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Analysis and Modeling of Driver Behavior for Assistance Systems at Road Intersections

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Mojoj porodici

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Zusammenfassung

Diese Arbeit befasst sich mit Verkehrssituationen an Kreuzungen, da diese ein hohes Potenzial für die Stärkung der Verkehrssicherheit und Mobilität bieten. Eine stetige Zunahme des innerstädtischen Verkehrs, eine immer älter werdende Gesellschaft und ein schon ausgeschöpftes Potential für Fahrerassistenzsysteme für den Längsverkehr erhöhen den Druck auf die Entwicklung von Methoden und Technologien für Kreuzungsassistenzsysteme. Die bisherige Ansätze für das Design von Kreuzungsassistenzsystemen sind entweder durch die fehlende Nutzerakzeptanz, Ineffizienz oder hohe Investitionskosten charakterisiert.

Es wird ein innovativer und ergonomischer Ansatz für die Fehlervermeidung im Verkehrsgeschehen präsentiert. Es wird gezeigt, dass die Analyse der Fahraufgabe und die Modellierung der Kognition die Grundlage für die Entwicklung ergonomischer Assistenzsysteme sind. Mit Hilfe der durchgeführten Analysen in Kombination mit dem Stand der Forschung wird ein kognitives und simulatives Fahrermodel aufgestellt. Das Ziel dieses Modells ist die Unterstützung bei der Entwicklung neuer Fahrerassistenzssyteme. Desweiteren wurden die Anforderungen an Kreuzungsassistenzsysteme aus den Ergebnissen diverser Fahrsimulatorexperimente abgeleitet. Diese Arbeit zeigt, dass allein die Nutzung von im Fahrzeug vorhandenen Sensoren und Kartenmeterial die nötigen Informationen liefern kann, um die gefährlichsten Fehler bei Fahrmanövern im Kreuzungsbereich zu reduzieren. Im Vergleich zu vorhandenen Warnungsassistenzsystemen kann ein solcher Ansatz die Akzeptanz des Nutzers erhöhen und ist zudem kosteneffizient.

Durch die Identifikation der wichtigsten Einflussgrößen auf die Fahraufgabe an einer Kreuzung und durch die systematische Analyse ihre Auswirkungen auf Blickbewegungs-Strategien, Risiko Wahrnehmung und menschlicher Kognition wird eine Grundlage für die Entwicklung weiterer Assistenzsysteme auf der Führungsebene gelegt.

Abstract

This thesis focuses on relevant topics of traffic safety and future mobility by identifying intersections as traffic situations with the highest potential for improvement of road safety. The increase of inner city traffic, effects of aging societies, increasing mobility and reaching the limits of assistances in the longitudinal traffic, brings intersections in the focus of future scientific research. Conventional approaches in the design of Intersection Assistances lack the user's acceptance, are often ineffective or present the high-cost solutions.

Within this thesis, an innovative, human-centered approach for error prevention in the traffic is given. The analysis and modeling of driver cognition during the negotiation of an intersection is identified as the crucial element for the development of an ergonomic Intersection Assistance. The performed analysis in the combination with advanced research in this area has resulted in the foundation for the computer simulation of driver cognition, which can be applied in the process of assistance development. Experiments in the driving simulator environment, conducted within this work, identified the substantial requirements for the support in intersection scenarios. Furthermore, these experiments demonstrated that the information in the approaching segment of intersection, which is based on only navigation and on-board data, could prevent the most critical errors of intersection performance. The user acceptance can be increased in comparison to the available warning assistances, and presents a less costly solution than the automatic brake assistance.

By identifying the most important factors of the task performance at intersections and by a systematic analysis of their influence on applied visual strategies, risk perception, task demand and driver cognitive processing, this thesis offers a groundwork for the future development of Driving Assistances on the guidance level of the driving task.

