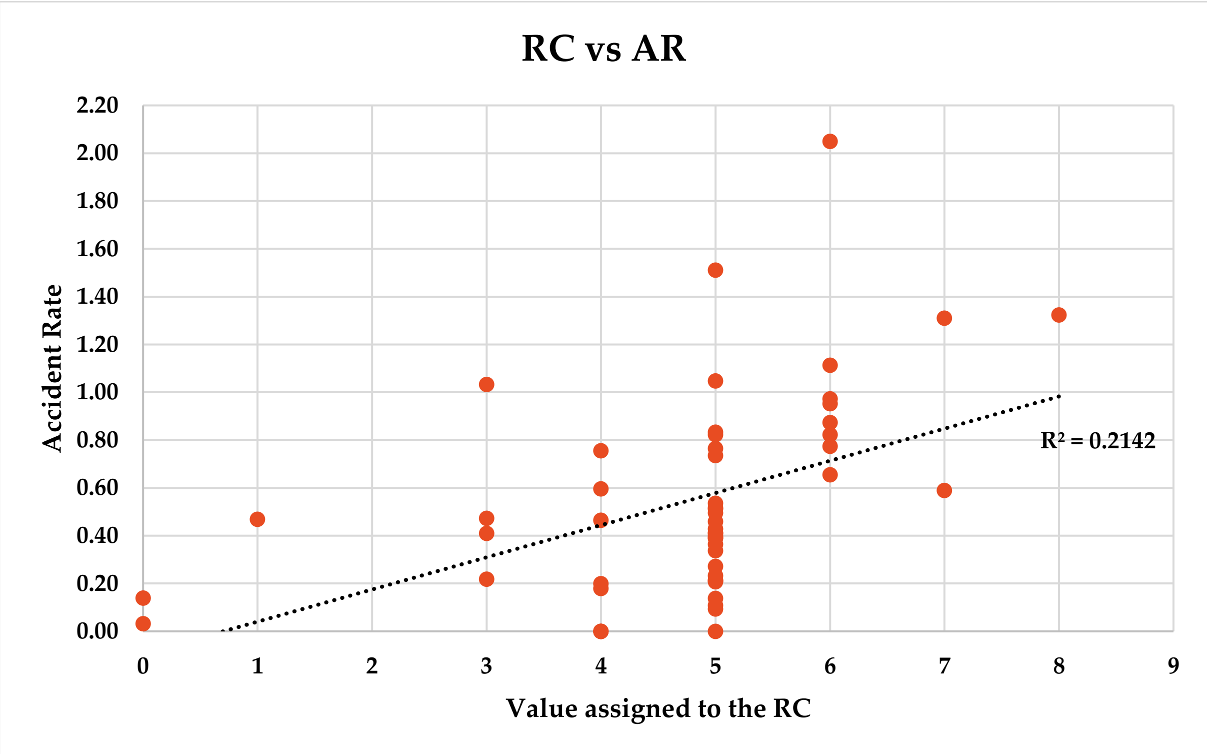

Figure 7.1 – Distribution and linear correlation between values assigned to the RC and accident rate values.

The results show a low correlation when all the NASs are considered. However, some interesting distribution of the results can be observed. The most varying results are linked to the value "5", corresponding to RC = R1. Such RC means that one of the rules present some major problems that need attention, but the other aspects are quite good. Such RC identifies a medium risk level. Because of the structure of the procedure that gives more weight to the worst situation, such results can be expected as collateral drawbacks, because in the R1 sections it is possible to expect a high variance of accidents: the critical issue identified may cause some accidents, but if many other aspects are good, it is possible to also expect a small number of accidents. This represent the central level of the RC: thus, as already stated, the procedure can clearly identify critical locations, and locations that are not critical at all, but it is not much precise in the intermediate level. The same can be say about accident-based performance measure because the intermediate level are those much sensitive to accidents variations over the different years of the analyzed period. So, it can be stated that in this higher variance around RC = R1, the two measures are in some way concordant.

The correlation is better (r = 0.86) while considering the average value of accident rate within each RC. The results are shown in Figure 7.2.

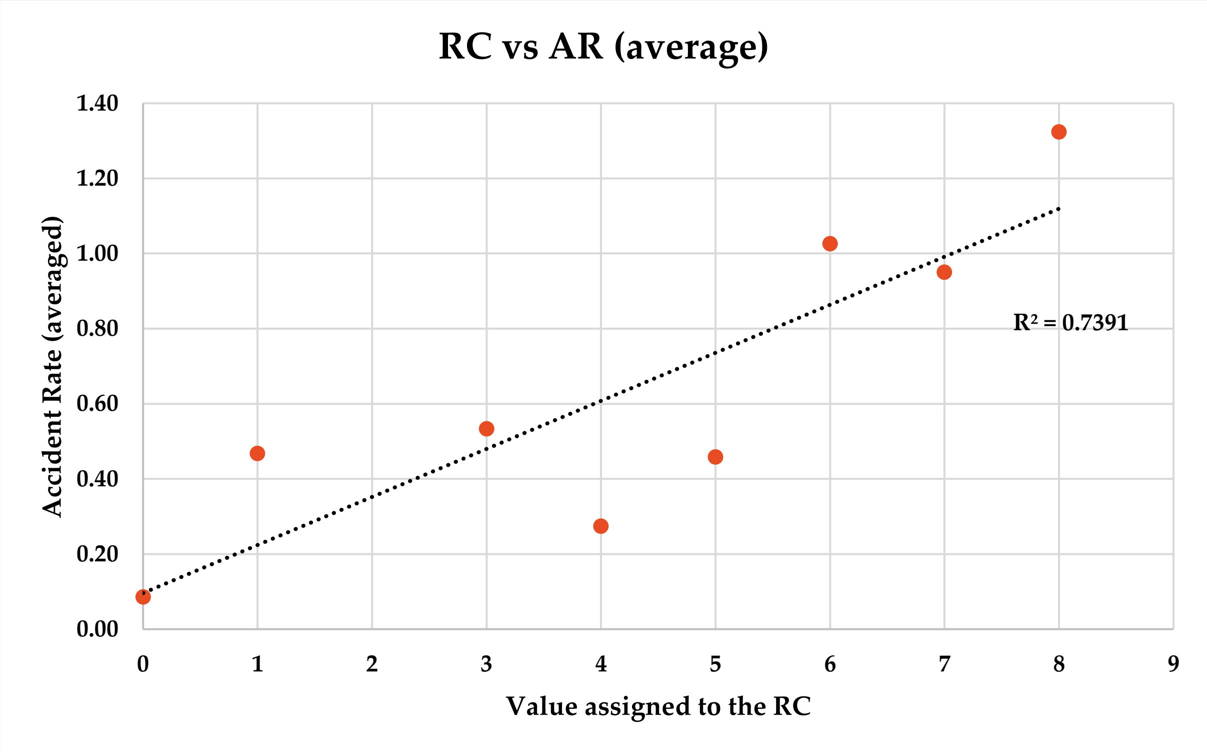

Figure 7.2 – Distribution and linear correlation between values assigned to the RC and accident rate values averaged within each RC.

This confirms the overall good prediction of the procedure. Nevertheless, additional analysis and evaluations (larger dataset) are suggested before defining a numerical relationship between the two variables.

7.2 Repeatability: comparison between the two applications on SR2

The repeatability of the procedure has been investigated too. The results from the application from Di Michele and Lanuza (Di Michele and Lanuza, 2022) demonstrates that even if applied by different inspectors, the HFE procedure leads to very similar results, which can be considered as "same" results if considering the network extension and the purpose of the procedure (definition of safety levels and ranking, and not calculation of specific values).

However, some weaknesses have also been identified, which should be managed. The main weaknesses identified are listed below.

a) Hard identification of urban areas to exclude from the analysis. Even if some references are provided concerning the density of PCLs in urban area (5.3.3) to define if they should be excluded from the analysis, some situations may be ambiguous and thus the choices from inspectors can be slightly different. This aspect must be deeply analyzed. However, thinking on the application of the HFE procedure by road agencies, some "helps" in defining the boundaries of the analysis will be provided, because road agencies have their own administrative boundaries on the road, which generally change while entering urban areas. Thus, some urban segments will be excluded in advance by road agencies.
b) Ambiguous difference between at-grade intersections and driveways. Sometimes the difference is obvious, but sometimes it is not and some carriageways that are classified as at-grade intersections, may have characteristics (functional and geometric) more like driveways. The description of the main characteristics considered to judge if the junction is a driveway or intersection, may allow a more homogeneous classification between different inspectors.
c) Identification of EXSEs. Identifying EXSEs is a crucial task. The second application of the procedure shows that when longer sections of road are considered, the PPI level can be ambiguous. Different evaluations of PPI, reflect in the evaluation of PCLs, both concerning GEXs and VISs. However, if an EXSE will be judged as "medium" PPI instead of "low", but the winding level is the same, the risk of missing information is moderate, and medium level CHLs are likely missed. On the opposite, if the PPI is judged as "low" instead of "medium", no information will be missed, but more CHLs will be identified with some additional computing time while applying the HFET.
d) Subjective judgments of PEX. Even if references and short checklists have been provided to evaluate PEXs, the judgments are still subjective, thus different results in the evaluation may occur. However, the procedure shown that those differences are few. Moreover, the choice of giving greater importance to the most critical result for evaluating HFESs and NASs, allow to reduce the error of PEXs judgements in Step 1. That is because very critical location for PEX will likely be identified by all inspectors. The main difference in the evaluations is related to "medium level" PCLs (by means of PEX), because they can be ambiguous, and the inspector cannot be sure if they must be selected or not. If the PCL is excluded because of low risk PEX, this will hardly translate in a wrong overall evaluation. Indeed, if the PCL is not promoted to a CHL, is because also GEX or VIS have been considered as low risk.
e) Semi-subjective judgments of VIS, if no visibility data are present. This type of error in the evaluation may occur when visibility data are not present, and inspectors must try to evaluate the visibility from design planimetry and satellite images. However, even this is the case, the error from VIS judging is generally very low.
f) The application of the updated version of the HFET by different inspectors may lead to some difference in judgments. However, looking at the results from the second

application of the procedure to the SR2, it appears that the use of guidelines greatly reduces the possibilities of different evaluations. Moreover, if minor differences are present, the global evaluation of a HFES, and even more of a NAS, seems to be robust against these differences.

g) Definition of NASs' length. The NASs' length may change according to the different length of the analyzed stretch, or because of different lengths and positions of the HFET. The first issue is related to the identification of the road stretch to be analyzed and is discussed in point a) of this list. The second issue is expected to not greatly modified the NAS length (difference within 200 m are acceptable). However, even if great differences occur, the structure of the procedure allows for partially account for those differences. A greater NAS length implies higher probability of including a HFES, which in turn implies higher probability of identifying some deficiencies by one of the rules or considering the Total HFS. Thus, longer NAS will likely be more critical than shorter one, notwithstanding that the compute of the RC give higher importance to very critical locations. This aspect is discussed deeply in 7.3.

h) Limited sample for the study. Despite the overall good results, additional tests should be made considering additional road stretches and additional inspectors' groups.

Overall, the comparison of the two applications, also analyzing the outcomes from each single steps of the procedure are good and very encouraging.

7.3 Consistency: changing the network assessment sections' length

The consistency of the procedure has been already indirectly discussed in 7.2. Anyhow, one aspect must be deeply analyzed, which answer to the question: will the results change if a different reference length for NAS is chosen? This aspect requires additional consideration because, while the other steps of the procedure, and the RC calculation are fixed, the NASs' length is up to the road agencies. The outcomes from this research suggest a fixed length of 1 km, but it is necessary to also consider the possibility to adapt this choice to specific circumstances.

In addition to the comparison of the two applications of the procedure on SR2, one additional evaluation is considered: the application of the procedure considering NASs of different length. Thus, only the reference segmentation has been changed in Step 3 of the procedure. Two different segmentations are proposed: considering a fixed length of 2 km and considering variable length. The second choice was made according to traffic variations. This new application was made both on SR2 and B38 stretches.

Table 7.11 and Table 7.12 shows the RC and the characteristics of the SR2 NASs obtained considering respectively a segmentation of 2 km and a segmentation based on traffic characteristics (when the AADT changes, another segment is defined). The results are graphically represented in Figure 7.3.

Table 7.11 – Outcome from the application of the HFE procedure to the SR2 stretch (NAS of 2 km)

NAS ID	Start [km]	End [km]	Length [km]	RC	Risk Level	Ranking
NAS 1	0.000	1.200	1.200	R1-47-92/18	Medium	6
NAS 2	1.200	3.150	1.950	R4-34-51/25	Very High	1
NAS 3	3.150	5.250	2.100	R1-42-67/27	Medium	4
NAS 4	5.250	7.500	2.250	R2-40-69/28	High	3
NAS 5	7.500	8.400	0.900	R1-46-74/26	Medium	5
NAS 6	9.250	11.600	2.350	R3-40-75/28	High	2

Table 7.12 – Outcome from the application of the HFE procedure to the SR2 stretch (NAS based on traffic)

NAS ID	Start [km]	End [km]	Length [km]	RC	Risk Level	Ranking
NAS 1	0.000	8.400	8.400	R4-34-68/29	Very High	1
NAS 2	9.350	11.600	2.250	R3-40-74/28	High	2

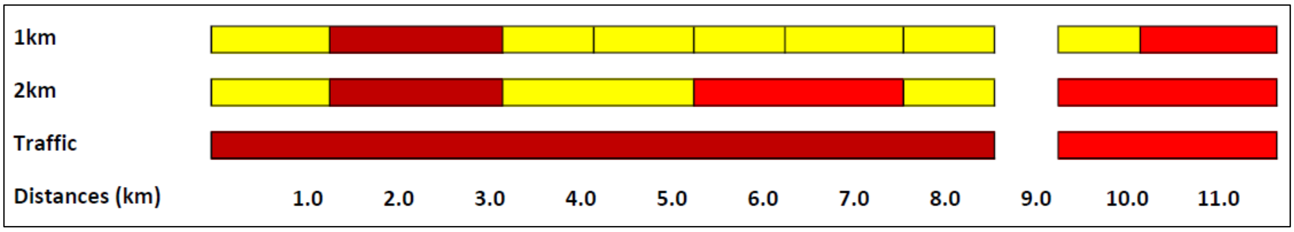

Figure 7.3 – Graphical representation of the risk level obtained for each NAS for each different NAS segmentation, SR2

Table 7.13 and Table 7.14 shows instead the RC and the characteristics of the B38 NASs obtained considering respectively a segmentation of 2 km and a segmentation based on traffic characteristics (when the AADT changes, another segment is defined). The results are graphically represented in Figure 7.4.

Table 7.13 – Outcome from the application of the HFE procedure to the B38 stretch (NAS of 2 km)

NAS ID	Start [km]	End [km]	Length [km]	RC	Risk Level	Ranking
NAS 1	0.000	1.200	1.200	R1-47-92/18	Medium	6
NAS 2	1.200	3.150	1.950	R4-34-51/25	Very High	1
NAS 3	3.150	5.250	2.100	R1-42-67/27	Medium	4
NAS 4	5.250	7.500	2.250	R2-40-69/28	High	3
NAS 5	7.500	8.400	0.900	R1-46-74/26	Medium	5
NAS 6	9.250	11.600	2.350	R3-40-75/28	High	2

Table 7.14 – Outcome from the application of the HFE procedure to the B38 stretch (NAS based on traffic)

NAS ID	Start [km]	End [km]	Length [km]	RC	Risk Level	Ranking
NAS 1	0.000	8.400	8.400	R4-34-68/29	Very High	1
NAS 2	9.350	11.600	2.250	R3-40-74/28	High	2

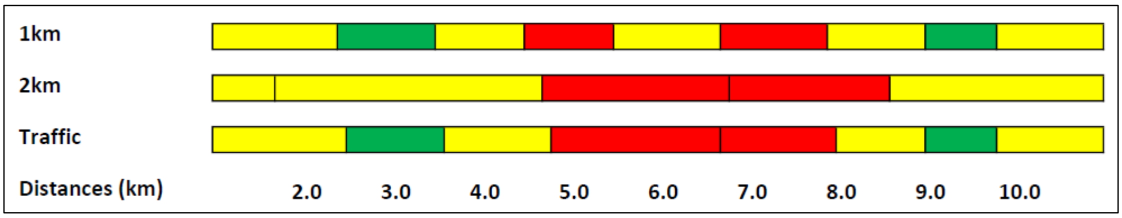

Figure 7.4 – Graphical representation of the risk level obtained for each NAS for each different NAS segmentation, B38

Looking at the results, the following considerations can be made.

a) HFESs containing intersections where a change in traffic is present have been included wholly within the same NAS, thus for a very short segment close to the intersection the traffic of the NAS assumes a different value.
b) NAS length is related to the HFESs. Sometimes it is not easy to define short sections (e.g., 1 km), and sometimes it is not easy to define long sections (e.g., 2 km). For this reason, the results should be consistent even if sometimes NASs have a length that differ much from the reference one.
c) When a lack of traffic data is present, NAS defined considering traffic, may become very long, missing much of their significance. This is the case of SR2. In this case, even if traffic is chosen as a reference for NAS segmentation, it is suggested to consider a maximum section length (2 km seems a good choice).
d) It has been confirmed that longer NASs are likely classified as riskier than shorter NASs, because they may include more “red results” (high risk) from the HFESs.
e) The presence of high risk HFESs is never hide, because of the choice of considering the worst result. If a longer NAS is taken, it will be judged as the most critical results within. This is very important, otherwise some risky sections could be underestimated.

Because of this analysis, it can be stated that the procedure maintains its consistency even when considering different NAS segmentation when considering the capacity of identify the most critical section of the road. On the other hand, when very long sections are considered, the risk is present of section risk overestimation, thus reducing the consistency about the overall judgment.

For these reasons, it is also confirmed the suggestions of making fixed length sections of no more than 2 km (1 km would probably be the best solution).

7.4 Applicability of the Human Factors Evaluation (HFE) procedure

The HFE procedure demonstrates to be a useful instrument for road safety analysis in network-wide road safety assessments (NWRSAs). This instrument also carries an added value because it allows the evaluation of road safety aspects related to Human Factors. After the evaluation of its effectiveness, repeatability, and consistency, it is essential to evaluate its applicability by road agencies. A further advantage is, that the implementation of the HFE procedure doesn't require specific road data, thus it can be immediately applied to all existing rural highways. This makes it suitable also for implementation in low- and medium-income countries, where often a lack of data is present. On the other hand, the inspectors have to be trained in understanding and applying the tool (as it is also necessary in other analysis procedures like RSIs and accident analysis). But the training will not be critical for road agencies, as demonstrated in the two-days training course of the two inspectors that analyzed the SR2 stretch for the second application of the procedure.

Concerning the application of the HFET, the updated version is more clear and easily applicable. However, additional improvements can be made. During the development of this work, it emerges that some aspects are much more critical than others, and this should reflect more in the HFET.

Considering the definition of risk code (RC), the choice of giving more weight to the worst results, but also creating an algorithm that partially accounts for the number of the critical locations, has been proven to be a right choice.

Lastly, it has to be discussed if also traffic data should be included. This may be done by qualitative analysis or quantitative data. Evaluating the high priority sections of a road where countermeasures must be taken immediately, the traffic density could be crucial because traffic is one of the most influencing variables in accident number.

It obvious that the developed procedure will get some refinements and improvements and maybe also simplification in the future with additional applications, but it is right now ready to be used in practice.

Some considerations can also be made considering the time required to improve the HFE procedure to all the stretches, both considering implementing the Step 1 (first screening) and without its implementation (evaluating all the PCLs). Table 7.15 shows the length of each analyzed stretch, the number of total PCLs and identified CLs belonging to each stretch, their density, and the reduction percentage, which is the rate between the number of CLs and the number of PCLs.

Table 7.15 – Number of PCLs, CHLs, and density considering stretches' length

	Length [km]	Number of PCLs	Number of PCLs/km	Number of CHLs	Number of CHLs/km	Reduction rate [%]
SR2	10.65	161	15.1	61	5.7	62%
SR206	14.60	94	6.4	32	2.2	66%
B38	10.89	30	2.8	19	1.7	37%
L3106	6.39	64	10.0	29	4.5	55%
L3408	2.91	35	12.0	14	4.8	60%
106	16.00	123	7.7	47	2.9	62%
All roads	**61.44**	**507**	**8.3**	**202**	**3.3**	**60%**
Average	**10.20**	**85**	**9.0**	**34**	**3.7**	**57%**

The observed reduction in the number of PCLs is about 60% on average. Considering the density of PCLs/km it is of 9.0 on average, while the density of CHLs/km is only of 3.7 on average. Thus, considering the single km, 5.3 PCLs are not analyzed with the new developed procedure on average.

Based on these results it is possible to estimate the time required to carry out the procedure considering one km of road. Table 7.16 show the results for the estimation. For one road km, it can be expected to take half an hour for the implementation of the first step. This time is largely regained because you can select out of the total number of PCLs, a lower number of CHLs that have to be analyzed. Considering an average application time of the HFET for each CHLs of about 20 minutes, the saved time is about 80 minutes for each km, which is about 40% less, than the procedure without step 1.

The results of Table 7.16 also offer the possibility to estimate the time required for the analysis of a network. Considering a network of about 1000 km, it will take 1900 hours to analyze it with the HFE procedure. 1900 hours are about 240 working days (48 weeks), that is about one year of work. In one year, a network of 1000 km can be analyzed, and such an analysis is not required every year, but only if some change in the roads occurred or after many years (5 years are suggested). So, if the procedure once is done and implemented, the follow up efforts will decrease dramatically. This effect could be also very efficient if some part of the procedure can be programmed using A.I. procedures. This is the work for the future that must be done.

Table 7.16 – Expected time required to carry out each step of the procedure, considering applying or not the first step (please note that 0.5 hour = 30 min)

	With Step 1 [h/km]	Without Step 1 [h/km]
Step 1	0.5	0.0
Step 2	1.2	3.0
Step 3	0.2	0.2
Total	**1.9**	**3.2**

CHAPTER 8 CONCLUSIONS

Chapter list of acronyms

CHL	Challenging Location
HFE	Human Factors Evaluation
HFES	Human Factors Evaluation Segment
HFET	Human Factors Evaluation Tool
HFS	Human Factors Score
NAS	Network Assessment Section
NWRSA	Network-wide Road safety Assessment
PCL	Potentially Critical Location
RC	Risk Code
RSI	Road Safety Inspection

8.1 The objectives have been achieved

The main purpose of this work was to develop and validate a network-wide road safety assessment procedure based on Human Factors. Moreover the procedure should include visual inspections of the road, it should be a pro-active procedure, and it should provide at least three level of risk (European Parliament and the Council, 2019).

All these objectives have been achieved. Table 8.1 shows a summary of the main objectives and the sub-objectives, the consequent requirements, and the solutions.

Table 8.1 – Summary of primary objectives, secondary objectives, requirements, and solution implemented in this research

Main objectives	Sub-objective	Requirements	Solution implemented
NWRSA procedure	Provide a ranking	quantitative or qualitative values for ranking	Development of the RC, which allows to rank the NASs with 4 levels of risk
		Segmentation of road stretches	Double segmentation: one for the analysis, and one for the synthesis of the results. NASs should be 1 km long.
	Applicable on a large scale	Less requirements of data	The required data can be obtained by fast on-field inspection (it doesn't need exact measures)
		Efficiency in time and effort	Selection of CHLs out of PCLs allows a great reduction in application time. In average about 2 hours/km are needed.
			Review of the HFET, implementation of automated digital sheets for evaluation, definition of the HFET Guideline
	Practicability of results	Practical segmentation for efficient work of road agencies	Double segmentation: one for the analysis, and one for the synthesis of the results. NASs should be 1 km long.

Based on Human Factors	Include the HFET	Adjustment of HFET	Review of the HFET, implementation of automated digital sheets for evaluation, definition of the HFET Guideline
		Definition of a step by step procedure	Definition of three steps: 1. preparing the data, 2. application of the tool, 3. calculate results for the NWRSA
		Consistency of judgments by different inspectors	Development and application of a two-days training course on the basis of automated digital sheets and HFET Guideline
		Reliability	Consistency in the first and second application of the tool. Consistency of 56%-81% between risk code and accident rate.
		Weighting the results of the Human Factors sub-scores	The final RC weights the results obtained for all the Human Factors sub-scores
Include visual inspection	Use of the HFET	See previous	See previous
Proactive procedure	No need of accident data	Do not need accident data	The procedure does not need accident data to be implemented
At least three level of risk	Provide risk levels	Quantification of risk levels	Definition of four risk levels for NAS: low, medium, high, and very high. The former two mean that an intervention is not required in short times. The last two mean that an intervention is required in short times.
Test of the procedure	Reliability of the results	Results from application must highlight real dangerous locations	In 81% of analyzed NAS, HFE procedure and accident-based analysis identified the same NAS upon which intervention is needed or not needed.
	Repeatability	Different inspection teams must obtain the same results (on the same road)	A different inspection team apply the procedure on the same stretch of SR2. The results are the same. The intermediate results are consistent.
	Consistency in different segmentation	Results must not change considering different NAS segmentation	NAS always provides the worst result. The procedure is consistent. To lose no information about specific locations, it has been found that a segmentation of 1 km is the best option.

8.2 Reasons to implement the procedure

The reasons for a road agency to implement the procedure and for researchers to work on its improvements are many.

First, **it provides a validated instrument that analyzes the road by means of Human Factors**. Such an instrument is innovative and highly required because most of the accidents occurred because of human errors induced by the road.

It has been found that **it has a high capacity to identify dangerous locations**. The comparison with accident-based analysis shows a good statistics correspondence between the results. An average of 56% of NAS have been considered with the same risk level for both the analysis. Considering the identification of sections which require intervention (high risk) and sections which do not require intervention (low and medium risk), the concordance rise at 81%. Overall, statistic analyses also prove that such concordance is not by chance but significant.

This procedure **overcomes many of the segmentation issues** that always burdened road safety analysis. Those issues are very common in standard RSIs analysis and accident-based analysis. This has been done considering different segmentation for different levels and mainly considering the definition of segments after the identification of the points to be analyzed (i.e., CHLs).

It is a pro-active procedure because accident data are not required. Thus, it can be applied to those road stretches for which no accident data are available: new roads, poor accident data. So it can be also included in Road Safety Audits.

It provides information about the risks of the road, aiding in the decision of possible interventions. Procedures which are only based on the number of accidents, lack such information. Moreover, the defined RC allows the synthesis of the four different results (HFSs) provided by the application of the HFET.

It doesn't need much data and the ones needed can be easily found. The main amount of data required by the procedure is the list of the PCLs along the network that must be analyzed. However, once the list is made for the first time, it only needs further possible updates, and do not need to be made once more. Furthermore, such a list is useful also for many other road applications. Data on geometry is also necessary, but the level of detail is such, that it can be also obtained from satellite view analysis. Therefore, the procedure can be easily implemented also in low- and medium-income countries.

It allows the definition of intervention priority. The calculated RC allows to identify four levels of risk and to order the NAS within those levels from the most critical to the less critical. This allows road agencies to define where and how to primarily intervene.

It provides a quantification of the risk of the road for the single road user. Such a characteristic is crucial for road engineers. The influence of traffic on the number of accidents is crucial too, but the two measures must be both provided: the dangerous of the road stretch for the single users, and the total risk considering also the exposure (traffic).

It proves to be repeatable and easy to be implemented after short training courses. This has been proven by the application of the procedure from a different inspection team that was trained about Human Factors principles. The training course was a two-days course. The definition of the guideline for the use of the HFET (see APPENDIX 1) provide a fundamental instrument to achieve greater homogeneity of judgments.

The time required to implement the procedure is short considering its usefulness upon several years. It has been estimated that 2 hours per km are necessary to implement the procedure. This suggest that about one year of work (8 hours per day and five days per week) is necessary to analyze a road network of two-lane two-way rural roads of 1000 km. The amount of time is huge, but it becomes very short when considering that this procedure must be carried out only once. Then the results should be only updated when some changes in the road occur. However, to account for possible changes also in the environment around the road, it is suggested to make the evaluation once every 5 years. This will not be a problem for road agencies.

Of course, this work leaves some questions opens and additional efforts should be made to enhance even more the HFE procedure. Specific limitations were discussed within this work when the specific topic they referred to was addressed. However, at least five main possible remarks may be made by the reader and thus a detailed answer must be provided to those remarks.

The **first possible remark** concerns the implementation of the procedure on a limited number of road stretches. Even if the analysis of the about 62 km provides good results, a wider application should be considered to clearly prove the effectiveness and reliability of the procedure. This work provides a first important contribution, but the HFE procedure should be applied to a whole network to have complete feedback about its effectiveness (and not only considering its reliability to identify risky location, but also how much practice could be its application and the management of the results).

The **second remark** is that the procedure must be tested strongly against inspector subjective judgments. Also in this case, this research provides a first important step in that direction, but to be sure about the reliability and repeatability of the procedure, more inspectors should apply it to the same road (and also to other), and the judgments results should be compared.

The **third remark** concern the target of the procedure. Indeed, it must be remembered that this procedure focuses on the identification of road stretches that are prone to cause accidents, thus it identifies those points of the road where an accident can likely occur. It doesn't consider the consequence of an accident; hence, it doesn't consider the severity of an accident. For this reason, in order to have a comprehensive analysis of all the safety aspect of the road, this procedure should be complementary to some other which are able to identify the how severe could be the possible outcome. Nevertheless, it is necessary to underline that this is not a limitation of the procedure, because it is of a great use to have the possibility of identifying only the possibility of accidents occurrence, separated from the severity. Indeed, a road segment where many accidents occurred, even if with low severity, need to be improved, because accidents bring damage to things and people, and because one day one of those accidents can be more severe.

The **fourth remark** is that the HFE procedure doesn't account for the influence of traffic. As already stated, this is not a limit, but another index could be developed, which adds traffic data to the result of the procedure. Traffic is often the most relevant variable that determines the accidents number: the greater the traffic, the higher the possibility of an accident. The HFE procedure has been developed to analyze the safety level of a road without considering traffic exposure. The results from the procedure identify the risk of a single vehicle driving along the road to incur into an accident because road-induced driver behavior doesn't comply with the road characteristics. This value of risk is fixed for a specific road stretch, based on its characteristics. This information is crucial for road engineers.

Instead, the number of accidents often increases as the traffic increases. It must also be stated that considering traffic is also important because sometimes it may also happen that a higher volume of traffic may influence the risk of the road. That is, perception of the road is greatly increased when drivers can see a vehicle travelling the road in front of them. That vehicle become the main reference for their driving and, overall, most of the factors influencing the driver perception of the road reduce their influence. Of course, the first car of a possible queue, is still totally influenced from the road and its environment, but the relationship between the traffic and risk of an accident change (because the following cars may have the heading car as a guide). For all these reasons, traffic should be considered for further research. The procedure should still provide a result considering the risk of a road stretch driven by a single vehicle but may also provide a result that also considers the traffic influence. This is essential to improve even more the reliability of the procedure as an instrument to be used by road agencies. This last consideration also suggest that the procedure allow for a better reliability of low volume roads, than high volume roads. This study clearly demonstrates that a high concordance is present between Human Factors deficiencies and number of accidents for road with a low to medium level of traffic.

The **fifth and last remark** concerns the resources necessary to carry out the procedure on a network range. The application of the procedure requires time and trained inspectors. Fast analyses that consider only observed accidents are easier to be implemented. This point has already been presented, but additional considerations should be made.

1. Accident data are not easy to be obtained and they must be carefully reported to improve reliable analysis.
2. Accounting also for the accident report phase, the resource needed greatly increase also for accident-based analysis.
3. RSIs are now periodically required in many countries for the analysis of the safety level and maintenance level that can influence safety in the main road network (i.e., motorway and relevant highway). The HFE procedure can be easily implemented during a standard RSI procedure and its results included in a NWRSA.
4. Inspectors' training courses last about 2 days, which is in line with other training courses for safety analysis procedures.
5. More detailed road analyses (such as RSI) are time expending, but they are necessary to implement a proactive safety management system. Relying on reactive mechanical procedures based on accident data could help find some critical locations, but on the

opposite could ignore hazardous locations which can later become critical location, with a cost that nowadays is no more sustainable in term of road death and injuries.

6. Detailed inspections give an added value, which is the survey of the road by safety experts, which cannot be replaced by a standardized mechanical procedure that input data in a formula which provide a result. Inspector visual analysis allows to identify specific problems related to the site that otherwise will likely be not considered. Road surveys are time expending and resource expending but are mandatory to achieve the goal of a safe road system.
7. The HFE procedure does not need to be implemented every year. Once a road stretch has been evaluated, it doesn't need any additional evaluation (neither inspection) unless something in the road is changed (and considering that standard road maintenance is carried out). For this reason, the application of the HFE procedure to the whole network may require many resources for its first application, but then the required resources will decrease. On the other hand, classifications based on accidents data should be updated every year.

8.2.1 Human factors and automated driving

As highlighted, the procedure developed in this work is proposed as a tool to analyze all those aspects related to the interaction between man and the road, that is, those aspects that are at the basis of the triggering of an accident. The fact that road accidents are almost entirely the result of human error, whether road-induced or not, is evident from the first moment in which cars began to circulate and therefore, both to improve the functionality of the roads and above all to reduce the number of accidents on our roads (and if possible cancel it), society, research and industry are trying to automate the driving processes, aiming at the use of Connected and Automated Vehicles (CAVs), in able to read and use the road perfectly. The achievement of the final stage of technological evolution of these vehicles and their complete diffusion would certainly eliminate the problems linked to the man-road relationship and probably would almost eliminate accidents. From this point of view, the procedure presented in this work appears anachronistic and potentially not useful for the future. The future just described here is, however, still a distant future, which can be glimpsed in flashes, but which is still more ideal than really concrete. Although the push for the development and introduction of CAVs is great, it will still take a few decades before all vehicles on the road are CAVs of a sufficiently advanced level of technology to completely exclude the need for a driver. In all this time, road safety cannot remain immobile. Furthermore, the knowledge of the perceptual aspects that regulate the driver's behavior on the road is an indispensable tool precisely to better manage that transitional period necessary between the current state and the condition of complete use of the CAVs. In fact, there will be a long period in which standard vehicles, driven by people, will have to stay on the road together with automatic vehicles, and it will be essential to understand how the drivers will behave. Finally, the process of adaptation to automatic vehicles includes adaptation of our roads. On the one hand roads need to be adapted to the needs of CAVs, but on the other hand, in order to have a safe transitional period, it is necessary to keep in mind all those aspects that are the basis of the generation of accidents and that have been analyzed in this text. The procedure presented here is therefore not anachronistic and on the contrary, the aspects considered must be of reference even in the transitional period in which our roads will have to be adapted to allow the complete use of self-driving vehicles.

After a sufficient number of CAVs will have started circulating on our roads, thus when some observations are available on the interaction within CAVs and drivers, then this procedure will be updated, also considering the influence of CAVs and the possible modification to the road required for CAVs introduction.

8.3 Additional added values provided by this research

To achieve the objectives listed previously, some analyses have been carried out and solutions have been adopted. Some of these provide a contribution to the field of research also outside the procedure. The main relevant among them are here listed.

- **The expectation-based theory**. The literature analysis of risk theories, perceptual factors, and driving task analysis, allow to identify expectations as the most relevant influencing factors in road perception and driving behaviour. For this reason, the concepts of expectations have been deepened, providing an expectation-based theory which synthetize many of the theories already present in literature. Moreover, the concepts of punctual expectations, general expectations, and visibility (related to expectations) have been introduced. Those concepts help to schematize both temporal and logical different phases of driving, and how driver manage to change their behaviour when needed.
- **The translation of expectations concepts into engineering parameters**. An analysis process has been developed which allow to assign a risk level to the above explained concepts of general expectations, punctual expectations, and visibility. This level is based on the road and the road environment characteristics. It mainly focuses on single PCLs, which can be classified at different risk level considering all the cited aspects. The process is applied in the step 1 of the procedure to identify the CLs to be analyzed among all the PCLs.
- **Human Factors Evaluation Guideline has been developed**. The HFET can be used also as a standalone instrument to evaluate road safety, for example to analyze the accident causation at black spots. In both cases (used as a standalone instrument or within the procedure), to increase the homogeneity of judgements and to facilitate the work of inspectors, guidelines are mandatory with examples and detailed descriptions of the many requirements to be evaluated. PIARC didn't provide any guidelines, thus this first version of a guideline is also innovative.

8.4 Conclusive summary

This research demonstrates the importance and heavy weight of Human Factors in road safety. It is possible to include the analysis of Human Factors aspects into NWRSAs. This work seems to be the first of this kind. A structured methodological approach to analyze road network safety considering Human Factors aspects, was never tried before. Human Factors are crucial aspects to account for when analyzing driver behavior.

It also proves to be repeatable, and thus strong against subjectivity. Moreover, the developed procedure is a proactive procedure, which requires few input data and strictly follow the requirements of the new updated 2008/96/EU directive.

Road agencies should consider the use of this procedure for their network safety analysis and ranking (even just to test its effectiveness on their own network), not be discouraged by the apparent difficulty of its application. Road safety must become the priority of road agencies, together with road functionality. A safe road design must always consider that the main users of the road are drivers, and thus the road must be designed around them, and for them, accounting for all their limitations and qualities.

GLOSSARY

Some uncommon or specific terms are listed here together with their meaning to allow the reader an easier understanding. The list of acronyms used in each chapter is presented at the beginning of each chapter.

Term	Meaning
Behavioral Script:	are behavioral procedures or, simply, behaviors, which are consequences of the schemata.
Challenging location (CHL):	CHLs are PCLs that are not clearly perceived by the driver, because of some problems concerning VIS, GEXs, and/or PEXs. The consequence is that the driver doesn't change his driving program, or tries to change it too late, causing hazardous maneuvers. More precisely CHLs are PCLs that occurs surprisingly for the driver without sufficient TZ because it breaks the Human Factors demands of the driver (6-Second Rule, Field of View-Rule, Logic Rule).
Challenging transition (CHT):	is the area preceding and including the CHL. The preceding area is the TZ ahead of a challenging location.
Critical location (CRL):	any area where drivers must adapt their driving program by changing speed, braking, steering, or changing lanes. Normally they are junctions, intersections, stops of public transport, exits, driveways, curves, carriageway width reductions, or pedestrian/cyclist crossings.
Desired speed (V_{des}):	speed the driver tends to, under unconstraint condition.
Expectation section[22] (EXSE):	road section where the driver has specific similar driving demands like a curvy section with similar radius, an interurban section with a logical consistence of design elements and speed. At the same time the roadside gives the driver a consistent impression that contributes to an overall impression of the road section. So, the driver will build up subconsciously a specific expectation how the road alignment will develop and which driving program is appropriate.
Expected Speed (V_E)	Expected Speed has been introduced to provide a range of possible speeds for an EXSE. Based on the EXSE characteristics it is expected that drivers travelling the EXSE will hold a speed between the range of the V_E.
Eye-catching objects/elements:	similarly, but more influencing than fixation objects. Eye-catching objects attracts unconsciously driver's gaze because of their characteristics that make them easily distinguishable (e.g., high luminance contrast with the background, and lines' intersection points).

[22] It must be noted that expectations provided by the road and its environment can also change gradually, therefore identify a specific and well-defined "section", is a small forcing, which is necessary to identify a delimited part of the road where the same expectations characteristics are present. The point of sectioning must be decided by the inspector.

Field of View:	the visual area over which information can be extracted at a brief glance without deliberately eye or head movements. It decreases with age, most likely due to decrease in visual processing speed, reduced attentional resources, and less ability to ignore distracting information. The Field of View performance is correlated with several real-world functions including risk of an automobile crash.
Field-dependency:	degree to which human perception is dependent on the holistic perceptual field so that the performance of perception cannot be separated from the overall impression of the environment. Today psychological tests concerning field-dependency are used to select pilots that are able to separate the perception of their own position independently from the visual information they get.
Fixation objects/elements:	humans and many animals do not look at a scene in fixed steadiness. The eyes move around, locating attracting parts of the scenery. These parts are scanned frequently. This is the base for building up a mental, three-dimensional "map" of the scenery.
General Expectation (GEX):	Expectations the driver has about the road, derived from previous experience: both life experience (e.g., road type) and "last-km" experience (based on the characteristics of the last km of road travelled).
Gestalt:	perceptual impression ("figure") that is clearly distinguishable from the background of the whole scenery. The details of which are so integrated as to constitute a functional unit with properties not derivable by summation of its parts. Gestalt perception is a dynamic process. The result perceived depends on experiences, expectations, and individual preferences of an individual. So, the result what individuals "see" under same conditions might be very different.
Human Factor Evaluation Segment (HFES):	a sequence of consecutive and/or overlapping challenging transitions that are merged. This segment must be assessed in one application of the →Human Factors Evaluation Tool. It must be marked blue before the Evaluation. After the Evaluation was done it will be marked with the color of the achieved results. The name is HFES-SR2-N1.
Human/driver Behavior	The natural response of the driver to the road system under standard conditions. The driver behavior considered includes and *it* is influenced by the unconscious and automatic response to the road stimuli (e.g., road perception). Driver behavior is not the consequence of road perception alone.
Human Factors Score (HFS):	The result in percentage of the application of the Human Factors Evaluation Tool. It is called HFS both the results of the First, Second and Third Rule and the Total of all the Rules.
Human Factors Evaluation Tool (HFT):	A series of checklist presented by PIARC and improved in this work, which allow to evaluate the compliance of the road characteristics with the Human Factor demand.

Human Factors:	it is the generic term for those psychological and physiological patterns which are verified as contributing to operational errors in machine and vehicle handling. In the case of road safety, the Human Factors concept considers road features that influence driver's right or wrong driving activities. It considers the causes of driver operational error as the first step in a chain of actions which may proceed to an accident. Many of the often-observed operational errors result from the direct interaction between road characteristics and the driver's psychological and physiological limitations of information processing, learning and activity regulation. Worldwide literature refers to human factors as all the human limitations that influence driver's driving performances. In the context of this thesis, Human Factors will refer specifically to those standard and non-altered conditions common to all drivers which play a fundamental role in the driver-road interaction and will be written with first letters as capital letters. This means that altered condition such as the use of alcohol and drugs, handicaps, state of anxiety, etc. are not considered as Human Factors.
I Rule (6-Seconds Rule):	average drivers need 4–6 seconds to completely change their driving program. At a speed of 100 km/h this results in up to 300 m being travelled while the change is being made. A user-friendly road will allow an appropriate adjustment of driving actions to a new situation. It is necessary to arrange transition zones, remove visibility restrictions, to ensure visibility or use markings/advanced information and signage to indicate at least 6 seconds ahead critical locations such as junctions, curves, railway crossings, bus stops or bicycle paths.
II Rule (Field of View Rule):	motorized driving changes the field of view much more than any other movement. Monotonous or high-contrast periphery, optical misguidance and illusions affect the quality of driving. The field of view can either stabilize or destabilize drivers and can tire or stimulate them. Speed, lane keeping, and reliability of directions are functions of the quality of the → field of view.
III Rule (Logic Rule):	drivers follow the road with an expectation and orientation logic formed by their experience and recent perceptions from the last 5 minutes – 10 minutes. Unexpected abnormalities disturb a mostly automated chain of actions and may cause drivers to "stumble". Several critical seconds pass before the disturbance can be processed.
Inconspicuous Segment (INCS):	part of a road Section that is easy to drive and without any obvious design deficiencies or Human Factors deficiencies. It has not to be evaluated with the Human Factors Evaluation Tool.
Network Assessment Section (NAS):	Section considered to provide the result of the HFE procedure. The whole analyzed network will be divided in many NASs. NASs will be the element to which the road agency will refer to decide where to intervene. NASs may include many HFESs.
Network-wide Road Safety Assessment (NWRSA):	is reviewing a transportation network to identify sites based on the potential for reducing average crash frequency. This term has been introduced in the updated 2008/96/CE Directive (European Parliament and the Council, 2019). See also Network Safety Screening.
Optical density of the field of view:	Amount of color and brightness contrast that result in a sufficient or a poor optical flow. It influences the quality of driving. Driver's speed is a function of the number of objects/information that contrast with the background and the visible amount of road's surface.

Optical illusion:	the word illusion comes from the Latin verb illudere meaning, "to mock”. Illusions are the result of the complex information processing of the brain and the visual system that tricks us into perceiving something differently than it exists. So, what we see does not correspond to physical reality.
Punctual Expectation (PEX):	Expectations the driver has about the road, derived from contingent location: the punctual Road image (and the Gestalt), create specific expectation about the specific location.
Reaction time:	the delay between the presentation of a stimulus and the initiation of a response.
Risk Code (RC):	Code which resumes the outcomes of the application of the HFE procedure for each NAS.
Road agency:	Agency/administration/society that manages the road.
Road image:	how the road appears to the driver, and not how the road is. This concept is linked to the concept of Gestalt but means the objective visual image of the whole scenery.
Road Safety Inspection (RSI):	a systematic, on-site review, conducted by road safety expert(s), on an existing road or section of road to identify hazardous conditions, faults and deficiencies that may lead to serious accidents (PIARC, 2012a).
Safe Speed	Safe speed is when a vehicle travels under the threshold speed, under which the risk of an accident is acceptable, irrespective of the posted speed limit.
Schemata:	a general pattern of thoughts or behaviors that arranges acquired information and the relationships among them, limiting them to a predefined type of occurrences.
Section:	A part of a road of different length (generally more than 1 km), which is part of a stretch.
Segment:	A part of a road of short length (generally within 1 km), which is part of a section.
Stretch:	A part of a road of several kms.
Transition zone:	passage from a higher-speed road section to a lower-speed road section like the change from a rural road to a town or village streetscape. It allows the driver an appropriate adjustment of driving program to a new situation. It should give enough time for anticipation, driver’s decision, and braking maneuvers. The length depends on the kind of change, the weather conditions, and the driving speed. The more complex the scenery and demands the longer it must be. Start the transition about 10 sec. ahead of the challenging location.
Visibility (VIS):	When the VIS term is used, it means the available sight distance between the driver and the PCL, which allow the driver to see, perceive, and understand the PCL.

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APPENDIX 1 Human Factors Evaluation Tool Guideline

The Human Factors Evaluation Tool Guideline is provided as a standalone document at the following link:

https://drive.google.com/drive/folders/1DZRXweHiad3FDxpRhKumqj0EP-58RiVv.

The guideline also contains the description of the final version of the HFET. The digital version of the HFET (Excel file) is available at the same link of the guideline.

For additional information contact andrea.paliotto@unifi.it.

APPENDIX 2 The HSM procedure in the IHSDM-HSM Predictive Method software

The HSM provide an APM that already has an inherent transferability because of its structure based on three different main elements[23]: the SPF, which is the base-function and depends only on road segments main characteristics; the product of the CMFs that allow to take into account specific characteristic of a segment; the Calibration Factor (C) that has the function to adjust the model to take into account different conditions of the analyzed site from the ones on which the HSM predictive model has been implemented. The more information is accessible from the local database, the more reliable will be the prediction, but even in the absence of some specific segment characteristics data, such a structure allows to implement an APM. Eq. 18 shows the predictive model provided by the HSM, which is the same used in the IHSDM-HSM Predictive Method software:

$$N_p = N_{SPF} \times (CMF_1 \times .... \times CMF_m) \times C \qquad \text{Eq. 18}$$

Where:
N_p = predicted average crash frequency for a specific site;
N_{SPF} = predicted average crash frequency determined for the base conditions by means of the Safety Performance Function (SPF);
CMF_1 .... CMF_m = crash modification factors (that could be also derived from crash modification functions) accounting for specific site conditions (geometric design, traffic control features etc.);
C = calibration factor to adjust the SPF for local conditions related to the network. This accounts for all factors that are not considered by the safety prediction methodology itself (e.g. differences in climate, differences in driver populations and trip purposes, differences in road standards, etc.).