Glossary

ABS - Antiblock-locking System
ACC - Active Cruise Control or Adaptive Cruise Control
ADAS - Advanced Driver Assistance Systems
AOI - Area of Interest
C2C - Car to Car
C2I - Car to Infrastructure
C2X - Car to Car and Car to Infrastructure
CoP - Code of Practice
CWS - Collision Warning System
ESP - Electronic Stability Program
FoE - Focus of Expansion
FSM - Finite State Machine
GIDAS - German In-Depth Accident Study
HMI - Human Machine Interface
HUD - Head-up Display
ITS - Intelligent Transport Systems
IVIS - In-Vehicle Information Systems
LDW - Lane Departure Warning
LKA - Lane Keeping Assistance
LTM - Long-Term Memory
MAS - Multi-Agent System
SA - Situational Awareness
STM - Short-Term Memory
TCI - Task Capability Interface model from Füller
TCS - Traction Control System
TTI - Time To Intersection
WM - Working Memory

Contents

Chapter 1

Introduction

1.1 Motivation and Objective

Expanding requirements on mobility in everyday life and the increasing importance of transportation for today's economy has led to the development of *Advanced Driver Assistance Systems (ADAS)* whose goal is to increase road safety and driving comfort. The scope of emerging ADAS ranges from systems that support the driver in route planning to systems that directly stabilize the vehicle. Some of them are comfort oriented, such as *Automated Parking Assistance*, while others, the *Traffic Sign Recognition Assistance* for example, decrease the driver workload. Currently available systems are predominantly designed to assist the driver on highways and rural roads. The introduction of new sensor and tracking technologies and communication protocols like *Car2Car (C2C)* have lately prompted a growing interest among research and investment communities, especially in systems that will enable driver assistance in urban areas.

Around $1,300,000$ traffic accidents happened on the European Union roads in the year 2007 [EC]. These accidents resulted in $42,500$ deaths, $1,600,000$ injuries and financial losses estimated to 200 billion Euros. This number is comparable to five medium-sized passenger airplanes crashes in EU per week. Thereupon, depending on the country, between 30% and 60% of traffic accidents occur in the intersection areas [INTERSAFE]. The particularly troubling fact is that up to a third of traffic collisions occur during traveling for work related purposes.

To improve traffic safety, in 2001 the European Union set a goal to reduce the number of deaths down to $20,000$ by year 2010 [EC WhitePaper01]. This decision resulted in a series of projects whose objectives include the further technological, legal and market development of ADAS and sensor technologies. The major concentration included developments of assistances for the support of longitudinal control of the driving task. It is expected that in upcoming years emerging driver assistances will reduce accident occurrences in longitudinal traffic, which will leave intersections as the most problematic "black-spots". Additionally, intersections are particularly critical for elderly drivers, who are, based on demographical trends, assumed to become the most representative group of drivers [StatBA]. This fact requires strategies and methods for the development of an *Intersection Assistance* that will support the driver in negotiating intersections. Technical feasibility of such an assistance has been shown within EU project [INTERSAFE], where the demonstration assistances for support at left turn, turning/crossing and traffic lights were realized [Fuerstenberg05]. Altogether, the safety potential of Intersection Assistance was ranked very high. In addition, several other projects such as [AKTIVE-AS], [KAS], [ConnectedDrive] or recently started project [Ko-FAS] deal with development of technologies for Intersection Assistance.

Nonetheless, the interest in intersection safety is constantly increasing. The reason is that the development of effective and ergonomic Intersection Assistance is highly challenging and should consider not only the technology but also the functionality and the *Human-Machine Interface (HMI)* as well. Already the definition of functionality is a complex problem which becomes evident when determining the possible application scenarios. The reason lies behind the complexity of driving tasks even at the simplest intersections. The approach applied till recently in defining functionality of driver assistances is known as the *Bottom-Up* approach, which means that the developed functionality is based on state-of-the-art sensor and communication technologies. The drawback with ADAS developed in this manner, however, is that they often offer support in situations where drivers do not need it and have no functionality for critical situations. This resulted in low acceptance and willingness of users to buy new technologies [Kassner06].