In HSM approach, a SPF is determined by means of a regression models developed from data for several similar sites with specific base conditions, i.e., geometric design and traffic control features. The SPF for rural two lanes two ways roads only depends on two exposure variables: AADT and segment length as shown by Eq. 19.

$$N_{spf,rs} = L \cdot \text{AADT} \cdot 365 \cdot 10^{-6} \cdot e^{-0.312} \qquad \text{Eq. 19}$$

[23] The assumption is to prior define the base conditions about geometric design, traffic control features etc.

CMFs are then used to account for differences between the base conditions and any specific site conditions as described in 2.3.2. The specific calculation of each used CMF is provided in AASHTO HSM (AASHTO, 2010).

After calculating the predicted number of accidents "NP" for the homogeneous roadway segment for all years of the before-period of time it must be calculated the overdispersion parameter "k" for the homogeneous roadway segment or intersection. For roadway segments "k" should be calculated from Eq. 20:

$$k = \frac{0.236}{L} \qquad \text{Eq. 20}$$

where:

k = overdispersion parameter associated with the roadway segment;

L = length of roadway segment (mi).

Then, the weight to be placed on the crash frequency predicted by the safety prediction methodology is calculated from Eq. 21:

$$w = \frac{1}{1 + k \times \sum_{1}^{n} N_{P,i}} \qquad \text{Eq. 21}$$

where:

w = weight of the crash frequency predicted by the safety prediction methodology;

n = number of years in the analysis period;

$N_{P,i}$ = predicted average crash frequency for the homogeneous roadway segment for the year "i".

Finally, the Empirical Bayes expected crash frequency for before period based on a weighted average of N_P and N_O is calculated for FI and PDO crashes, following Eq. 22.

$$N_{EB-P} = w \times N_{P,tot} + (1 - w) \times N_{O,tot} \qquad \text{Eq. 22}$$

where:

N_{EB-P} = expected average crash frequency for the homogeneous roadway segment for all years of the before-period;

$N_{P,tot}$ = predicted average crash frequency for the homogeneous roadway segment for all years of the before-period;

$N_{O,tot}$ = number of crashes observed for the homogeneous roadway segment for all years of the before-period.

APPENDIX 3 Geometrical data of the analyzed roads

SR2

Km posts to real distance conversion

Appendix Table 1 shows the relationship between the distances pointed out by the km posts and the real development of the road.

Appendix Table 1 – SR2, relationship between km posts and real distance

Km posts	Real distances		Km posts	Real distances		Km posts	Real distances
280.600	280.600		284.700	284.600		288.800	288.600
280.800	280.800		285.000	284.800		289.000	288.800
281.000	281.000		285.200	285.000		289.200	289.000
281.200	281.200		285.400	285.200		289.400	289.200
281.400	281.400		285.600	285.400		289.600	289.400
281.600	281.600		285.800	285.600		289.800	289.600
281.800	281.800		286.000	285.800		290.000	289.800
282.000	282.000		286.200	286.000		290.200	290.000
282.200	282.200		286.400	286.200		290.400	290.200
282.400	282.400		286.600	286.400		290.600	290.400
282.600	282.600		286.800	286.600		290.800	290.600
282.800	282.800		287.000	286.800		291.000	290.800
283.000	283.000		287.200	287.000		291.200	291.000
283.200	283.200		287.400	287.200		291.400	291.200
283.400	283.400		287.600	287.400		291.600	291.400
283.600	283.600		287.800	287.600		291.800	291.600
283.800	283.800		288.000	287.800		292.000	291.800
284.000	284.000		288.200	288.000		292.200	292.000
284.200	284.200		288.400	288.200		292.400	292.200
284.500	284.400		288.600	288.400			

Horizontal alignment

Detailed information about the characteristics of the horizontal elements is provided in Appendix Table 3.

Appendix Table 2 – SR2, horizontal geometrical elements characteristics

Element	Starting Km post [km]	Ending Km post [km]	Radius	Directi on		Element	Starting Km post [km]	Ending Km post [km]	Radius	Directi on
Tangent	280.600	280.606	0.000			Curve	285.827	285.904	518.423	R
Curve	280.606	280.639	78.281	R		Tangent	285.904	286.130	0.000	
Tangent	280.639	280.708	0.000			Curve	286.130	286.265	395.652	R
Curve	280.708	280.756	91.235	R		Tangent	286.265	286.515	0.000	
Tangent	280.756	280.872	0.000			Curve	286.515	286.651	195.472	L
Curve	280.872	280.931	65.855	R		Tangent	286.651	286.835	0.000	
Tangent	280.931	281.010	0.000			Curve	286.835	287.223	578.160	R
Curve	281.010	281.096	105.869	L		Tangent	287.223	287.361	0.000	

Tangent	281.096	281.154	0.000			Curve	287.361	287.529	170.683	R
Curve	281.154	281.200	78.007	R		Tangent	287.529	287.570	0.000	
Tangent	281.200	281.222	0.000			Curve	287.570	287.906	173.177	L
Curve	281.222	281.294	63.995	L		Tangent	287.906	287.931	0.000	
Tangent	281.294	281.311	0.000			Curve	287.931	288.020	116.567	L
Curve	281.311	281.422	59.120	R		Tangent	288.020	288.133	0.000	
Tangent	281.422	281.458	0.000			Curve	288.133	288.185	256.951	R
Curve	281.458	281.500	100.024	L		Tangent	288.185	288.228	0.000	
Tangent	281.500	281.512	0.000			Curve	288.228	288.299	143.244	L
Curve	281.512	281.548	138.844	R		Tangent	288.299	288.356	0.000	
Tangent	281.548	281.566	0.000			Curve	288.356	288.417	142.251	R
Curve	281.566	281.623	123.869	L		Tangent	288.417	288.435	0.000	
Tangent	281.623	281.650	0.000			Curve	288.435	288.499	98.307	R
Curve	281.650	281.702	142.669	R		Tangent	288.499	288.581	0.000	
Tangent	281.702	281.736	0.000			Curve	288.581	288.674	85.491	R
Curve	281.736	281.819	108.562	L		Tangent	288.674	288.769	0.000	
Tangent	281.819	281.891	0.000			Curve	288.769	288.806	167.218	L
Curve	281.891	281.962	123.920	R		Tangent	288.806	288.823	0.000	
Tangent	281.962	281.993	0.000			Curve	288.823	288.913	164.647	R
Curve	281.993	282.055	191.803	L		Tangent	288.913	288.936	0.000	
Tangent	282.055	282.109	0.000			Curve	288.936	288.972	224.634	R
Curve	282.109	282.213	49.802	L		Tangent	288.972	289.004	0.000	
Tangent	282.213	282.307	0.000			Curve	289.004	289.033	97.850	L
Curve	282.307	282.357	124.625	R		Tangent	289.033	289.153	0.000	
Tangent	282.357	282.448	0.000			Curve	289.153	289.232	102.455	R
Curve	282.448	282.521	151.285	R		Tangent	289.232	289.268	0.000	
Tangent	282.521	282.669	0.000			Curve	289.268	289.300	269.811	L
Curve	282.669	282.807	51.068	R		Tangent	289.300	289.341	0.000	
Tangent	282.807	282.999	0.000			Curve	289.341	289.398	79.365	R
Curve	282.999	283.069	201.459	L		Tangent	289.398	289.430	0.000	
Tangent	283.069	283.117	0.000			Curve	289.430	289.485	111.163	L
Curve	283.117	283.152	80.000	L		Tangent	289.485	289.495	0.000	
Tangent	283.152	283.155	0.000			Curve	289.495	289.563	211.267	L
Curve	283.155	283.226	34.027	L		Tangent	289.563	289.604	0.000	
Tangent	283.226	283.332	0.000			Curve	289.604	289.660	150.000	L
Curve	283.332	283.433	187.074	R		Tangent	289.660	289.967	0.000	
Tangent	283.433	283.497	0.000			Curve	289.967	290.119	698.965	L
Curve	283.497	283.595	246.608	L		Tangent	290.119	290.239	0.000	
Tangent	283.595	283.611	0.000			Curve	290.239	290.280	101.519	L
Curve	283.611	283.656	48.860	L		Tangent	290.280	290.333	0.000	
Tangent	283.656	283.690	0.000			Curve	290.333	290.379	131.150	R
Curve	283.690	283.729	58.023	R		Tangent	290.379	290.406	0.000	
Tangent	283.729	283.803	0.000			Curve	290.406	290.446	103.454	L
Curve	283.803	283.934	175.299	R		Tangent	290.446	290.499	0.000	
Tangent	283.934	283.955	0.000			Curve	290.499	290.551	159.265	R
Curve	283.955	284.013	68.450	R		Tangent	290.551	290.563	0.000	
Tangent	284.013	284.036	0.000			Curve	290.563	290.594	133.939	L
Curve	284.036	284.074	90.652	L		Tangent	290.594	290.955	0.000	
Tangent	284.074	284.156	0.000			Curve	290.955	290.959	30.000	L
Curve	284.156	284.302	88.693	L		Tangent	290.959	290.972	0.000	
Tangent	284.302	284.360	0.000			Curve	290.972	291.055	222.293	R
Curve	284.360	284.463	100.872	L		Tangent	291.055	291.173	0.000	
Tangent	284.463	284.568	0.000			Curve	291.173	291.270	432.689	L
Curve	284.568	284.962	177.024	R		Tangent	291.270	291.336	0.000	

Tangent	284.962	285.260	0.000			Curve	291.336	291.401	190.908	L
Curve	285.260	285.326	139.502	L		Tangent	291.401	291.554	0.000	
Tangent	285.326	285.415	0.000			Curve	291.554	291.622	384.109	L
Curve	285.415	285.501	126.934	L		Tangent	291.622	291.741	0.000	
Tangent	285.501	285.544	0.000			Curve	291.741	291.813	577.627	L
Curve	285.544	285.597	191.290	R		Tangent	291.813	291.990	0.000	
Tangent	285.597	285.827	0.000			Curve	291.990	292.103	208.895	R

SR206

Km posts to real distance conversion

Appendix Table 3 shows the relationship between the distances pointed out by the km posts and the real development of the road.

Appendix Table 3 – SR206, relationship between km posts and real distance

Km posts	Real distances		Km posts	Real distances		Km posts	Real distances
27.800	27.800		32.600	32.600		37.200	37.400
28.000	28.000		32.800	32.800		37.400	37.600
28.200	28.200		33.000	33.000		37.600	37.800
28.400	28.400		33.200	33.200		37.800	38.000
28.600	28.600		33.400	33.400		38.000	38.200
28.800	28.800		33.600	33.600		38.200	38.400
29.000	29.000		33.800	33.800		38.400	38.600
29.200	29.200		34.000	34.000		38.600	38.800
29.400	29.400		34.200	34.200		38.800	39.000
29.600	29.600		34.400	34.400		39.000	39.200
29.800	29.800		34.600	34.600		39.200	39.400
30.000	30.000		34.800	34.800		39.400	39.600
30.200	30.200		35.000	35.000		39.600	39.800
30.400	30.400		35.200	35.200		39.800	40.000
30.600	30.600		35.400	35.400		40.000	40.200
30.800	30.800		35.600	35.600		40.200	40.400
31.000	31.000		35.800	35.800		40.400	40.600
31.200	31.200		36.000	36.000		40.600	40.800
31.400	31.400		36.200	36.200		40.800	41.000
31.600	31.600		36.400	36.400		41.000	41.200
31.800	31.800		36.700	36.600		41.200	41.400
32.000	32.000		37.000	36.800		41.400	41.600
32.200	32.200		37.200	37.000			
32.400	32.400		37.000	37.200			

Horizontal alignment

Detailed information about the characteristics of the horizontal elements is provided in Appendix Table 4.

Appendix Table 4 – SR206, horizontal geometrical elements characteristics

Element	Starting Km post [km]	Ending Km post [km]	Radius	Direction		Element	Starting Km post [km]	Ending Km post [km]	Radius	Direction
Tangent	27.800	27.922	0.000			Tangent	33.258	33.505	285.000	L
Curve	27.922	28.089	490.000	L		Curve	33.505	34.118	0.000	
Tangent	28.089	28.272	0.000			Tangent	34.118	34.538	2950.000	L
Curve	28.272	28.364	400.000	L		Curve	34.538	34.598	0.000	
Tangent	28.364	29.240	0.000			Tangent	34.598	34.939	3120.000	R
Curve	29.240	29.395	350.000	L		Curve	34.939	35.129	0.000	
Tangent	29.395	29.514	0.000			Tangent	35.129	35.314	235.000	L
Curve	29.514	29.795	240.000	R		Curve	35.314	35.635	0.000	
Tangent	29.795	30.042	0.000			Tangent	35.635	35.828	265.000	R
Curve	30.042	30.198	300.000	L		Curve	35.828	35.899	0.000	
Tangent	30.198	30.302	0.000			Tangent	35.899	35.973	630.000	L
Curve	30.302	30.366	250.000	L		Curve	35.973	41.434	0.000	
Tangent	30.366	30.810	0.000			Tangent	41.434	41.586	2200.000	R
Curve	30.810	30.931	1390.000	L		Curve	41.586	41.588	0.000	
Tangent	30.931	31.534	0.000			Tangent	41.588	41.653	170.000	R
Curve	31.534	31.993	880.000	R		Curve	41.653	41.671	0.000	
Tangent	31.993	32.652	0.000			Tangent	41.671	41.694	0.000	
Curve	32.652	32.666	45.000	L		Curve	41.694	41.724	80.000	R
Tangent	32.666	32.690	0.000			Tangent	41.724	41.753	0.000	
Curve	32.690	32.714	0.000			Curve	41.753	41.867	930.000	R
Tangent	32.714	32.726	45.000	L		Tangent	41.867	41.950	0.000	
Curve	32.726	33.000	0.000			Curve	41.950	42.180	950.000	L
Tangent	33.000	33.186	405.000	R		Tangent	42.180	42.383	0.000	
Curve	33.186	33.258	0.000							

APPENDIX 4 Accidents databases

All accidents databases are available under request.

Composition of the Italian databases

The accidents database used for the two Italian road stretches (SR2 and SR206) consist in two different databases: one provided by ISTAT (Istituto Nazionale di Statistica) that comprises all the severe accidents, and one provided by local police which provides the property damage only (PDO) accidents.

The severe accidents database contains the information shown in Appendix Table 5.

Appendix Table 5 – Contents of the accidents Italian database for severe accidents (from ISTAT)

#	Name	Description
1	anno	Year of the accident occurrence
2	provincia	Province where the accident occurred
3	comune	City where the accident occurred (municipality)
4	giorno	Day of the accident occurrence
5	organo_di_rilevazione	Who (type of police) detect the accident
6	localizzazione_incidente	Type of the road
7	denominazione_della_strada	Name of the road
8	tronco_di_strada_o_autostrada	Part of the road (e.g., left carriageway)
9	tipo_di_strada	Umber of road carriageways
10	pavimentazione	Pavement type
11	intersezione_o_non_interse3	Accident occurred at intersection or not
12	fondo_stradale	Surface conditions (e.g., wet surface)
13	segnaletica	Type of signs and markings (e.g., work zones)
14	condizioni_meteorologiche	Atmospheric conditions
15	natura_incidente	Accident type (e.g., rear-end, lateral, with pedestrian, etc.)
16	tipo_veicolo_a	Vehicle “a” type
17	tipo_veicoli__b_	Vehicle “b” type
18	tipo_veicolo__c_	Vehicle “c” type
19	veicolo__a____circostanze_10	What vehicle “a” was doing - 1
20	veicolo__a____circostanze_11	What vehicle “a” was doing - 2
21	veicolo__b____circostanze_13	What vehicle “b” was doing - 1
22	veicolo__b____circostanze_14	What vehicle “b” was doing - 2
23	veicolo__a___anno_immatric18	Year of matriculation of vehicle “a”
24	immatricolazione_veicolo__b_	Year of matriculation of vehicle “b”
25	immatricolazione_veicolo__c_	Year of matriculation of vehicle “c”
26	veicolo__a___et__conducente	Age of driver of vehicle “a”
27	veicolo__a___sesso_conducente	Gender of driver of vehicle “a”
28	veicolo__a___esito_conducente	Condition after accident of driver of vehicle “a”
29	veicolo__a___patente_condu29	Driving license type of driver of vehicle “a”
30	veicolo__a___anno_rilascio30	Year of the driving license of driver of vehicle “a”
31	veicolo__a___passeggeri_an35	Condition after accident of passenger 1 of vehicle “a”
32	veicolo__a___et__passegger36	Age of passenger 1 of vehicle “a”
33	veicolo__a___sesso_passegg37	Gender of passenger 1 of vehicle “a”
34	veicolo__a___esito_passegg38	Condition after accident of passenger 2 of vehicle “a”

35	veicolo__a___et__passegger39	Age of passenger 2 of vehicle “a”
36	veicolo__a___sesso_passegg40	Gender of passenger 2 of vehicle “a”
37	veicolo__a___esito_passegg41	Condition after accident of passenger 3 of vehicle “a”
38	veicolo__a___et__passegger42	Age of passenger 3 of vehicle “a”
39	veicolo__a___sesso_passegg43	Gender of passenger 3 of vehicle “a”
40	veicolo__a___esito_passegg44	Condition after accident of passenger 4 of vehicle “a”
41	veicolo__a___et__passegger45	Age of passenger 4 of vehicle “a”
42	veicolo__a___sesso_passegg46	Gender of passenger 4 of vehicle “a”
43	veicolo__a___altri_passegg47	Other dead male passengers of vehicle “a”
44	veicolo__a___altri_passegg48	Other dead female passengers of vehicle “a”
45	veicolo__a___altri_passegg49	Other injured male passengers of vehicle “a”
46	veicolo__a___altri_passegg50	Other injured female passengers of vehicle “a”
47	veicolo__b___et__conducente	Age of driver of vehicle “b”
48	veicolo__b___sesso_conducente	Gender of driver of vehicle “b”
49	veicolo__b___esito_conducente	Condition after accident of driver of vehicle “b”
50	veicolo__b___patente_condu51	Driving license type of driver of vehicle “b”
51	veicolo__b___anno_rilascio52	Year of the driving license of driver of vehicle “b”
52	veicolo__b___passeggeri_an57	Condition after accident of passenger 1 of vehicle “b”
53	veicolo__b___et__passegger58	Age of passenger 1 of vehicle “b”
54	veicolo__b___sesso_passegg59	Gender of passenger 1 of vehicle “b”
55	veicolo__b___esito_passegg60	Condition after accident of passenger 2 of vehicle “b”
56	veicolo__b___et__passegger61	Age of passenger 2 of vehicle “b”
57	veicolo__b___sesso_passegg62	Gender of passenger 2 of vehicle “b”
58	veicolo__b___esito_passegg63	Condition after accident of passenger 3 of vehicle “b”
59	veicolo__b___et__passegger64	Age of passenger 3 of vehicle “b”
60	veicolo__b___sesso_passegg65	Gender of passenger 3 of vehicle “b”
61	veicolo__b___esito_passegg66	Condition after accident of passenger 4 of vehicle “b”
62	veicolo__b___et__passegger67	Age of passenger 4 of vehicle “b”
63	veicolo__b___sesso_passegg68	Gender of passenger 4 of vehicle “b”
64	veicolo__b___altri_passegg69	Other dead male passengers of vehicle “b”
65	veicolo__b___altri_passegg70	Other dead female passengers of vehicle “b”
66	veicolo__b___altri_passegg71	Other injured male passengers of vehicle “b”
67	veicolo__b___altri_passegg72	Other injured female passengers of vehicle “b”
68	veicolo__c___et__conducente	Age of driver of vehicle “c”
69	veicolo__c___sesso_conducente	Gender of driver of vehicle “c”
70	veicolo__c___esito_conducente	Condition after accident of driver of vehicle “c”
71	veicolo__c___patente_condu73	Driving license type of driver of vehicle “c”
72	veicolo__c___anno_rilascio74	Year of the driving license of driver of vehicle “c”
73	veicolo__c___passeggeri_an79	Condition after accident of passenger 1 of vehicle “c”
74	veicolo__c___et__passegger80	Age of passenger 1 of vehicle “c”
75	veicolo__c___sesso_passegg81	Gender of passenger 1 of vehicle “c”
76	veicolo__c___esito_passegg82	Condition after accident of passenger 2 of vehicle “c”
77	veicolo__c___et__passegger83	Age of passenger 2 of vehicle “c”
78	veicolo__c___sesso_passegg84	Gender of passenger 2 of vehicle “c”
79	veicolo__c___esito_passegg85	Condition after accident of passenger 3 of vehicle “c”
80	veicolo__c___et__passegger86	Age of passenger 3 of vehicle “c”
81	veicolo__c___sesso_passegg87	Gender of passenger 3 of vehicle “c”
82	veicolo__c___esito_passegg88	Condition after accident of passenger 4 of vehicle “c”
83	veicolo__c___et__passegger89	Age of passenger 4 of vehicle “c”

84	veicolo__c___sesso_passegg90	Gender of passenger 4 of vehicle “c”
85	veicolo__c___altri_passegg91	Other dead male passengers of vehicle “c”
86	veicolo__c___altri_passegg92	Other dead female passengers of vehicle “c”
87	veicolo__c___altri_passegg93	Other injured male passengers of vehicle “c”
88	veicolo__c___altri_passegg94	Other injured female passengers of vehicle “c”
89	pedone_morto_1__sesso	Gender of dead pedestrian 1
90	pedone_morto_1__et_	Age of dead pedestrian 1
91	pedone_ferito_1__sesso	Gender of injured pedestrian 1
92	pedone_ferito_1__et_	Age of injured pedestrian 1
93	pedone_morto_2__sesso	Gender of dead pedestrian 2
94	pedone_morto_2__et_	Age of dead pedestrian 2
95	pedone_ferito_2__sesso	Gender of injured pedestrian 2
96	pedone_ferito_2__et_	Age of injured pedestrian 2
97	pedone_morto_3__sesso	Gender of dead pedestrian 3
98	pedone_morto_3__et_	Age of dead pedestrian 3
99	pedone_ferito_3__sesso	Gender of injured pedestrian 3
100	pedone_ferito_3__et_	Age of injured pedestrian 3
101	pedone_morto_4__sesso	Gender of dead pedestrian 4
102	pedone_morto_4__et_	Age of dead pedestrian 4
103	pedone_ferito_4__sesso	Gender of injured pedestrian 4
104	pedone_ferito_4__et_	Age of injured pedestrian 4
105	altri_veicoli_coinvolti	Other involved vehicles
106	morti_maschi_coinvolti_su_95	Number of deads male on other vehicles
107	morti_femmine_coinvolti_su96	Number of deads female on other vehicles
108	feriti_maschi_coinvolti_su97	Number of injured males on other vehicles
109	feriti_femmine_coinvolti_s98	Number of injured females on other vehicles
110	morti_entro_24_ore	Deads within 24 hours
111	morti_entro_30_giorni	Deads within 30 days
112	feriti	Total number of injured people
113	descrizione_strada	Road description (location of the accident description)
114	ora_nuova	Time (considering the “new hour”)
115	minuti	Minutes
116	chilometri	Km
117	ettometrica	Hm (hectometric)
118	Trimestre	Trimester

In addition, when the accidents were georeferenced, the X, Y coordinates and the reference system type were provided.

The PDO database was provided later, thus it has not been considered during the first application of the original version of the tool. The PDO database was provided by the municipality police and contains less information than the database provided by ISTAT. The information contained in the PDO database are shown in Appendix Table 6.

Appendix Table 6 – Contents of the accidents Italian database for PDO accidents (from police)

#	Name	Description
1	anno	Year of the accident occurrence
2	comune	City where the accident occurred (municipality)
3	denominazione_della_strada	Name of the road
4	Accident cause	Alleged accident cause
5	Number of vehicles	Number of vehicles involved in the accident
7	chilometri	Km
8	ettometrica	Hm (hectometric)

Even if both databases contain much information, detailed description of accidents dynamics have not been provided.

Composition of the German database

The accidents database used for the three German road stretches (38, L3106, and L3408) has been provided by Hessen Mobil and comprises both the severe accidents, and PDO accidents. The accidents database includes a detailed description of each accident.

The accidents database contains the information shown in Appendix Table 7.

Appendix Table 7 – Contents of the German accidents database (from Hessen Mobil)

#	Name	Description
1	STR	Road type and number
2	ABS	Node network section number
3	HA-Nr	Not known
4	STAT	Station
5	DTV	AADT
6	St Ri	Direction
7	OL	Urban or rural area
8	Datum	Date
9	Tag	Day of the week
10	Zeit	Time when accident occurred
11	TO	Number of deads
12	SV	Number of serious injuries
13	LV	Number of slight injuries
14	U Art	Accident type
15	Char	Accident characteristics
16	Bes	Accident peculiarities
17	V Zul	Speed Limit
18	Lich	Light conditions
19	Zust	Road conditions
20	A Urs	General cause of the accident
21	Un kat	Accident category
22	U Typ	Accident typology
23	Auf Hi	Impact with objects on the road margins
24	Urs 1	Definitive cause 1
25	Urs 2	Definitive cause 2

26	Alter	Not known
27	VBet1	Vehicle Type 1
28	VBet2	Vehicle Type 2
29	VBet3	Vehicle Type 3
30	COMVOR-Nr	Reference number

The location of the accident is defined by the "station" attribute.

Composition of the Slovenian database

The accidents database used for the Slovenian road stretch has been provided by Slovenian Infrastructure Agency and comprises both the severe accidents, and PDO accidents.

The accidents database contains the information shown in Appendix Table 8.

Appendix Table 8 – Contents of the German accidents database (from Slovenian Infrastructure Agency)

#	Name	Description
1	IDpn	Accident ID
2	Year	Year of accident occurrence
3	Severity code	Severity identification code
4	Severity	Severity description
5	Cause	Alleged cause defined by the police
6	Type	Accident type
7	Weather	Weather condition
8	Road condition	Road surface condition
9	Road category	Category of the road based on the design standards
10	Road	Name of the road
11	Road section	Name of the road section

The location of the accident is defined by the "location" attribute.

APPENDIX 5 First application of the HFET: results comparison

The results are organized in two sections: ranking analysis and linear correlation analysis. For each section three different testing groups are considered: TG1 (all the segments), TG2 (considering separately segments belonging to each road), and TG3 (considering separately each segment type).

Ranking analysis

Appendix Table 9 – TG1, ranking comparison

Road	ID	Section type	Acc. Freq.*	Acc. Rate**	HFS	Rank Freq.	Rank Acc. Rate	Rank HFS
SR2	291_0	Intersections	2.40	1.06	34%	1	4	1
SR2	282_9	Intersections	1.67	1.58	36%	3	1	2
SR2	281_6	Roadway Segment	0.98	1.05	43%	7	5	3
SR2	292_0	Intersections	1.38	0.76	45%	6	7	4
SR206	040_1	Intersections	1.71	0.51	45%	2	9	5
SR2	283_9	Intersections	0.38	1.23	47%	18	2	6
SR2	291_7	Urban Segment	1.49	1.10	47%	4	3	7
SR2	285_6	Roadway Segment	0.78	0.55	48%	10	8	8
SR2	287_8	Intersections	0.53	0.43	48%	15	11	9
SR2	285_1	Intersections	0.21	0.28	53%	23	16	10
SR2	288_6	Roadway Segment	0.12	0.19	54%	28	23	11
SR206	036_9	Intersections	0.68	0.31	57%	13	14	12
SR206	038_4	Urban Segment	1.41	0.47	58%	5	10	13
SR2	282_2	Intersections	0.71	0.91	59%	12	6	14
SR2	286_5	Intersections	0.19	0.24	61%	24	18	15
SR2	287_0	Roadway Segment	0.18	0.14	61%	25	29	16
SR206	035_9	Roadway Segment	0.72	0.34	62%	11	13	17
SR206	037_4	Roadway Segment	0.94	0.31	62%	8	15	18
SR206	036_4	Intersections	0.56	0.26	62%	14	17	19
SR206	038_1	Intersections	0.07	0.05	64%	34	38	20
SR206	040_7	Intersections	0.45	0.16	66%	17	27	21
SR2	283_6	Roadway Segment	0.09	0.21	67%	31	21	22
SR2	284_6	Roadway Segment	0.08	0.12	68%	32	31	23
SR2	289_0	Intersections	0.03	0.10	68%	38	32	24
SR206	039_4	Intersections	0.14	0.06	69%	27	37	25
SR206	031_1	Roadway Segment	0.37	0.21	71%	19	20	26
SR2	284_3	Intersections	0.08	0.22	72%	33	19	27
SR206	033_6	Roadway Segment	0.18	0.07	72%	26	34	28
SR206	030_2	Roadway Segment	0.81	0.38	73%	9	12	29
SR206	029_6	Intersections	0.50	0.19	73%	16	22	30
SR206	033_4	Intersections	0.07	0.08	76%	35	33	31
SR206	039_1	Roadway Segment	0.24	0.14	81%	22	30	32
SR2	282_7	Roadway Segment	0.06	0.18	82%	36	24	33
SR206	039_8	Roadway Segment	0.11	0.06	82%	30	36	34
SR206	030_7	Intersections	0.29	0.17	83%	20	25	35
SR206	041_2	Roadway Segment	0.11	0.07	84%	29	35	36
SR2	284_1	Roadway Segment	0.06	0.16	85%	37	26	37
SR206	034_6	Roadway Segment	0.26	0.15	90%	21	28	38

** [acc/year]; ** [acc/(year·Mvehicles·km)]*

Appendix Table 10 – TG2, SR2, ranking comparison

Road	ID	Section type	Acc. Freq.*	Acc. Rate**	HFS	Rank Freq.	Rank Acc. Rate	Rank HFS
SR2	291_0	Intersections	2.40	1.06	34%	1	4	1
SR2	282_9	Intersections	1.67	1.58	36%	2	1	2
SR2	281_6	Roadway Segment	0.98	1.05	43%	5	5	3
SR2	292_0	Intersections	1.38	0.76	45%	4	7	4
SR2	291_7	Urban Segment	1.49	1.10	47%	3	3	6
SR2	283_9	Intersections	0.38	1.23	47%	9	2	5
SR2	285_6	Roadway Segment	0.78	0.55	48%	6	8	7
SR2	287_8	Intersections	0.53	0.43	48%	8	9	8
SR2	285_1	Intersections	0.21	0.28	53%	10	10	9
SR2	288_6	Roadway Segment	0.12	0.19	54%	13	14	10
SR2	282_2	Intersections	0.71	0.91	59%	7	6	11
SR2	286_5	Intersections	0.19	0.24	61%	11	11	12
SR2	287_0	Roadway Segment	0.18	0.14	61%	12	17	13
SR2	283_6	Roadway Segment	0.09	0.21	67%	14	13	14
SR2	284_6	Roadway Segment	0.08	0.12	68%	15	18	15
SR2	289_0	Intersections	0.03	0.10	68%	19	19	16
SR2	284_3	Intersections	0.08	0.22	72%	16	12	17
SR2	282_7	Roadway Segment	0.06	0.18	82%	17	15	18
SR2	284_1	Roadway Segment	0.06	0.16	85%	18	16	19

** [acc/year]; ** [acc/(year·Mvehicles·km)]*

Appendix Table 11 – TG2, SR206, ranking comparison

Road	ID	Section type	Acc. Freq.*	Acc. Rate**	HFS	Rank Freq.	Rank Acc. Rate	Rank HFS
SR206	040_1	Intersections	1.71	0.51	45%	1	1	1
SR206	036_9	Intersections	0.68	0.31	57%	6	5	2
SR206	038_4	Urban Segment	1.41	0.47	58%	2	2	3
SR206	035_9	Roadway Segment	0.72	0.34	62%	5	4	4
SR206	037_4	Roadway Segment	0.94	0.31	62%	3	6	5
SR206	036_4	Intersections	0.56	0.26	62%	7	7	6
SR206	038_1	Intersections	0.07	0.05	64%	18	19	7
SR206	040_7	Intersections	0.45	0.16	66%	9	11	8
SR206	039_4	Intersections	0.14	0.06	69%	15	18	9
SR206	031_1	Roadway Segment	0.37	0.21	71%	10	8	10
SR206	033_6	Roadway Segment	0.18	0.07	72%	14	15	11
SR206	030_2	Roadway Segment	0.81	0.38	73%	4	3	12
SR206	029_6	Intersections	0.50	0.19	73%	8	9	13
SR206	033_4	Intersections	0.07	0.08	76%	19	14	14
SR206	039_1	Roadway Segment	0.24	0.14	81%	13	13	15
SR206	039_8	Roadway Segment	0.11	0.06	82%	17	17	16
SR206	030_7	Intersections	0.29	0.17	83%	11	10	17
SR206	041_2	Roadway Segment	0.11	0.07	84%	16	16	18
SR206	034_6	Roadway Segment	0.26	0.15	90%	12	12	19

** [acc/year]; ** [acc/(year·Mvehicles·km)]*

Appendix Table 12 – TG3, roadway segments, ranking comparison

Road	ID	Section type	Acc. Freq.*	Acc. Rate**	HFS	Rank Freq.	Rank Acc. Rate	Rank HFS
SR2	281_6	Roadway Segment	0.98	1.05	43%	1	1	1
SR2	285_6	Roadway Segment	0.78	0.55	48%	4	2	2
SR2	288_6	Roadway Segment	0.12	0.19	54%	11	8	3
SR2	287_0	Roadway Segment	0.18	0.14	61%	9	12	4
SR206	035_9	Roadway Segment	0.72	0.34	62%	5	4	5
SR206	037_4	Roadway Segment	0.94	0.31	62%	2	5	6
SR2	283_6	Roadway Segment	0.09	0.21	67%	14	7	7
SR2	284_6	Roadway Segment	0.08	0.12	68%	15	14	8
SR206	031_1	Roadway Segment	0.37	0.21	71%	6	6	9
SR206	033_6	Roadway Segment	0.18	0.07	72%	10	15	10
SR206	030_2	Roadway Segment	0.81	0.38	73%	3	3	11
SR206	039_1	Roadway Segment	0.24	0.14	81%	8	13	12
SR2	282_7	Roadway Segment	0.06	0.18	82%	16	9	13
SR206	039_8	Roadway Segment	0.11	0.06	82%	13	17	14
SR206	041_2	Roadway Segment	0.11	0.07	84%	12	16	15
SR2	284_1	Roadway Segment	0.06	0.16	85%	17	10	16
SR206	034_6	Roadway Segment	0.26	0.15	90%	7	11	17

** [acc/year]; ** [acc/(year·Mvehicles·km)]*

Appendix Table 13 – TG3, intersections, ranking comparison

Road	ID	Section type	Acc. Freq.*	Acc. Rate**	HFS	Rank Freq.	Rank Acc. Rate	Rank HFS
SR2	291_0	Intersections	2.40	1.06	34%	1	3	1
SR2	282_9	Intersections	1.67	1.58	36%	3	1	2
SR2	292_0	Intersections	1.38	0.76	45%	4	5	3
SR206	040_1	Intersections	1.71	0.51	45%	2	6	4
SR2	283_9	Intersections	0.38	1.23	47%	11	2	5
SR2	287_8	Intersections	0.53	0.43	48%	8	7	6
SR2	285_1	Intersections	0.21	0.28	53%	13	9	7
SR206	036_9	Intersections	0.68	0.31	57%	6	8	8
SR2	282_2	Intersections	0.71	0.91	59%	5	4	9
SR2	286_5	Intersections	0.19	0.24	61%	14	11	10
SR206	036_4	Intersections	0.56	0.26	62%	7	10	11
SR206	038_1	Intersections	0.07	0.05	64%	17	19	12
SR206	040_7	Intersections	0.45	0.16	66%	10	15	13
SR2	289_0	Intersections	0.03	0.10	68%	19	16	14
SR206	039_4	Intersections	0.14	0.06	69%	15	18	15
SR2	284_3	Intersections	0.08	0.22	72%	16	12	16
SR206	029_6	Intersections	0.50	0.19	73%	9	13	17
SR206	033_4	Intersections	0.07	0.08	76%	18	17	18
SR206	030_7	Intersections	0.29	0.17	83%	12	14	19

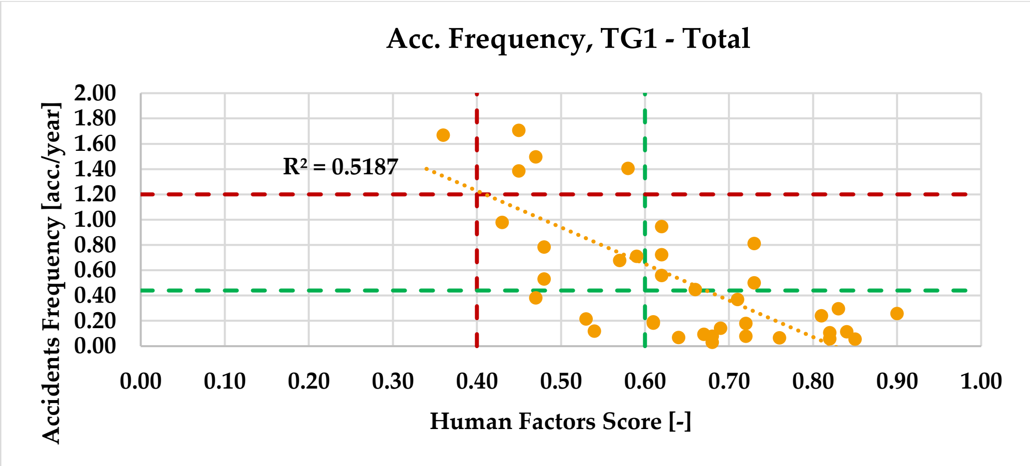
** [acc/year]; ** [acc/(year·Mvehicles·km)]*

The urban segments are not presented because they comprise only two segments.

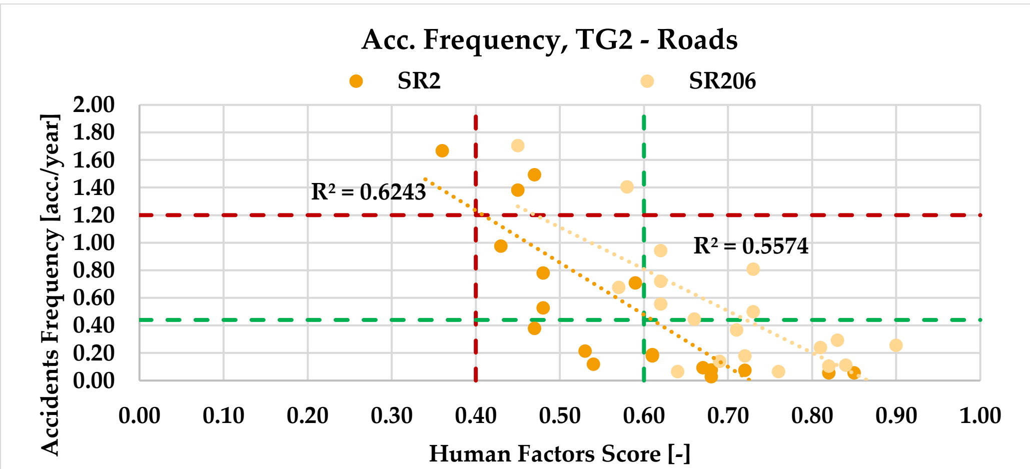
The cells' colors of TG1 and TG2 refer to the Total classification, while the colors of TG3 refers to each segment type classification (see Table 5.6).

Linear correlation analysis

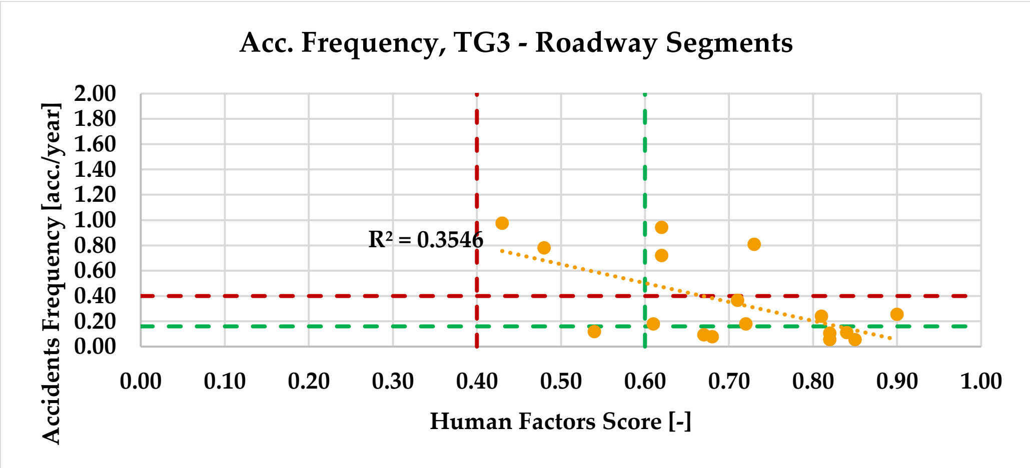
In the following graph, the thresholds values are highlighted. The thresholds values for the HFS are 0.40 and 0.60. Value below 0.40 identify high risk segments, values between 0.40 and 0.60 (included) identify medium risk segments, and values above 0.60 identify low risk segments. The thresholds values of each performance measures are those identified in Table 5.6. Value below T_{mean} identify low risk segments, values between T_{mean} and T_{90} (included) identify medium risk segments, and values above T_{90} identify high risk segments. The threshold line between the low risk and medium risk is depicted in red, while the threshold line between medium and low risk is depicted in green. For TG1 and TG2 the thresholds values of the performance measures refer to the total of the segments in the network (see Table 5.6), while for TG3, the thresholds refer to the single type of segment (roadway, intersection, and urban).



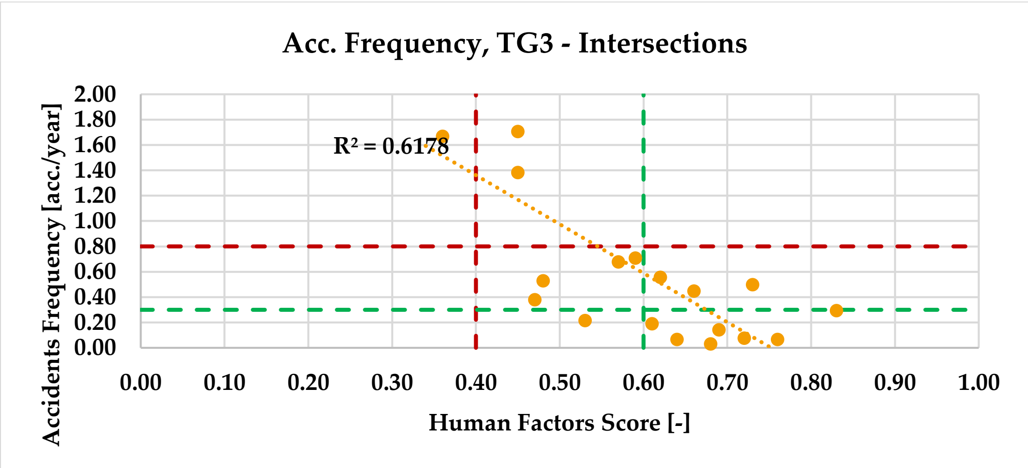
Appendix Figure 1 – Accidents Frequency, TG1 – Total analyzed segments.



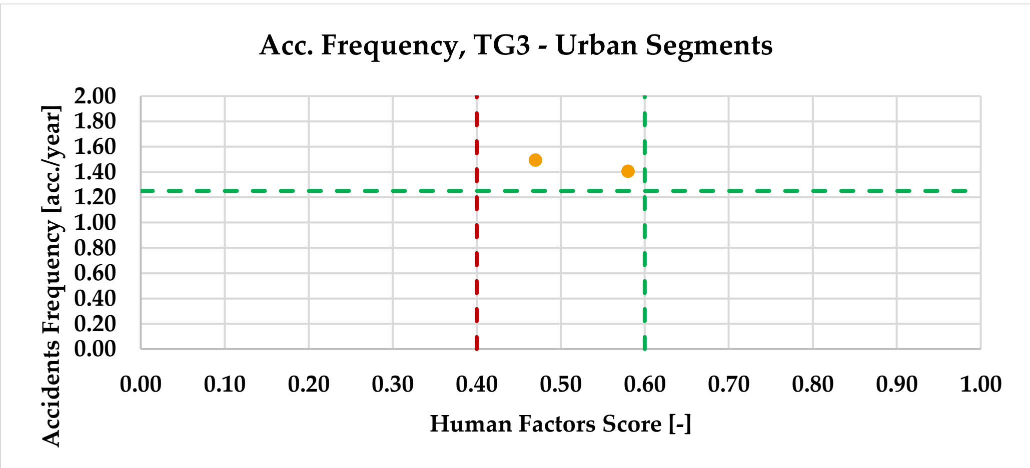
Appendix Figure 2 – Accidents Frequency, TG2 – divided by roads.



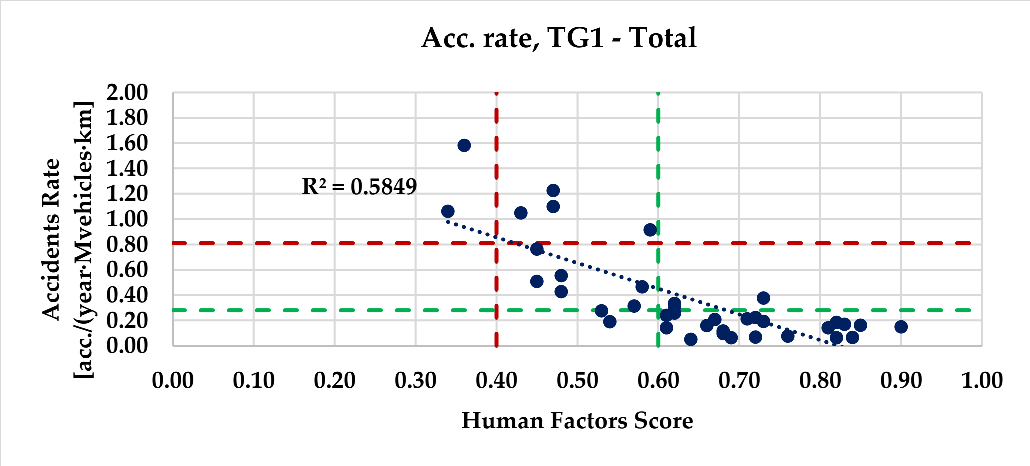
Appendix Figure 3 – Accidents Frequency, TG3 – divided by segment type, roadway segments.



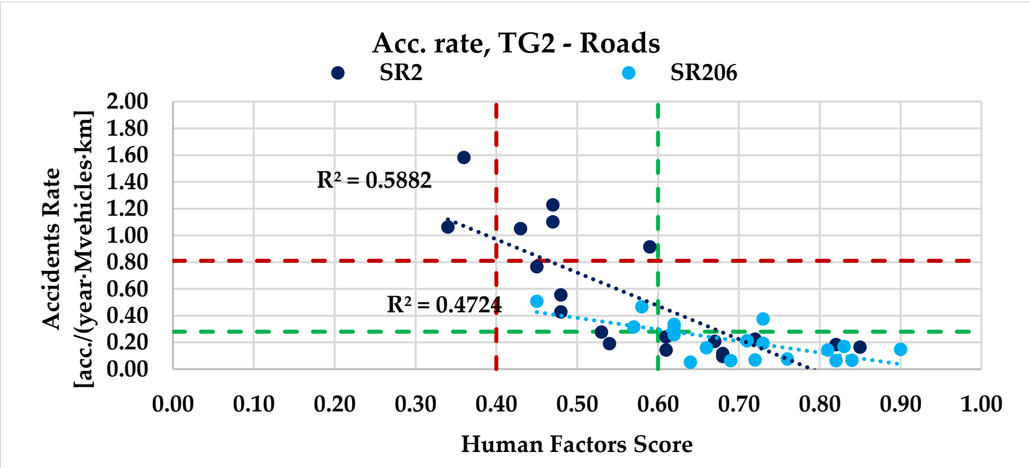
Appendix Figure 4 – Accidents Frequency, TG3 – divided by segment type, intersections segments.



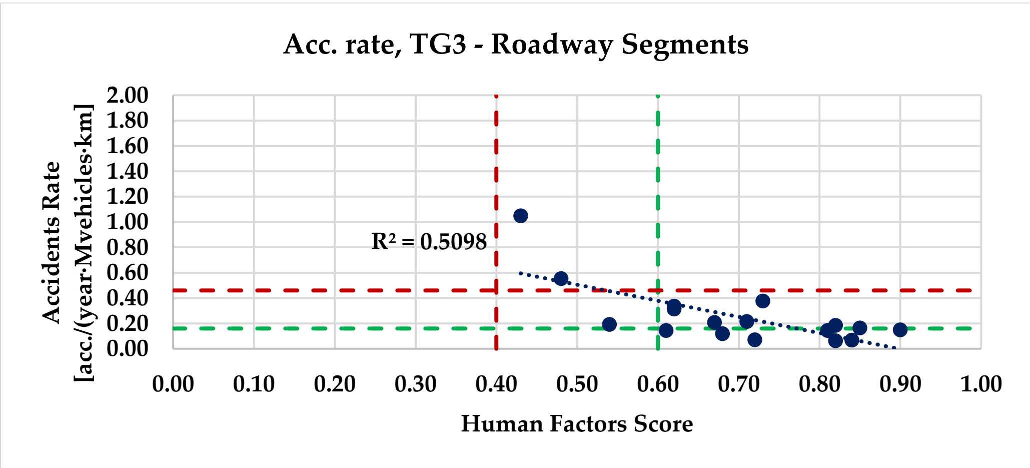
Appendix Figure 5 – Accidents Frequency, TG3 – divided by segment type, urban segments.



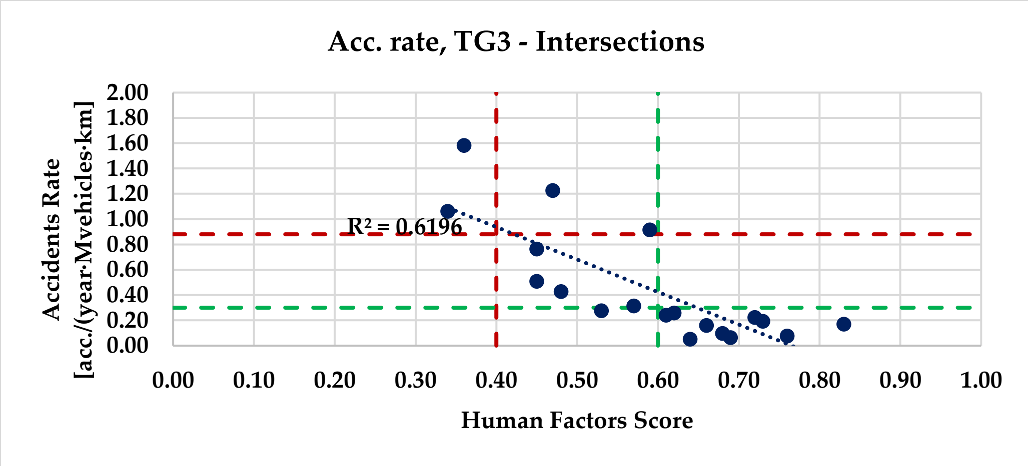
Appendix Figure 6 – Accidents Rate, TG1 – Total analyzed segments.



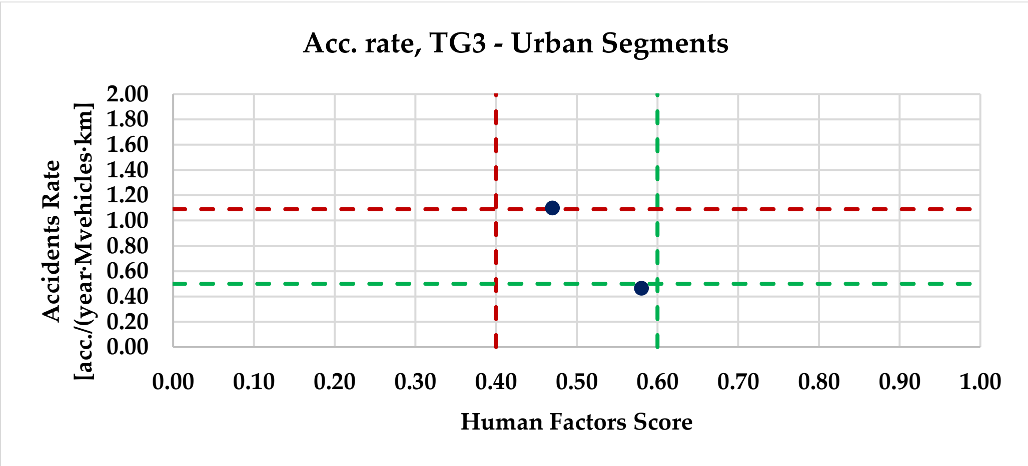
Appendix Figure 7 – Accidents Rate, TG2 – divided by roads.



Appendix Figure 8 – Accidents Rate, TG3 – divided by segment type, roadway segments.



Appendix Figure 9 – Accidents Rate, TG3 – divided by segment type intersections segments.



Appendix Figure 10 – Accidents Rate, TG3 – divided by segment type, urban segments.

APPENDIX 6 Evaluation of the Curvature Change Rate

In this appendix the results of the CCR calculation for the case study roads are presented. Satellite images of the road and statistics about road geometry are also presented. Statistics of the road comprehend:

- minimum radius length (R min),
- maximum radius length (R max),
- average radius length (R av),
- percentage of curve within the stretch (R %),
- minimum CCR of the single curve (CCR min),
- maximum CCR of the single curve (CCR max),
- average CCR of the single curve (CCR av),
- minimum straight length (L min),
- maximum straight length (L max),
- average straight length (L av), and
- percentage of straights within the stretch (L %).

The following graphs have the same ratio between x and y axis, even if the maximum and minimum value may change. Furthermore, the x-axis may include the km posts or simply the relative distance considering the 0 as the first point of analysis. This is because in some countries the km post restart for every intersection.

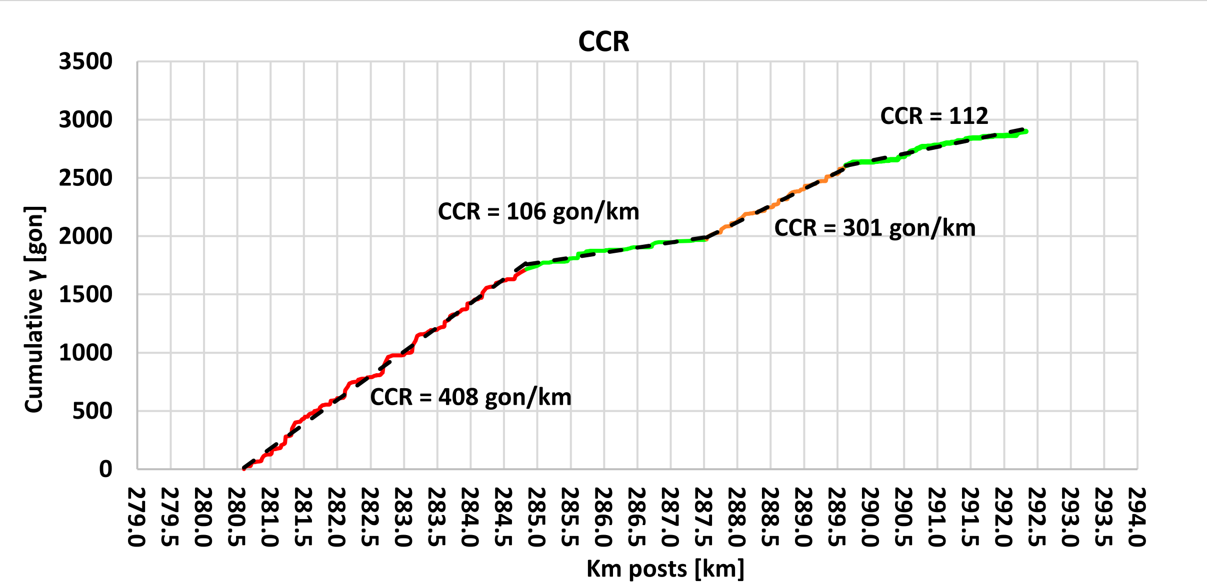
The presented CCRs concern the evaluation of the road stretch, without considering the EXSE division.

SR2

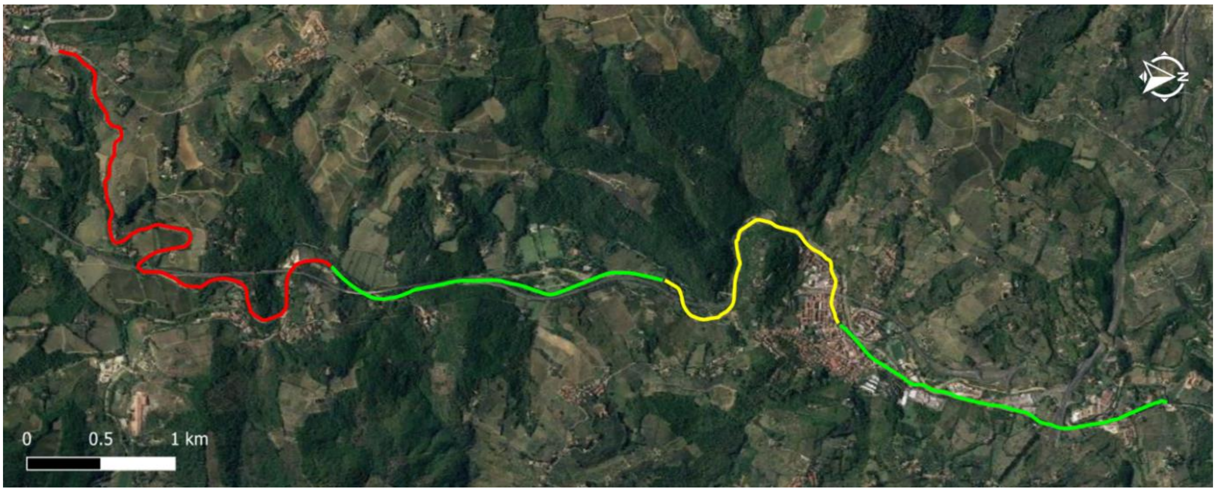
Appendix Table 14 – SR2, geometrical elements statistics

Stretch	Total CCR [gon/km]	Winding	R min [m]	R max [m]	R av [m]	R %* [%]	CCR min [gon/km]	CCR max [gon/km]	CCR av [gon/km]	L min* [m]	L max* [m]	L av* [m]	L %* [%]
1	408	H	36	270	110	46	236	1760	727	2	53	16	14
2	106	L	140	510	280	13	125	472	302	3	102	45	37
3	301	M	100	290	160	42	222	764	470	8	42	15	11
4	112	L	100	584	252	14	109	633	342	1	97	22	39

*When a clothoid was present, half has been added to the adjacent curve and half to the adjacent straight.



Appendix Figure 11 – SR2, cumulative deviation angles and CCR



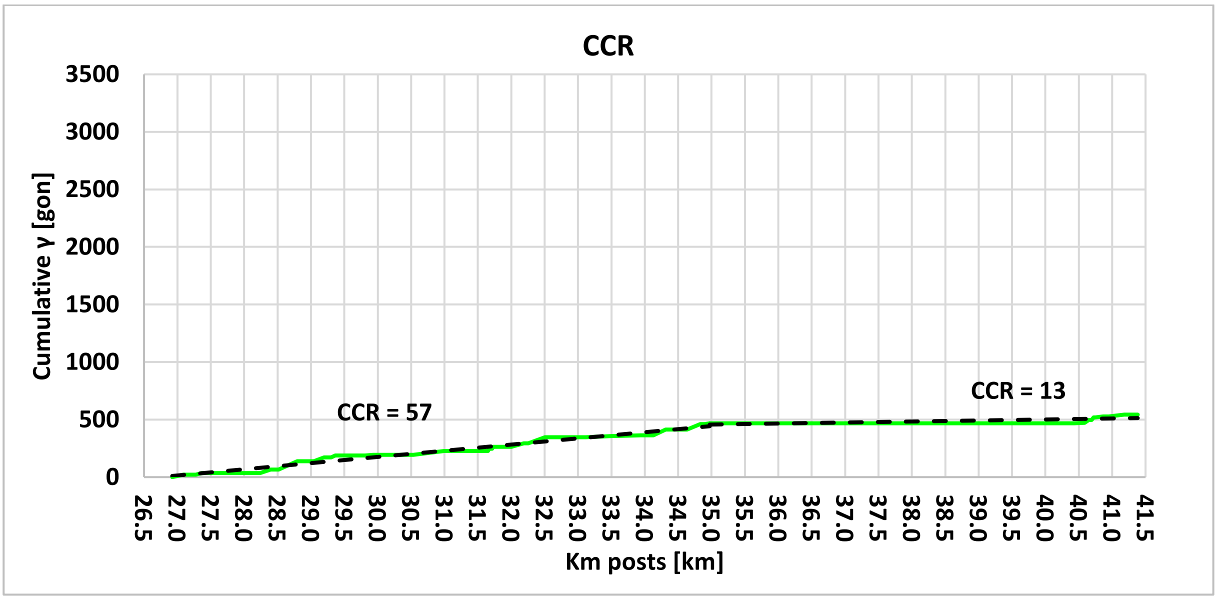
Appendix Figure 12 – SR2, stretches with the same CCR on satellite image (red= high CCR, yellow = medium CCR, green = low CCR)

SR206

Appendix Table 15 – SR206, geometrical elements statistics

Stretch	Total CCR [gon/km]	Winding	R min [m]	R max [m]	R av [m]	R %* [%]	CCR min [gon/km]	CCR max [gon/km]	CCR av [gon/km]	L min* [m]	L max* [m]	L av* [m]	L %* [%]
1	57	L	235	3120	812	37	20	270	157	24	876	280	63
2	13	L	140	510	280	9	29	374	135	2	5460	831	91

*When a clothoid was present, half has been added to the adjacent curve and half to the adjacent straight.



Appendix Figure 13 – SR206, cumulative deviation angles and CCR

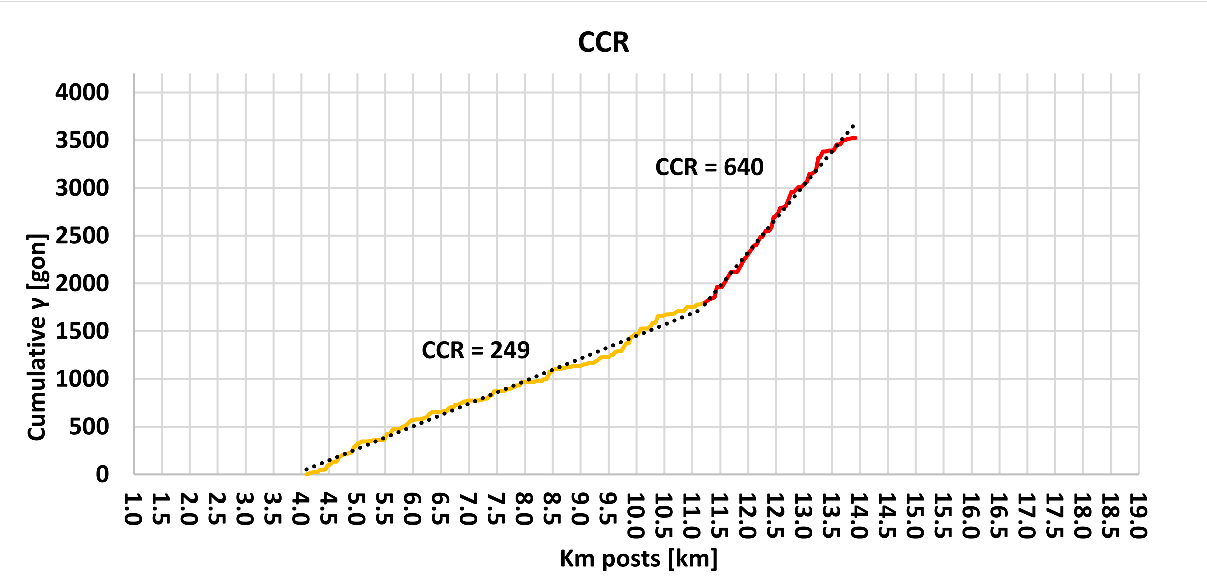
Appendix Figure 14 – SR206, stretches with the same CCR on satellite image (red= high CCR, yellow = medium CCR, green = low CCR)

SR302

Appendix Table 16 – SR302, geometrical elements statistics

Stretch	Total CCR [gon/km]	Winding	R min [m]	R max [m]	R av [m]	R %* [%]	CCR min [gon/km]	CCR max [gon/km]	CCR av [gon/km]	L min* [m]	L max* [m]	L av* [m]	L %* [%]
1	249	M	33	1024	172	45	20	270	157	1	177	60	55
2	640	H	24	537	100	70	29	374	135	10	89	38	30

*When a clothoid was present, half has been added to the adjacent curve and half to the adjacent straight.



Appendix Figure 15 – SR302, cumulative deviation angles and CCR

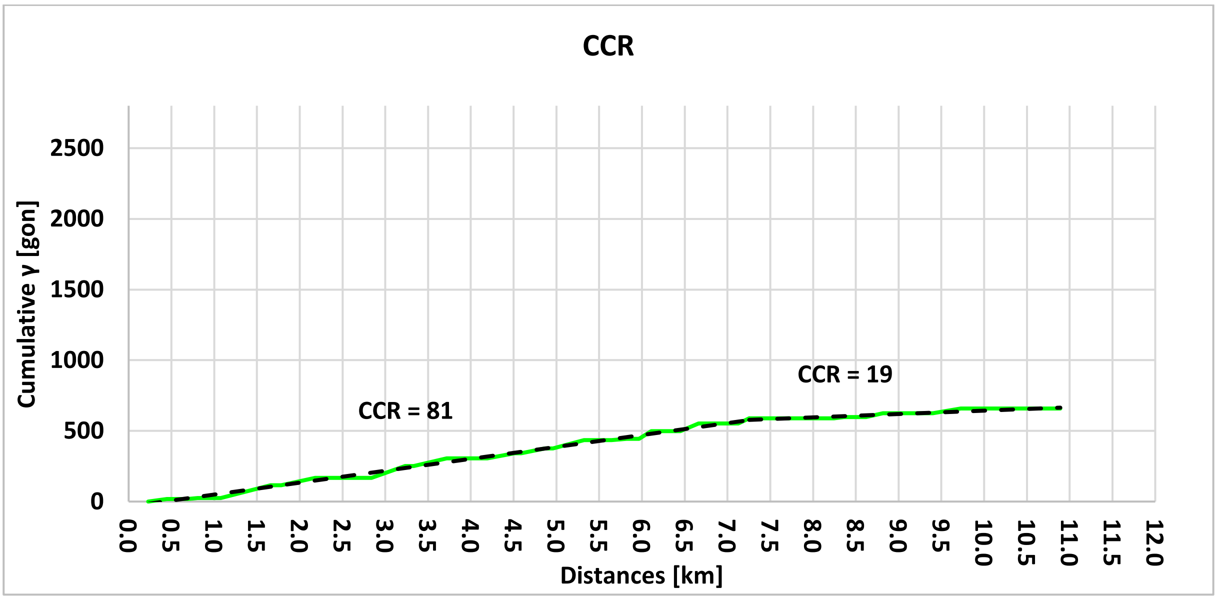
Appendix Figure 16 – SR302, stretches with the same CCR on satellite image (red= high CCR, yellow = medium CCR, green = low CCR)

B38

Appendix Table 17 – B38, geometrical elements statistics

Stretch	Total CCR [gon/km]	Winding	R min [m]	R max [m]	R av [m]	R %* [%]	CCR min [gon/km]	CCR max [gon/km]	CCR av [gon/km]	L min* [m]	L max* [m]	L av* [m]	L %* [%]
1	81	L	170	1200	531	51	53	374	165	80	659	272	49
2	19	L	460	870	650	18	73	138	105	257	1162	749	82

*When a clothoid was present, half has been added to the adjacent curve and half to the adjacent straight.



Appendix Figure 17 – B38, cumulative deviation angles and CCR

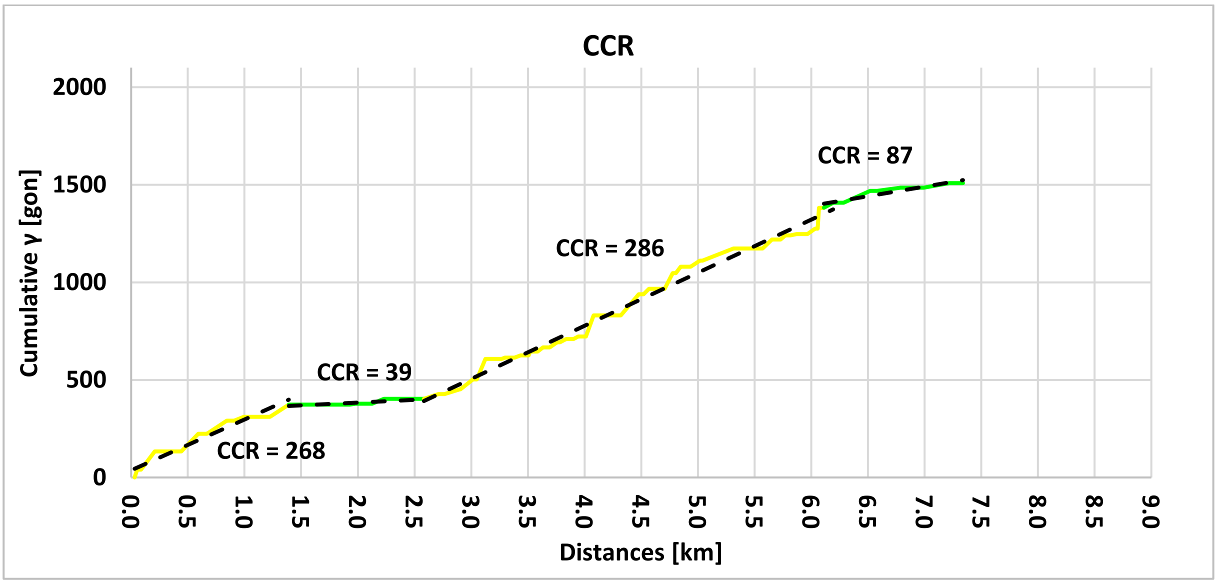
Appendix Figure 18 – B38, stretches with the same CCR on satellite image (red= high CCR, yellow = medium CCR, green = low CCR)

L3106

Appendix Table 18 – L3106, geometrical elements statistics

Stretch	Total CCR [gon/km]	Winding	R min [m]	R max [m]	R av [m]	R %* [%]	CCR min [gon/km]	CCR max [gon/km]	CCR av [gon/km]	L min* [m]	L max* [m]	L av* [m]	L %* [%]
1	268	M	36	270	138	51	236	1782	694	31	234	113	49
2	39	L	270	700	485	16	91	236	163	147	537	345	84
3	286	M	7	570	175	52	182	1591	609	3	256	77	48
4	87	L	200	800	463	62	80	318	190	62	203	120	38

*When a clothoid was present, half has been added to the adjacent curve and half to the adjacent straight.



Appendix Figure 19 – L3408, cumulative deviation angles and CCR

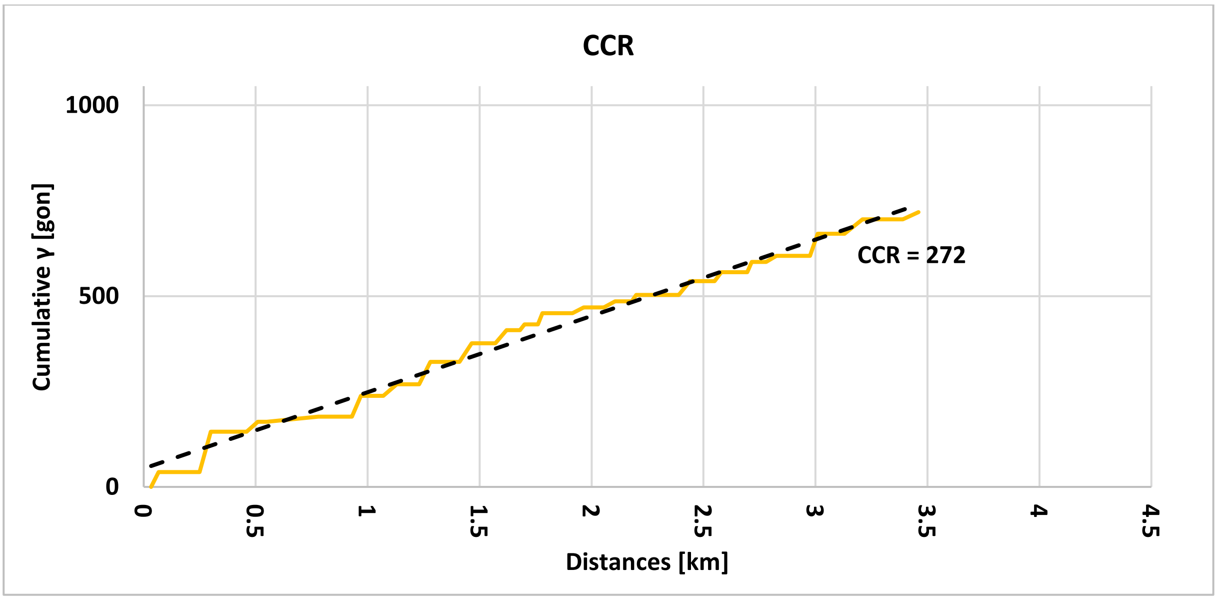
Appendix Figure 20 – L3408, stretches with the same CCR on satellite image (red= high CCR, yellow = medium CCR, green = low CCR)

L3408

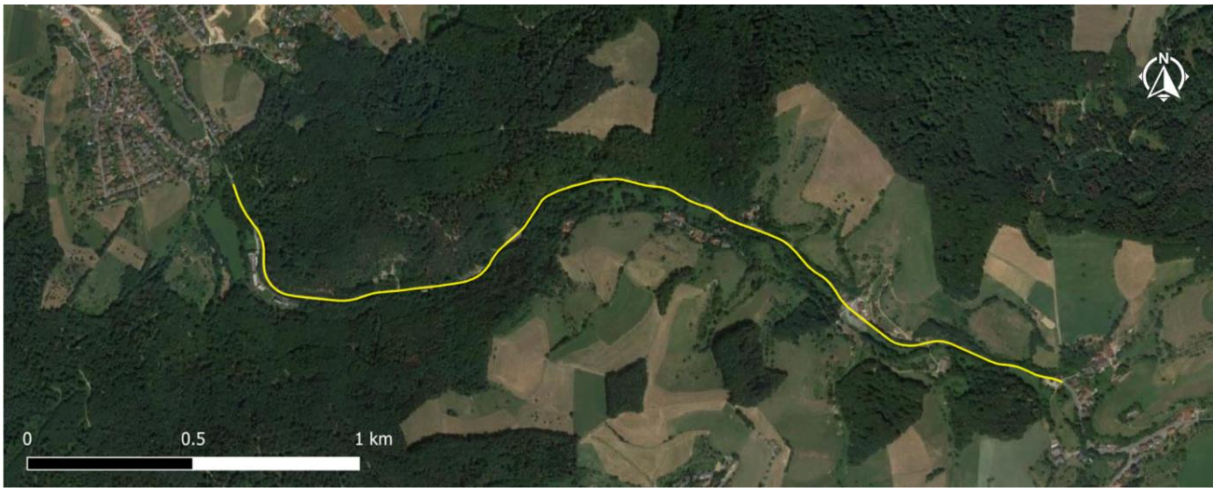
Appendix Table 19 – L3408, geometrical elements statistics

Stretch	Total CCR [gon/km]	Winding	R min [m]	R max [m]	R av [m]	R %* [%]	CCR min [gon/km]	CCR max [gon/km]	CCR av [gon/km]	L min* [m]	L max* [m]	L av* [m]	L %* [%]
1	272	M	75	220	138	55	289	849	498	18	255	59	45

*When a clothoid was present, half has been added to the adjacent curve and half to the adjacent straight.



Appendix Figure 21 – L3408, cumulative deviation angles and CCR



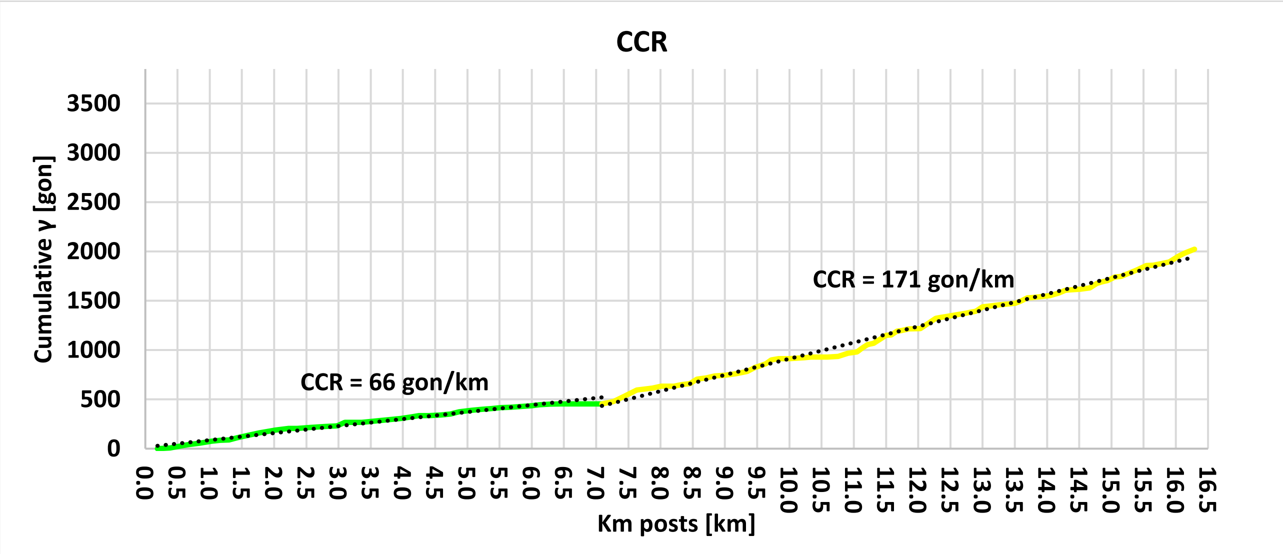
Appendix Figure 22 – L3408, stretches with the same CCR on satellite image (red= high CCR, yellow = medium CCR, green = low CCR)

106

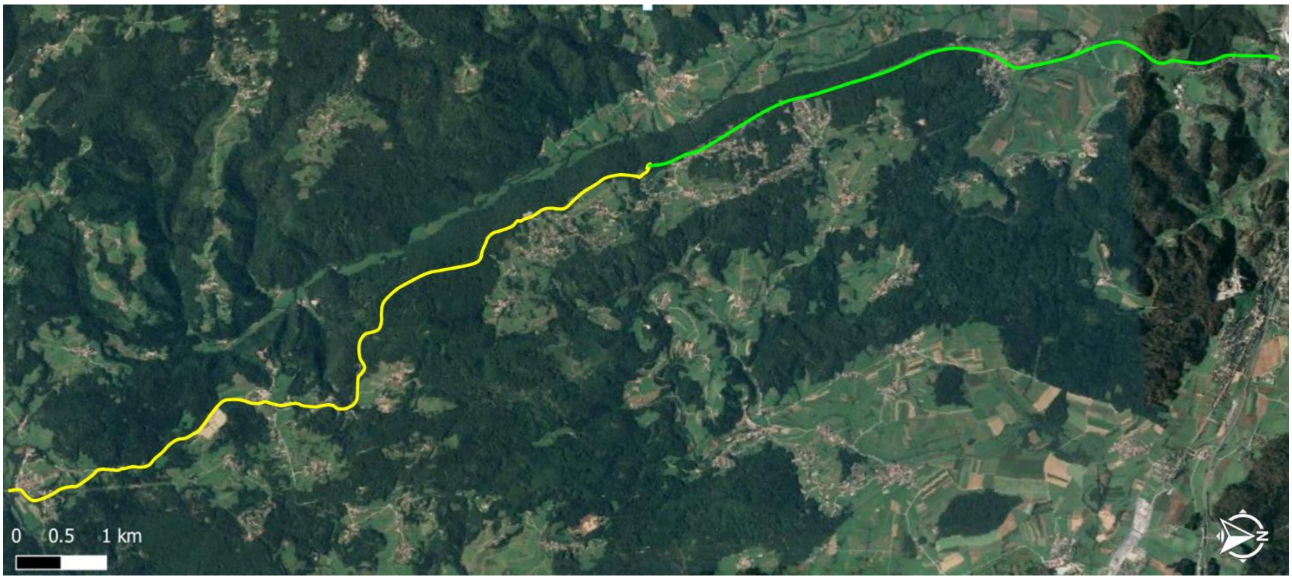
Appendix Table 20 – SR2, geometrical elements statistics

Stretch	Total CCR [gon/km]	Winding	R min [m]	R max [m]	R av [m]	R %* [%]	CCR min [gon/km]	CCR max [gon/km]	CCR av [gon/km]	L min* [m]	L max* [m]	L av* [m]	L %* [%]
1	66	L	200	5500	1285	84	12	318	85	135	632	297	16
2	171	M	130	4000	653	95	16	490	193	163	257	210	5

*When a clothoid was present, half has been added to the adjacent curve and half to the adjacent straight.



Appendix Figure 23 – 106, cumulative deviation angles and CCR



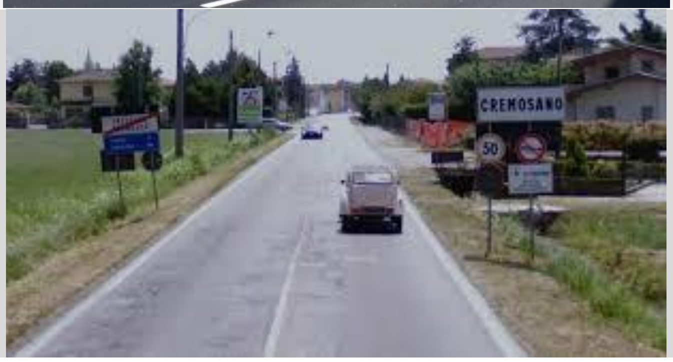
Appendix Figure 24 – 106, stretches with the same CCR on satellite image (red= high CCR, yellow = medium CCR, green = low CCR)

APPENDIX 7 Evaluation of Perceived Possible Interaction

In the following some images are presented as example of medium PPI level and low PPI level. The images are provided in two different table. Appendix Table 21 illustrates the examples of rural roads with a medium PPI, while Appendix Table 22 illustrates the examples of rural roads with low PPI. Each table provide the images in the first column and the source of the images on the second column.

Appendix Table 21 – Medium level PPI examples

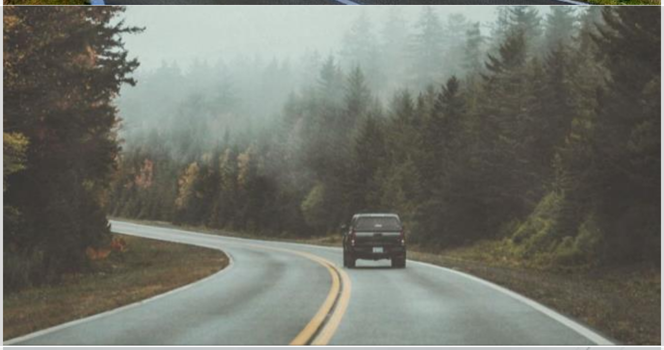
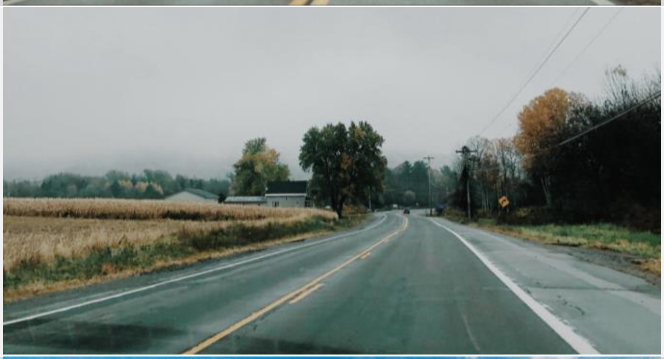
#	Image	Source
1		Google street view 01/03/2021
2		Google street view 01/03/2021
3		Google street view 01/03/2021

4		Google street view 01/03/2021
5		https://commons.wikimedia.org/wiki/File:Suburban_Road_near_Crownhill_-_geograph.org.uk_-_102420.jpg 01/03/2021
6		https://www.livingin-australia.com/melbourne-profile/ 01/03/2021
7		https://www.perugiaonline.net/strade-piu-sicure-a-magione-asfaltato-il-tratto-che-attraversa-il-centro-abitato-di-santarcangelo/ 01/03/2021
8		https://www.provincia.cremona.it/strade/all/lineeguidaCA.pdf 01/03/2021

9		https://www.comune.rosa.vi.it/it/news/interventi-per-maggiore-sicurezza-nelle-strade-prov 01/03/2021
10		https://www.sicurauto.it/news/codice-della-strada/cassazione-autovelox-fissi-solo-sulle-strade-urbane-di-scorrimento/ 01/03/2021
11		https://www.rimininotizie.net/cronaca/2020/05/25/rimini-dai-primi-di-giugno-tecnici-anas-al-lavoro-per-realizzare-la-nuova-circonvallazione-di-santa-giustina/ 01/03/2021

Appendix Table 22 – Low level PPI examples

	Image	Source
12		https://constructionreviewonline.com/news/madagascar-receives-us-140m-grant-for-rural-transport-project/ 01/03/2021

13		Google street view 01/03/2021
14		https://www.motorefashion.it/codice-strada-lart-2-classifica-definisce-strade-chiariamoci-po-idee/ 01/03/2021
15		https://wchstv.com/news/local/wva-radio-stations-asked-to-play-take-me-home-country-roads-456-pm-friday 01/03/2021
16		https://www.coffeeandcrumbs.net/blog/2020/11/6/country-roads-take-me-home 01/03/2021
17		https://www.aib-insurance.co.uk/news/driving-on-country-roads-is-more-dangerous-than-on-motorways 01/03/2021

18		Google street view 01/03/2021
19		Google street view 01/03/2021
20		https://www.iwanttoquitsmoking.com/understanding-and-combating-highway-hypnosis/ 01/03/2021
21		https://free4kwallpapers.com/nature/rain-clouds-wallpaper--9JY 01/03/2021

22		https://www.provincia.cremona.it/strade/all/lineeguidaCA.pdf 01/03/2021
23		https://www.blogsicilia.it/ragusa/autostrada-ragusa-catania-ce-la-nomina-del-commissario-esulta-il-pd/573626/ 01/03/2021
24		https://www.gonews.it/2019/03/27/cinrconvallazione-sud-empoli-cambia-viabilita/ 01/03/2021

APPENDIX 8 The "Roads' perception" survey results

69 participants took part to the survey. More than 95% of the participants answer to all the survey's question. However, because each road image is evaluated independently from the others, it has been decided to consider also partially compiled surveys.

One of the purposes of the survey, was to identify if PPI differences are easy identifiable and consistent with drivers' judgements. For this reason, it has been decided to test by means of Chi-square statistic and evaluation of contingency tables, the relationship between the PPI level of the road in the image, with reference to the images in APPENDIX 7, and the participants answers.

Some statistics of the participants sample are also provided in Appendix Table 23, Appendix Table 24, Appendix Table 25, and Appendix Table 26 concerning the age of the participants, the gender, from how long the participants have a driving license, and how many kms they travelled every years (on average).

Appendix Table 23 – Participants' statistics – age of participants

Age of participants	Number of answers	Percentage among the total
Less than 30 years old	9	22,50%
Between 30 and 45 years old	13	32,50%
Between 45 and 60 years old	6	15,00%
More than 60 years old	12	30,00%

Appendix Table 24 – Participants' statistics – gender

Participants' gender	Number of answers	Percentage among the total
Male	9	22,50%
Female	13	32,50%

Appendix Table 25 – Participants' statistics – driving license

Driving License owner from	Number of answers	Percentage among the total
Less than 5 years	9	22,50%
Between 5 and 20 years	13	32,50%
More than 20 years	12	30,00%

Appendix Table 26 – Participants' statistics – kms travelled

Kms travelled every year	Number of answers	Percentage among the total
Less than 5000 km	9	22,50%
Between 5000 and 20000 km	13	32,50%
More than 20000 km	12	30,00%

The Chi-square test has been applied considering the number of total answers for each question. Those questions are listed below.

1. How much attention is needed to drive safely on this stretch of road (much, moderate, little)?
2. How much comfortable and easy would be driving on this road (much, moderate, little)?
3. How probable is it that a little further on the road are there points where it is necessary to slow down (much, moderate, little)?
4. Which speed range (in km/h) do you think is acceptable (considering safety and functionality) to travel on this road (30-50, 50-70, 70-90, 90-110)?

For each question it has been compared the number and type of answers for each level of PPI (medium or low). The obtained contingency tables and the test significance are presented in Appendix Table 27, Appendix Table 28, Appendix Table 29, and Appendix Table 30.

Appendix Table 27 – Contingency table and Chi-square test results, question #1

Number of answers			
	Low PPI	**Medium PPI**	***Row Totals***
Much	176	227	*403*
Moderate	336	418	*754*
Little	383	112	*495*
Column Totals	*895*	*757*	**1652** (Grand Total)
$\chi^2(2,1652) = 153.28$, *p-value* < 0.05			

Appendix Table 28 – Contingency table and Chi-square test results, question #2

Number of answers			
	Low PPI	**Medium PPI**	***Row Totals***
Much	399	73	*472*
Moderate	361	372	*733*
Little	109	290	*399*
Column Totals	*869*	*735*	**1604** (Grand Total)
$\chi^2(2,1604) = 298.32$, *p-value* < 0.05			

Appendix Table 29 – Contingency table and Chi-square test results, question #3

Number of answers			
	Low PPI	**Medium PPI**	***Row Totals***
Much	69	383	*452*
Moderate	285	294	*579*
Little	504	48	*562*
Column Totals	*858*	*725*	**1583** (Grand Total)
$\chi^2(2,1583) = 587.94$, *p-value* < 0.05			

Appendix Table 30 – Contingency table and Chi-square test results, question #4

Number of answers			
	Low PPI	**Medium PPI**	***Row Totals***
30-50 km/h	20	247	*267*
50-70 km/h	239	339	*578*
70-90 km/h	397	118	*515*
90-110 km/h	198	19	*217*
Column Totals	*854*	*723*	**1577** (Grand Total)
$\chi^2(2,1577) = 501.68$, *p-value* < 0.05			

Appendix Table 30 shows also an interesting trend about speeds. Most of the particpants choose a speed range between 70 and 90 km for low PPI level roads, and between 50 and 70 km/h for medium PPI level roads. This is consistent with the expected speed defined for EXSEs based on their characteristics (5.3.3.2). To deepen this aspect, it has been decided to test by Chi-square test, also the relationship between the speed and the combination of winding and PPI level.

Appendix Table 31 – Contingency table and Chi-square test results, question #4, different combinations of winding/PPI

Number of answers						
	HL	**LM**	**LL**	**MM**	**ML**	***Row Totals***
30-50 km/h	8	132	8	115	4	267
50-70 km/h	30	217	123	122	86	578
70-90 km/h	22	94	243	24	132	515
90-110 km/h	6	18	151	1	41	217
Column Totals	*66*	*461*	*525*	*262*	*263*	**1577** (Grand Total)
$\chi^2(2,1577) = 583.75$, *p-value* < 0.05						

APPENDIX 9 Evaluation of the Expected Speed (V_E)

In order to define the V_E on the basis of the road stretch characteristics, the influence of road category, winding and PPI has been considered separately, at first. Then, the results of the analysis have been joined together. In the following, the results of the analysis for each road stretch characteristics are presented.

Influence of the road category on V_E

The proposed procedure tries to summarize in three groups all the rural road types in the world. Obviously, if on one hand, this allows to enormously simplify the procedure and allows to apply the procedure in all country of the world, on the other hand it creates some little ambiguity, putting together road types which may have some differences from one country to another. However, the defined category seems to work quite well when the objective is the definition of the V_E. Appendix Table 32 shows some examples of roads and their associated design speed (V_P) and/or operating speed (V_{85}) according to the design standards of different countries. The road category has been defined based on the definitions provided in 5.3.3.2, and not on the definition of the single country. Rural highways are the focus of this work; thus, they have been highlighted in the table.

Appendix Table 32 – Design Speed (V_D) and Operating Speed (V_{85}) of different roads in different countries

Road Category	Road Country's Classification	Country	V_P [km/h]	V_{85} [km/h]
Motorway	Autostrada	Italy	90-140	-
Motorway	Strada Extraurbana Principale	Italy	70-120	-
Rural Highway	**Strada Extraurbana Secondaria**	**Italy**	**60-100**	**-**
Rural Local	Strada Locale extraurbana	Italy	40-100	-
Motorway	AS 0 / AS I (rural)	Germany	130	-
Motorway	AS II (rural)	Germany	120	-
Motorway	AS 0 / AS I / AS II (rural, EKA 2)	Germany	100	-
Rural Highway	**LS I**	**Germany**	**110**	**-**
Rural Highway	**LS II**	**Germany**	**100**	**-**
Rural Highway	**LS III**	**Germany**	**90**	**-**
Rural Local	LS IV	Germany	70	-
Motorway	IP / IC (motorway)	Portugal	120/140	130/140
Rural Highway	**IC (not motorway)**	**Portugal**	**80**	**100**
Rural Highway	**IC**	**Portugal**	**80**	**100**
Rural Highway	**EN**	**Portugal**	**60/80**	**80/100**
Rural Highway	**ER**	**Portugal**	**60/80**	**80/100**
Motorway	M (Class 1)	Australia	$\geq V_{85}$	100-110
Rural Highway	**A (Class 2)**	**Australia**	$\geq V_{85}$	**100-110**

Rural Highway	**B or C (Class 3) (High Speed)**	**Australia**	**$\geq V_{85}$**	**90-110**
Rural Highway	**B or C (Class 3) (Intermediate Speed)**	**Australia**	**$\geq V_{85}$**	**70-80**
Rural Highway	**B or C (Class 3) (Low Speed)**	**Australia**	**$\geq V_{85}$**	**60**
Rural Local	Class 4 (High Speed)	Australia	$\geq V_{85}$	90-110
Rural Local	Class 4 (Intermediate Speed)	Australia	$\geq V_{85}$	70-80
Rural Local	Class 4 (Low Speed)	Australia	$\geq V_{85}$	60
Motorway	Autobahnen und Schnellstraßen	Austria	100-130	-
Rural Highway	**Hauptverkersstraßen**	**Austria**	**80-100**	**-**
Rural Highway	**Regionale Straßen mit größerer Verkehrbedeutung**	**Austria**	**60-80**	**-**
Rural Local	Regionale Straßen mit geringerer Verkehrbedeutung	Austria	40-60	-
Motorway	AC (Avtocesta)	Slovenia	80-130	-
Motorway	HC (Hitra cesta)	Slovenia	70-120	-
Rural Highway	**GC (Glavna cesta)**	**Slovenia**	**60-100**	**-**
Rural Highway	**RC (Regionalna cesta)**	**Slovenia**	**50-80**	**-**
Rural Local	LC (Lokalna cesta)	Slovenia	40-60	-
Motorway	Freeway	Canada	100-130	-
Rural Highway	**Arterial**	**Canada**	**80-130**	**-**
Rural Highway	**Collector**	**Canada**	**60-110**	**-**
Rural Local	Local	Canada	50-110	-
Motorway	D2M, D3M, D4M	United Kingdom	120	-
Motorway	D2AP, D3AP	United Kingdom	100-120	
Rural Highway	**WS2, WS2+1**	**United Kingdom**	**100-120**	**-**
Rural Highway	**S2**	**United Kingdom**	**70-100**	**-**
Motorway	Hochleistungsstrassen	Switzerland	80-120	-
Rural Highway	**Hauptverkehrsstrassen**	**Switzerland**	**60-80**	**-**
Rural Local	Verbindungsstrassen	Switzerland	50-80	-

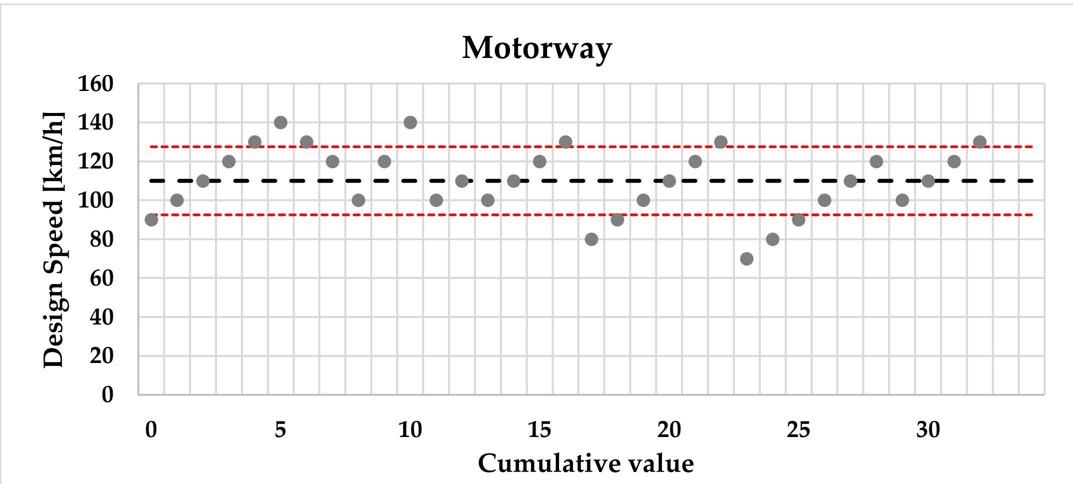
Data has been taken from:

- Australian design standards (Austroads, 2021) (Austroads, 2019)
- Canadian design standards (TAC, 2017)
- English design standards (Highways England, 2020)
- German design standards (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2008) (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012)
- Italian design standards (Ministero delle Infrastrutture e dei Trasporti, 2001)
- Portuguese design standards (Instituto da Mobilidada e dos Trasportes, 2010)
- Slovenian design standards (PIS, 2021)
- Swiss design standards (Vereinigung Schweizerischer Strassenfachleute, 1991)

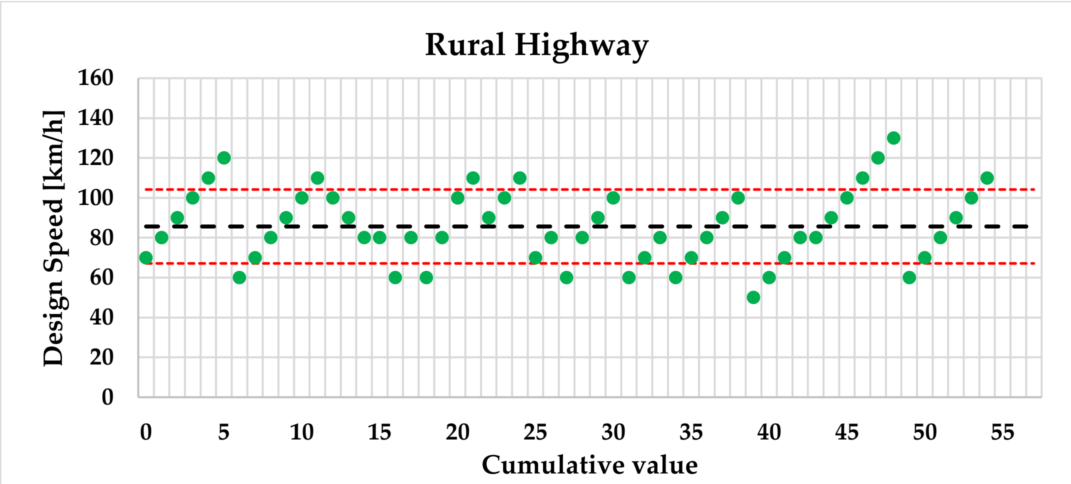
It is important to notice that, while motorways characteristics are very similar in many countries, rural highways and rural local roads have a higher variability, both in terms of speed and cross-sectional organization. Nevertheless, the most recurrent and common cross-section for these last two road categories is undoubtebly the two-lane two-way cross-section. The definition provided in 5.1.3 about road category, is suitable for all the analyzed roads. Appendix Table 33 shows the minimum, maximum and average design speed for each road category, considering the values presented in Appendix Table 32. The average speed and the standard deviation (sample) have been calculated assuming a different road for every 10 km/h in the speed range (e.g., RC (Regionalna cesta) with a range of 50-80, has been considered as RC(1) – speed 50, RC(2) – speed 60, RC(3) – speed 70, RC(4) – speed 80, otherwise an average value can't be considered). Furthermore, it must be noted that the design speed, both if a single speed or if a range of speeds are present, for some design standards represents the minimum reference value required to design the road elements, thus the road, once builded, will have with high probability a range of operating speed greater than the design speed. Appendix Table 33 shows the main statistics of the presented design standards of different countries, in terms of minimum design speed, maximum design speed, average design speed and design speed standard deviation, for each road category identified. The results of the analysis are also illustrated by graphs in Appendix Figure 25, Appendix Figure 26, and Appendix Figure 27. The single points represent the speed of all the identified different road (considering a different road every 10 km if a range of speed is provided).

Appendix Table 33 – Minimum and maximum speed values for each road category

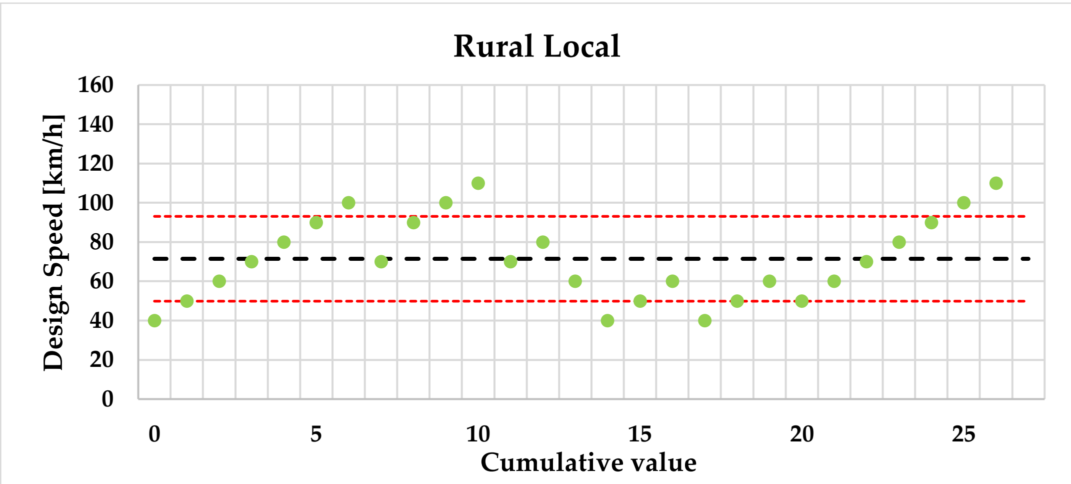
Road Category	Minimum Design Speed [km/h]	Maximum Design Speed [km/h]	Average Design Speed [km/h]	Standard Deviation [km/h]
Motorway	70	140	108	18
Rural Highway	50	130	85	18
Rural Local	40	110	71	22



Appendix Figure 25 – Design speed, design speed average and standard deviation for motorways



Appendix Figure 26 – Design speed, design speed average and standard deviation for rural highways



Appendix Figure 27 – Design speed, design speed average and standard deviation for rural locals

From Appendix Table 33, Appendix Figure 25, Appendix Figure 26, and Appendix Figure 27, some conclusions can be drafted:

- Motorway typical design speed appers to be more than 100 km/h;
- Rural Highway typical design speed is between 80 and 90 km/h;
- Rural Local roads are very similar to Rural Highways, but with a slight speed reduction, with a typical design speed of about 70 km/h;
- For all roads category, the speed range is wide (70 km/h, with a standard deviation of about 20 km/h), thus it is confirmed that in all the analyzed countries the design speed derives not only from the road type, but also from other charcteristics, such geometry.

Influence of winding on V_E

Looking again at the considered design standards, it can be noticed that the definition of speed is strictly linked to the geometry of the road, and thus to the winding, which comprehends the curve radii and the curve developments in a stretch of road.

For example, Italian standards set the speed of curve on the basis of the curve balance, thus considering the radius, the trasversal slope and the trasversal friction. Then, they required a minimum length of the curve of 2.5 seconds (thus varying with speed) and they required a consistency between consecutive curve. This will assure a gradual change in speeds and a choice of speed based on the geometry restraints.

Some even more clear examples derive from the design standards of Australia, Slovenia, and the United Kingdom, which identify different speed range on the basis of the terrain type that the road travels, and so the required curve radii. Some extract of the design standards are presented below. Appendix Figure 28 shows the design speed of different roads based on the terrain type. The figure is an extract from the Slovenian design standards.

Function and type of road	Plain and hilly terrain (km / h)	Hilly terrain (km / h)	Mountain terrain (km / h)
Long distance roads - DC			
Highway - AC	130	100	80
Expressway - HC	120	100	70
Main road - GC	100	80	60
Connecting roads - PC			
Main road - GC	90	70	60
Regional road - RC	80	60	50
Collective roads - ZC			
Regional road - RC	70	50	40
Local road - LC	60	50	40
Access roads - DP			
Local road - LC	50	40	transportability
Local route - LP	40	transportability	transportability

Appendix Figure 28 - Reference table for the typical design speed for rural roads where speeds are influenced by the road type and the complexity of the terrain (PIS, 2021)

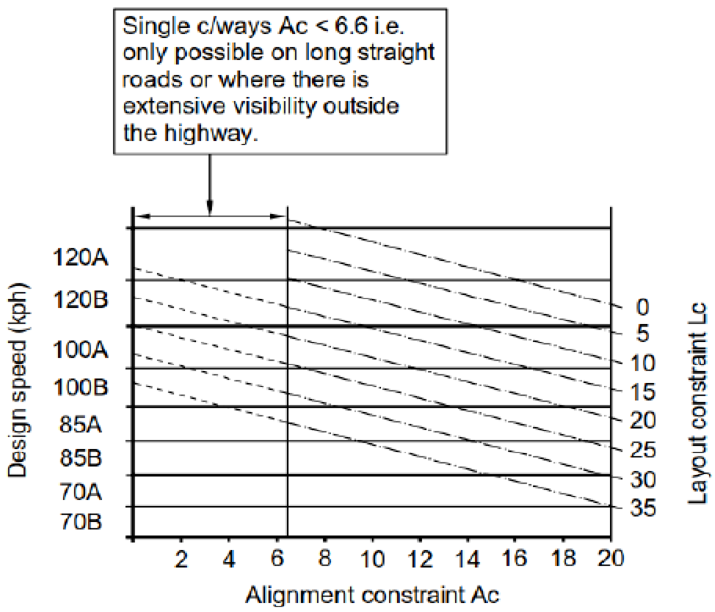
Appendix Figure 29 shows a table from the Australian design standards regulation, which identify some speed ranges of desired speed based on the terrain type and the approximate range of horizontal curve radius.

Approximate range of horizontal curve radii (m)[1]	Desired speed (km/h)[2, 3] Terrain type			
	Flat	Undulating	Hilly	Mountainous
Less than 75	–	–	75	70
75–300	–	90	85	80
150–500	110	100–110	95	90
Over 300–500	110	110	–	–
Over 600–700	110–120	–	–	–

1 *Value selected as representative of the road section's general geometric standard. These are not to be used as design values.*
2 *Desired speed as a function of overall geometric standard and terrain type. It is the speed regarded as acceptable to most drivers in the particular environment, and represented by the 85th percentile speed on unconstrained sections, e.g. straights, curves with radii well above those listed.*
3 *On roads with a speed limit < 100 km/h, the desired speed is typically equal to the speed limit + 10 km/h.*

Appendix Figure 29 – Reference table for the typical desired speed for rural roads where speeds are influenced by the horizontal alignment (Austroads, 2021)

Finally, a last example is taken from the United Kingdom design standards. Appendix Figure 30 shows the graph required to select the design speed of a rural road relying both on the alignment constraints and on the layout constraints. The first derives from the bendiness and the harmonic mean of visibility along the road, while the second derive from the verge wide, the road type and the density of commercial access, lay-bys, and junction. This also confirmed the importance of the possible interactions and their possible influence on driver speed.



Appendix Figure 30 – Reference graph for the definition of the design speed (Highways England, 2020)

All these examples provide some suggestions on how to define the speed range for different road types with different winding.

In the present work it has been decided to base the winding classification and the consequent influence on speed on CCR. The CCR has been widely used in literature to calculate the operating speed, both as a single influencing variable, both as a set of variable. In the following, some equations used to calculate the speed on the basis of CCR for rural two-lane two-way road (i.e. rural highways and rural local) are provided in order to validate the choice made in the procedure for the definition of the EXSE (see 5.3.3.2). The calculated speed represents a general value of the speed which refers to the geometrical charcateristics of the road.

Rural Highways

The first proposed equation is provided by Marchionna and Perco (Marchionna and Perco, 2008):

$$V_{des} = 123.54 - 2.79 \times \mathrm{CCR}^{0.47}$$ *Appendix Equation 1*

Where:

V_{des} = desired speed (km/h)

CCR = curvature change rate (gon/km)

A second equation to evaluate the desired speed on rural highways has been provided by (Abate, 2009):

$$V_{des} = 97.8514 - 0.05191 \times \mathrm{CCR}$$ *Appendix Equation 2*

Where:

V_{des} = desired speed (km/h)

CCR = curvature change rate (gon/km)

Koeppel (Koeppel, 1984), starting from analyzing data of German roads, proposed the following two equations:

$$V_{85} = 0.065 + 0.484 \times \mathrm{V}_{50} + 1.869 \times {\mathrm{V}_{50}}^{2} \times 10^{-2} - 1.349 \times {\mathrm{V}_{50}}^{3} \times 10^{-4}$$ *Appendix Equation 3*

$$V_{50} = 65.23 + 4.293 \times \mathrm{b} - 0.0756 \times \mathrm{CCR} + 0.0000364 \times \mathrm{CCR}^{2}$$ *Appendix Equation 4*

Where:

V_{85} = operating speed on a road stretch (i.e., environmental speed) (km/h)

V_{50} = fiftieth percentile of speeds on a road stretch (i.e., environmental speed) (km/h)

CCR = curvature change rate (gon/km)

b = width of the paved cross section (lanes and shoulders) (m)

Xenakis (Xenakis, 2008) proposed the following equation to calculate the operating speed on rural two-lane two-way highways, based on Greek data:

$$V_{85} = \frac{111222.738}{CCR + 994.957}$$ *Appendix Equation 5*

Where:
V_{85} = operating speed on a road stretch (i.e., environmental speed) (km/h)
CCR = curvature change rate (gon/km)

Rural Local
A first equation for local rural roads is provided by Cafiso et al. (Cafiso et al., 2008):

$$V_{env} = 100.05 - 0.197 \times \mathrm{CCR} + 2.147 \times \mathrm{W}$$ *Appendix Equation 6*

Where:
V_{env} = environmental speed (km/h)
CCR = curvature change rate (gon/km)
W = width of the paved cross section (lanes and shoulders) (m)

Another equation has been suggested by Dell'Acqua (Dell'Acqua, 2015):

$$V_{env} = 82.84 - 0.1033 \times \mathrm{CCR} + 3.44 \times \mathrm{L}$$ *Appendix Equation 7*

Where:
V_{env} = environmental speed (km/h)
CCR = curvature change rate (gon/km)

The six equations have been applied to a set of different CCR (ranging from 40 to 500 gon/km), considering a paved road width of 9.5 m (1 + 3.75 + 3.75 + 1). The results are shown in Appendix Table 34 where A, B, C, D, E, and F represent respectively Appendix Equation 1, Appendix Equation 2, , Appendix Equation 3, Appendix Equation 5, Appendix Equation 7, and Appendix Equation 6. The colors in the table represents the winding level (i.e., High = CCR > 350, Medium = 350 > CCR > 160, Low = CCR < 160). The same results are presented by graph in Appendix Figure 31. The symbols in the graphs represents the rural highways (circles) and the rural local roads (triangles).

Concerning the rural highways models, A, B and D provide very similar results. Model C shows instead a greater variation in the results, thus a higher influence of the CCR on operating speed. Hover, increasing the CCR, also model C converges to the results of model A, B, and D.

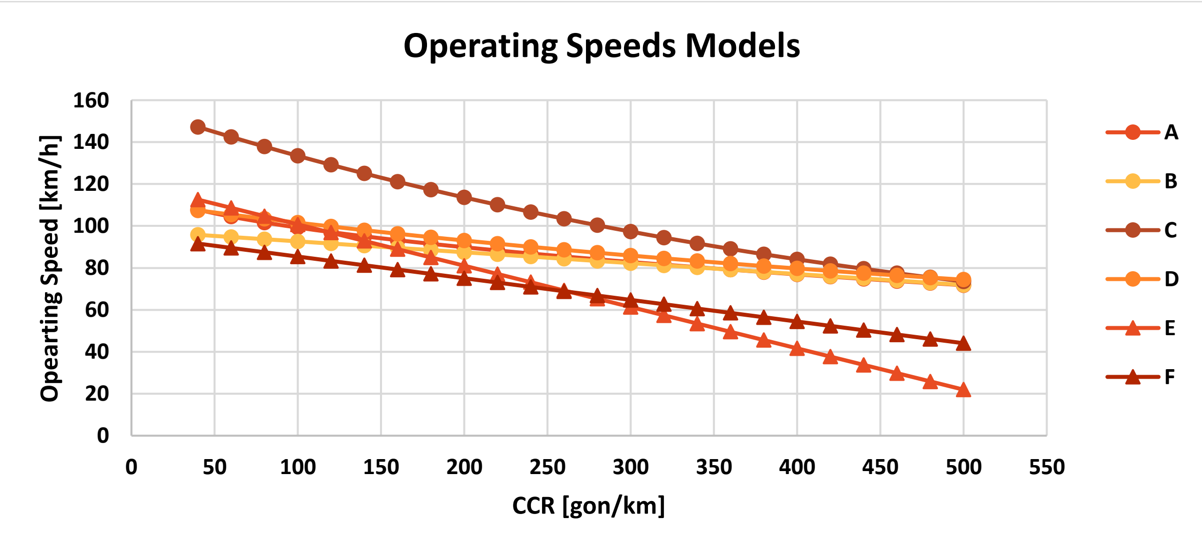
Considering the three different level of CCR identified, the results of the predictive model A, B and D suggest that for low CCR (green) the speeds range between 90 km/h and 110 km/h, for medium CCR (yellow) the speeds range between 80 km/h and 90 km/h, and for high CCR (red) the speeds range between 70 km/h and 80 km/h.

Equations for local rural roads shows maximum values that are similar to the ones of rural highways, however the operating speed decrease faster with the increase of the CCR. Furthermore, the two predicting model show some difference between each other.

From Appendix Table 34 it can be drafted that generally:

- For CCR ≤ 160 gon/km, all the models identify a speed always higher than 80 km/h;
- For CCR ≤ 350 gon/km and >160 gon/km, operating speed on rural highway are higher than 80 km/h, while operating speed on rural local roads are 15-20 km/h lower;
- For CCR > 350 gon/km, operating speed on rural highway are higher than 70 km/h, while operating speed on rural local roads are 20-30 km/h lower.

It must be underlined that equations A and B, evaluate the desired speed, which is the operating speed to which the driver tends under unconstrained conditions. Consequently, the speed along a road stretch of a given CCR will be always lower (or equal) than the one identified by the model.



Appendix Figure 31 – Operating speeds for different CCR for different models

Appendix Table 34 – Evaluation of the desired/environmental speed calculated with literature equations

CCR	V_{des} / V_{env} / V_{85}					
	A	B	C	D	E	F
20	112.14	96.81	100.80	109.58	116.51	93.67
40	107.74	95.78	100.79	107.47	112.57	91.61
60	104.43	94.74	100.69	105.43	108.63	89.54
80	101.66	93.70	100.50	103.47	104.69	87.48
100	99.24	92.66	100.23	101.58	100.75	85.41
120	97.07	91.62	99.88	99.76	96.81	83.34
140	95.08	90.58	99.47	98.00	92.87	81.28
160	93.23	89.55	99.00	96.30	88.93	79.21
180	91.51	88.51	98.48	94.66	84.99	77.15
200	89.88	87.47	97.91	93.08	81.05	75.08
220	88.34	86.43	97.30	91.54	77.11	73.01
240	86.87	85.39	96.65	90.06	73.17	70.95
260	85.46	84.35	95.97	88.63	69.23	68.88
280	84.12	83.32	95.27	87.24	65.29	66.82
300	82.82	82.28	94.54	85.89	61.35	64.75
320	81.56	81.24	93.79	84.58	57.41	62.68
340	80.35	80.20	93.04	83.32	53.47	60.62
360	79.17	79.16	92.27	82.09	49.53	58.55
380	78.03	78.13	91.49	80.89	45.59	56.49
400	76.92	77.09	90.71	79.73	41.65	54.42
420	75.84	76.05	89.93	78.61	37.71	52.35
440	74.78	75.01	89.15	77.51	33.77	50.29
460	73.75	73.97	88.38	76.44	29.83	48.22
480	72.75	72.93	87.61	75.41	25.89	46.16
500	71.77	71.90	86.86	74.40	21.95	44.09

Considering the influence of the road category and the winding, the following conclusions have been drafted.

Appendix Table 35 – Expected Speed related to the stretch characteristics

Road category	Winding	V_E [km/h]
MT	M	> 90
MT	L	> 110
RH	H	60-80
RH	M	80-90
RH	L	90-110
RL	H	50-70
RL	M	70-80
RL	L	80-100

Influence of PPI on V_E

The PPI (perception of possible interaction) is a concept introduced to account for the influence of possible conflicts points on speed and alertness. Such conflicts points must not only be present but must be clearly perceived by the driver. Some specific literature presents such conflicts points as factors influencing speed (Campbell et al., 2012): the higher the number of those points, the minor the operating speed. Starting from this concept as the basis for the following considerations, it must be clear that the inspector must try to figure out if this "risky environment" is well perceived or not. The influence of some specific road elements on speed are also highlighted by the design standards analyzed in the previous paragraphs.

United Kingdom design standards consider, for example, the layout constraints that are and the density of commercial access, lay-bys, and junction (Appendix Figure 30). To these, bus stops, pedestrian and bicycle crossings should be added. Furthermore, these elements are related to the environment: many houses in the outer margins suggest a higher possibility of access and crossings. Some examples of different environment composition and the related PPI level are presented in APPENDIX 7.

Because the presence of those elements often reduces the driver speed choice, it has been considered that low PPI will have no influence on the speed, medium PPI will have a medium influence on speed, and high PPI will have a high influence of speed. However, rural roads can't be never considered to have a high PPI, and motorways can't be never considered to have a medium or high PPI.

The combination of road category, road winding and road PPI, provides the results in Table 5.18, which are presented again in Appendix Table 36.

Appendix Table 36 – Expected Speed related to the stretch characteristics

Road category	Winding	PPI	V_E [km/h]
MT	M	L	H (80-100)
MT	L	L	F (>100)
RH	H	M	M (50-80)
RH	H	L	M (50-80)
RH	M	M	M (50-80)
RH	M	L	H (80-100)
RH	L	M	M (50-80)
RH	L	L	H (80-100)
RL	H	M	L (0-50)
RL	H	L	M (50-80)
RL	M	M	M (50-80)
RL	M	L	M (50-80)
RL	L	M	M (50-80)
RL	L	L	H (80-100)

These results are confirmed by the outcomes of the survey presented in APPENDIX 8.

Comparison between the actuated speed and the assumed V_E

A comparison has been made between the speed detected during the road inspection and the ranges of V_E identified by the procedure. The speed detected during the survey have been obtained through the data of the high resolution camera used to make the video recording, while driving at "normal" speed, that is the speed that the inspector should normally hold while driving on the stretch (whe they are not making an inspection). This speed is chosen as representative of the operating speed, even if only 6 driving have been recorded (3 for each direction). For this reason, this comparison is qualitative and of not proven significance, but the results confirm the correspondence between the theoretical assumptions and the reality.

APPENDIX 10 Application of AHP to evaluate GEX

A survey has been conducted to evaluate if drivers' expectations about PCLs are consistent with the level of GEX identified through the analysis of some design standards (as discussed in 5.3.3.3).

Participants were asked to evaluate which PCL is more expected among all PCLs considering different level of winding and PPI. This evaluation was made using the AHP.

One Excel file has been provided for each different PCL, each different type of PCLs, and each combination of winding and PPI, for a total of 48 Excel files. Those file were made and provided by Goepel (Goepel, 2018).

The participants compiled each Excel file. The results for the PCLs' types are provided in this ANNEX considering the total weights calculated from the answer of the 20 participants. The consistency ratio obtained is also provided. To consider a good agreement between the participants and to prove that the different evaluations of the same participant are consistent, the consistency ratio should be less than 10%. The less the consistency ratio, the greater the consistency. In the following tables acronyms assume the following meanings: RH = Rural Highways, HL = high winding and low PPI, HM = high winding and medium PPI, ML = medium winding and low PPI, MM = medium winding and medium PPI, LL = low winding and low PPI, LM = low winding and medium PPI. The results concerning the single PCLs are available under request.

Appendix Table 37 – AHP results, PCLs Type, RH-HL

PCLs Type	Weights	Relative Error
Curve	46.5%	14.4%
At-grade intersection	10.7%	1.6%
Driveway	13.4%	2.2%
Lane change	6.3%	0.8%
Stopping area	14.2%	2.1%
Railway intersection	3.1%	1.2%
Crossing	5.8%	1.5%
Consistency Ratio = 2.0%		

Appendix Table 38 – AHP results, PCLs Type, RH-HM

PCLs Type	Weights	Relative Error
Curve	39.5%	10.1%
At-grade intersection	14.8%	2.2%
Driveway	15.0%	2.0%
Lane change	7.6%	0.7%
Stopping area	11.6%	2.2%
Railway intersection	3.6%	1.1%
Crossing	7.8%	1.3%
Consistency Ratio = 1.4%		

Appendix Table 39 – AHP results, PCLs Type, RH-ML

PCLs Type	Weights	Relative Error
Curve	35.9%	7.6%
At-grade intersection	15.3%	2.1%
Driveway	15.8%	1.8%
Lane change	7.2%	0.7%
Stopping area	13.5%	1.1%
Railway intersection	4.3%	0.9%
Crossing	8.1%	0.8%
Consistency Ratio = 0.8%		

Appendix Table 40 – AHP results, PCLs Type, RH-MM

PCLs Type	Weights	Relative Error
Curve	26.9%	3.3%
At-grade intersection	18.2%	1.5%
Driveway	19.4%	1.3%
Lane change	8.8%	0.5%
Stopping area	12.6%	1.2%
Railway intersection	4.5%	0.8%
Crossing	9.6%	1.2%
Consistency Ratio = 0.5%		

Appendix Table 41 – AHP results, PCLs Type, RH-LL

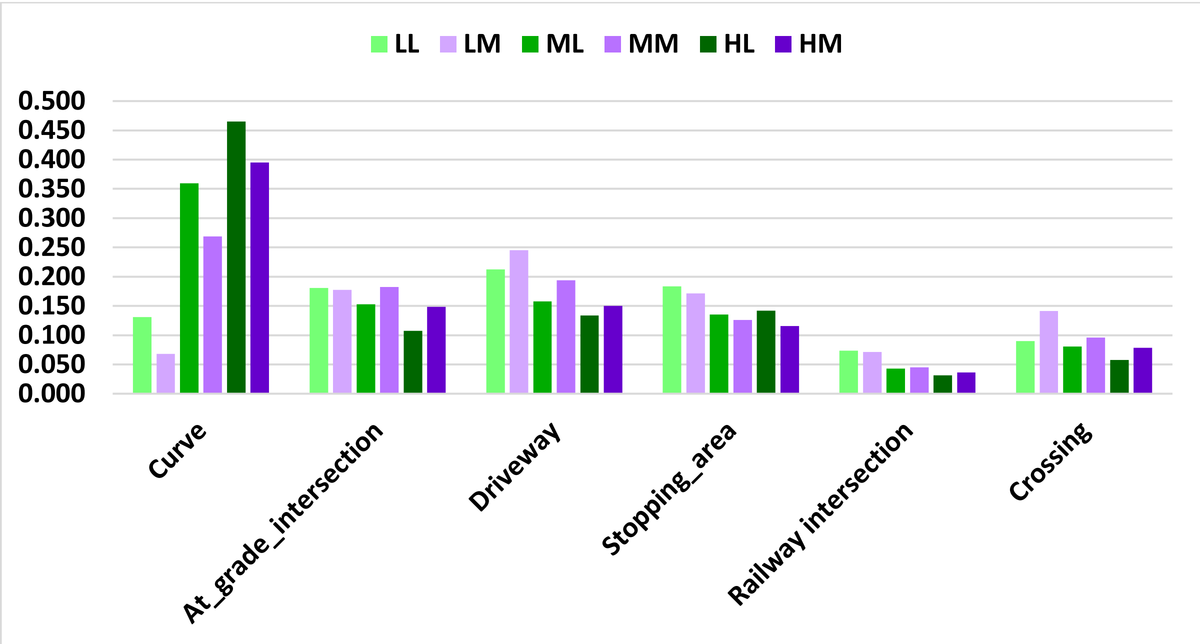
PCLs Type	Weights	Relative Error
Curve	13.1%	1.2%
At-grade intersection	18.1%	1.2%
Driveway	21.2%	1.6%
Lane change	12.9%	1.0%
Stopping area	18.4%	1.4%
Railway intersection	7.3%	0.8%
Crossing	9.0%	0.9%
Consistency Ratio = 0.3%		

Appendix Table 42 – AHP results, PCLs Type, RH-LM

PCLs Type	Weights	Relative Error
Curve	6.8%	0.4%
At-grade intersection	17.8%	1.0%
Driveway	24.5%	2.8%
Lane change	12.5%	0.7%
Stopping area	17.1%	1.6%
Railway intersection	7.1%	0.9%
Crossing	14.1%	1.5%
Consistency Ratio = 0.3%		

Appendix Figure 32 shows the results using histograms graph. From the graph some interesting trend can be noticed. Curves are the most expected PCLs type in rural highways, followed by driveways, and then at-grade intersections. Moreover, the higher the winding level of the road, the higher the expectations of a curve. On the opposite, the greater the PPI the lower the expectations of a curve. This suggests that participants generally associate urbanized areas to tangents. A similar trend occurred for stopping areas. This result is quite unexpected, because the more urbanized the area, the higher the possibilities to find bus stops and parking areas. The other types of PCLs have an opposite trend: the higher the PPI level, the higher the expectations to find that type of PCLs. Moreover, for all PCLs' types except curves, the higher the winding level, the lower the expectations to find that type of PCLs.

Intersections with railways, are the less expected type of PCLs. This is probably due also to the experience of participants. Indeed, they all come from the same area and in that area very few railway intersections are present. It must be also notice that crossings (pedestrian or cyclist) are the second most unexpected type of PCLs. Thus, this type of PCLs is not expected on rural highway.



Appendix Figure 32 – AHP results, all PCLs types, RH

APPENDIX 11 NASs' detailed analysis

In this APPENDIX additional descriptions and analysis are provided about some NASs. Those NASs were chosen among those that shown some interesting results, both because clearly exemplify some Human Factors related issues, both because a great difference is present between the two different classifications (HFE procedure, and accident-based analysis). For the accident rate, both the ranking and the definition of the safety level, consider all stretches together.

The following satellite images of the stretches are all north oriented.

Appendix Table 43 – List of NASs chosen as example to provide detailed description of the identified (or not) Human Factors-related issues.

Road	NAS ID	HFE procedure Risk Level	Accident Rate Risk Level	HFE procedure Rank	Accident Rate Rank
SR2	NAS 2	Very High	High	1	3
SR2	NAS 10	High	Medium	4	20
B38	NAS 6	High	High	2	4
B38	NAS 8	Low	High	50	7
106	NAS 7	High	High	7	5
106	NAS 9	Medium	High	23	6

SR2 – NAS 2

NAS 2 of SR2 has been judged as very high risk level considering the HFE procedure. In this section problems have been identified concerning all the three rules of Human Factors. The high risk of accidents is also confirmed by the high number of accidents occurred in this section in the analyzed period. An average frequency of 4 accidents per year has been recorded. The two most critical HFESs comprehend two curves where the highest number of accidents has been recorded. The two curves are highlighted in Appendix Figure 33. Along the whole section there are three sharp curve, four intersections (three are one-way intersections which connects to motorway's ramps), two driveways, one pedestrian crossing and two bus stops. The visibility of quite all the PCLs is low. One example is provided by a lack of visibility of the inner curve in both curves (Pictures 2, 3, 5 of Appendix Figure 34 and Pictures 7, 10, 11 of Appendix Figure 35). Another example is provided by the intersection immediately after a right curve, in Picture 8 of Appendix Figure 35). Moreover, even if the NAS is wholly included within EXSE 1, which is characterized by a high winding level, the two curves depicted in Appendix Figure 33 are sharper and longer than the previous ones (considering both directions). For this reason, they are unexpected. Pedestrian crossing is completely unexpected because it appears after a curve and the environment is totally rural (there is only a house that is partially visible). Pedestrian signs are present, but they appear suddenly with all other signs, providing too much information to be correctly elaborated (abrupt increasing of demand and low available resources) (Picture 1 of Appendix Figure 34).

A bad composition of the field of view is also present both close to the pedestrian crossing and along the two critical curves. In the first case, the road margins are not symmetrical (Picture 2 of Appendix Figure 34), in the latter the external lateral reference line provided by the trees, partially disappear. Moreover, a driveway is located exactly in the middle of the curve (Picture 3 of Appendix Figure 34).

The second curve present the same issues as the first, but in addition an overpass is present, which reduce the correct perception of the road space, and partially hide the reference line provided by the safety barrier (Picture 5 of Appendix Figure 34). An optical illusion is also present after curve 2: the road seems to go straight, but instead it turns right (Picture 6 of Appendix Figure 34).

Appendix Figure 33 – NAS 2 of SR2, view on satellite image and pictures' location

Appendix Figure 34 – Pictures from NAS 2 of SR2, northbound

Going from north to south, before curve 1, a wider space is perceived and here drivers speed up, until they reach curve 1 (Picture 9 of Appendix Figure 35). The development of curve 1 is not clear and drivers underestimate the risk of driving too fast on that curve. One of the main cause of accidents in the curve, is high speed. In both curves, many accidents are also described as "travelling in the opposite lane". This highlights a missing of external references and possible high speeds. Entering the inner lane with too high speed may cause to invade the opposite lane. Both these factors are linked to field of view issues and expectations-related issues.

Appendix Figure 35 – Pictures from NAS 2 of SR2, southbound

SR2 – NAS 10

NAS 10 of SR2 is another high risk section concerning the HFE procedure results. Considering the accident rate level calculated accounting for all the analyzed sections (all roads), this section is classified as medium level. However, the frequency of accidents in the analysis period is 4 accidents per year, like NAS 2 of the same road. The difference in the accident rate results is mainly due to the different traffic. The traffic of NAS 10 is three time higher than the traffic of NAS 2. Accidents in this section are mainly due to three main locations: an intersection before the underpasses (visible in Picture 2 of Appendix Figure 36), the short urban area that comprehends many conflicts points (Picture 3 of Appendix Figure 36), and another intersection close to the edge of the northern boundary of the urban area (Picture 4 of Appendix Figure 36). Most of accidents cause have not been identified for accidents occurred in this section. However, many accidents occurred while vehicles were maneuvering to enter or exit intersections or driveways.

In this section many issues are present concerning all the Human Factors' rules. In the southern part of the section worn out temporary yellow markings are present (Pictures 1, 2, 5, and 6 of Appendix Figure 36). The markings are not visible, and the road layout is not easy recognizable, mainly approaching the underpasses in both directions. In this segment, the carriageway is wide, with a very wide right shoulder southbound. The carriageway is not centered, but the road markings do not help to understand it (Picture 5 and 6 of Appendix Figure 36). This causes a wrong trajectory choice. A pedestrian crossing is also present, but it is completely invisible (Pictures 1 and 2 of Appendix Figure 36).

Going North, the first intersection on the right is not visible, because of the bad organization of lateral space and mainly because the attention is caught by the bright wall of the underpass (Pictures 1 and 2 of Appendix Figure 36).

Appendix Figure 36 – NAS 10 of SR2, view on satellite image and pictures of the road

The urban area is recognizable. Many houses are present and visible from a great distance. However, a long straight is present, and the end of the urban area is visible at the end of the straight. This may catch the attention of drivers and induce them to speed up (Pictures 3 of Appendix Figure 36). The northern intersection is also difficult to see both going northbound and going southbound. In the latter case, a little wall and some plants are present, which are an obstacle for visibility. Moreover, the attention is caught by the urban area immediately after the intersection (Picture 4 of Appendix Figure 36). For this reason, the intersection is not well perceived and can surprise the driver.

In this specific section, many risk are due to the loss of track, road cross sections not always clear, and speeding. However, the high volume of traffic, may have a positive influence of road safety. This is because when more vehicles are travelling on the road, the following vehicle has the heading vehicle as reference, thus it is harder to not understand the road. If the heading vehicle does so, the following vehicle can adjust its behavior. This point is very interesting and may be the objective of following research.

B38 – NAS 6

NAS 6 of B38 has been found to be one of the most critical sections analyzed. This is a clear demonstration that critical conditions occurred when there are many concurring issues (in this case related to two PCLs: a curve and an intersection). A total of 18 accidents occurred during the 3 years period of analysis, which means an accident frequency of 6 accidents per year. 10 of those accidents was classified as "not give the right of way", thus they are intersection-related accident. The remaining accidents have been classified as related to speed, to unspecified human error, and because drivers do not keep the right while driving. The latter type of accidents occurred in the curve because of vehicles invading the opposite lane.

Critical conditions arise considering both directions of travel, however, the worst condition is considering the southbound direction. In this direction a long straight precedes the curve. A big tree is located exactly in the apparent end of the straight. This helps to understand that the road probably doesn't go straight anymore, but at the same time this tree is an eye-catcher, and continuously catches the attention of the driver (distracting it from other location). Moreover, the curve develops in coincidence with a crest and no marginal elements of the outer curve are present. This assures to correctly perceive the curvature and the development of the curve. The situation is worsened by the marginal elements on the right that diverge from the road track immediately before the starting point of the curve, increasing the disturbance of curvature perception. (Picture 1 of Appendix Figure 37). The curve is consistent with the other curve of the stretch, but the speed is very high, and it must be correctly perceived to be correctly travelled. Within the curve the intersection is located (mainly in the last part of the curve). No reference from marginal elements is provided neither at intersection. Thus, also the intersection is completely invisible as shown in Picture 2 of Appendix Figure 37, which was taken approximately 20 m before the intersection. Moreover, the intersection is located on the right side of the road. The eye-catching tree is instead located in the left side of the road. The visibility from the point of view of an entering vehicle is shown in Picture 5 of Appendix Figure 37. A right turning lane is also present in the curve, for vehicles that must turn right in a country road (driveway). The added lane, reduce even more the curvature perception.

In the opposite direction, one of the main problems is again speed, because a long straight precedes the intersection (the main intersecting road is now on the left). The absence of any marginal elements that clearly identify the location of the intersection makes it hard to be identified. This may lead to sudden speed reduction for vehicles that must turn left. The driveway on the right is not signalized, neither is visible, but the necessity of the right turning lane in the opposite direction demonstrates that it is quite relevant (Pictures 3 and 4 of Appendix Figure 37). Concerning the curve, Picture 4 of Appendix Figure 37 shows the view to the curve about 100 m before it. The road direction is not perceivable, neither the curvature of the curve, so the driver cannot anticipate the road preparing the right maneuver (Pictures 4 shows also two vehicles that are the only reference to understand that a curve is present). Marginal elements on the outside margin of the curve are missing and do not provide any reference to the driver also in this direction. The only reference is provided by the elements in the inner curve, which are not parallel, as said before.

This series of problems, which are mainly related to the First and Second rules of Human Factors, together determine some critical conditions.

Appendix Figure 37 – NAS 6 of B38, view on satellite image and pictures of the road

B38 – NAS 8

NAS 8 of B38 also provide and interesting case study to analyze. In this case, the HFE procedure identified the section as a low risk section. On the opposite, accident rate was very high, so that the section was classified as high risk section. A frequency of 3 accidents per year has been observed in the section. Among the 9 accidents occurred in the analysis period, 7 were classified as "not enough safety distance from the preceding vehicle". As already discussed, driving to close to the preceding vehicle, concern human factors, because this is link to the difficult of the driver to compare distances and speed, however, is something that is not directly linked to the road perception. On the other hand, when rear-end collision occurred, it is often because a small distance between the two vehicles, and because a sudden braking of the heading vehicle. That sudden braking action may be caused by a wrong perception of the road. For this reason, this type of accidents has been included in the analysis. Looking at the position of the occurred accidents, they are mainly located around the four legs intersection in the middle of the section. Thus, this intersection represents the major issue of the section. Analyzing the Human Factors aspects, the first thing to say is that the intersection is a signalized intersection, which is placed in the center of a fast track (a long straight is present before the intersection in northbound direction, as depicted in Picture 1 of Appendix Figure 38). Such type of intersection is generally not expected in fast road. However, the intersection is clearly visible, and traffic lights are also visible against background in both direction (Pictures 2 and 3 of Appendix Figure 38). The field of view present some minor issue related to speed: a long far view that leads driver to speed up. Concerning the other aspects, conditions are good, such as margin composition. The northern curve in south direction misses some reference in the outer curve, but the curve is still well perceived (Pictures 3 of Appendix Figure 38).

Appendix Figure 38 – NAS 8 of B38, view on satellite image and pictures of the road

Consequently, the high number of rear-end accidents are probably due to the combination of fast speed and signalized intersection. Drivers may think they can pass with the green and speed up, but suddenly they must brake because of yellow or red lights. Additional on-site analysis of driver behavior (analysis of near to collision event), may help understanding if the high number of accidents also occurred by chance, or if some other issues are present that have not been identified by the HFE procedure.

106 – NAS 7

NAS7 of road 106 is classified as risky both by the HFE procedure and by accident rate. It is the section with higher accident rate within the 106 road stretch, with a total of 17 accidents occurred in the 5 years analysis period. 9 of those accidents occurred likely because vehicles invade the opposite lane (head-on collisions or glance collisions, which have been defined as the accident when the vehicles' sides are superficially rub or just of the lateral rear-view mirrors). 3 were rear-end collisions, and 4 were collisions with stationary object or building. All those accidents occurred in the area around (and inside) a curve outside the forest. Therefore, accident data suggests that many accidents occurred because of a wrong trajectory of the vehicle and a loss of control. This may be caused by excessive speed and by a missing of reference required to maintain the right position in the lane, while driving within the curve. It has been found that the configuration of the road may cause both of this. An intersection is also present in the middle of the curve.

Appendix Figure 39 – NAS 7 of 106, view on satellite image and pictures of the road

First, as already stated, this is a fast track. The stretches preceding the curve in both directions are characterized by straights and curve of high radius, thus the approaching speed is high, mainly coming from south. Both the preceding stretches develop in the forest. The lateral trees provide an optical guidance to drivers, identifying road margins. However, approaching the curve the trees disappear (all pictures of Appendix Figure 39), leaving an empty space. Lateral references are suddenly missing. Moreover, some optical lines are formed by the outline of the ridge which influence the curvature perception (Picture 2 of Appendix Figure 39). The house and the far way trees do not help to understand the right curvature, because they are not parallel to the road. The consequence is that the curvature is not easily recognized, and the position on the lane is harder to maintain. The combination of these two factors may provoke the invasion of the opposite lane. This seems to partially occur to the white vehicle in Picture 3 of Appendix Figure 39.

106 – NAS 9

NAS 9 of road 106 is another example where the accident rate shows a more critical situation than the result from the HFE procedure, which classified the section as at medium risk. 16 accidents occurred in this section in the analysis period of 5 years. Among those accidents, 5 are glance collision, which can be addressed to speeding and a loss of lateral reference, 1 is a rear-end collision, two are vehicle overturned, 3 are side impact and 5 have not been classified.

Some issues have been found concerning Human Factors, mainly considering field of view. The identified problem fits the accidents type occurred (mainly the glance collision and side impact), however the problem are such that few accidents are expected.

Appendix Figure 40 – NAS 9 of 106, view on satellite image and pictures of the road

The problems identified are mainly related to the field of view. Travelling southbound the first of the two sequential curves show a bad delineation of the outer margin. Indeed, the trees forming the ideal continuous wall are not parallel to the curve. They are converging (Picture 1 of Appendix Figure 40). This may lead to some problems in lane keeping. From the other side (southbound), a fast segment precedes the curve, with operating speed reaching about 90-100 km/h. Approaching the curve, the delineation of the outer margin is not continuous because two intersections are present (one close to the starting point of the curve, and one close to the end), and there the safety barrier and the trees interrupt. Moreover, the visibility of the second intersection is poor, because of the curves, in both directions.