The commonly discussed example of a such Bottom-Up developed assistance is *Active Cruise Control (ACC)*. ACC is an assistance system that allows adaption of the vehicle speed to the traffic environment without the driver's intervention. In such a way the driver task is shifted away from an active to the supervisory role. However, ACC sensors in current vehicles have their limits in that they cannot differentiate between small and large objects, regularly repeated structures and crash relevant objects [RESPONSE204]. Also, the dense traffic can make a car at smaller distances not visible for the system. When reaching these limits, ACC usually require the driver to take over the vehicle control. The supervision task may be monotonous for the driver and when suddenly requested to take over, the driver may react inappropriately or too late. By having such a functionality, ACC system directly interferes with the driver cognitive processing: anticipation, expectations, decision making and risk perception. The constraints of these processes were not considered with the first ACC systems that appeared on the market. The consequence was that the drivers did not gain enough understanding of ACC functionality, did not understand in which situation may the system request the driver to take over and they preferred the system being switched off [Buld03].

For an assistance system to be accepted and efficient, it is necessary for it to have a knowledge about driver cognitive processing and a mechanism to accordingly adapt its support. The driver should be directly involved into the development process and should not present only the evaluating factor at the end of the process chain. Therefore, drivers' behavior should be analyzed and modeled in a suitable way. There already exist hundreds of models that account for driver behavior and each of these models is developed for a distinct field of application and with a specific purpose in mind. The majority of such models are used for the development and improvement of vehicle dynamics and thus mainly account for the driver behavior on the stabilization level. For the development of assistances on the guidance level, it is necessary to model human-like cognitive processes relevant for the driving task. Recently, more of such models have appeared [Cacciabue07]. Some of these models are purely theoretical and some attempt to simulate the way the human brain works, irrelevant of the possible application. The perception is that they are still in its infancy and there are currently no clear concepts of how a cognitive model for the usage in the development process of ADAS should look like.

To be applicable and efficient for usage in the development process of driver assistances, the driver model should fulfill certain requirements. The ultimate goal is the creation of a model that operates in parallel with the driver and adapts ADAS operation to the driver state and intentions. The appearance of such a model on the market is however years, maybe decades away. The necessary effort and time for the applicable results may be the reason for the lack of the works in this direction even though the topic is recognized as highly relevant. However, even before the model will be developed for the practical usage, the efforts of modeling driver cognition support the design of assistances in several ways. For example, for evaluating and testing driver assistances, extensive usability tests should be conducted. They are costly and also complicated due to the unreliable participation in simulation studies caused by simulator sickness. Completion of experiments is especially complicated for elderly drivers. A solution is to model and simulate the driver behavior and to exchange many tests with an appropriate driver model. This way, ADAS performance is analyzed faster and at little cost in a variety of driving situations and under different conditions.

Considering all these issues, two goals are set as the objective of this thesis. The first goal is the analysis of drivers' behavior at intersections for defining the functionality and requirements on the Intersection Assistance. The second goal is to determine the specifications of the cognitive driver model that can be used for ADAS development. Both objectives form the grounding analyses in these areas and should be understood as the initial steps and impulses for the further works in this direction. To achieve these objectives within this thesis, the driver behavior at intersections was theoretically and experimentally analyzed. In parallel, the requirements on the computer simulation of the driver cognition were set and an implementation outline is presented. A more detailed approach and how this is achieved is given in the following text.

1.2 Approach, Contribution and Outline

The approach followed within this thesis is a combination of the Bottom-Up and *Top-Down* method. The Top-Down method, starting from the requirement analysis, assures that the assistance will exert support when needed the most. The Bottom-Up method assures that the functionality can be realized with the available technology. The content of each chapter and their connection to each other is presented in Figure 1.1. Chapters placed in blue trapezoids present a state-of-the-art or literary overview. The chapters placed in the green trapezoids present the core of the thesis and include the analysis and experiments conducted within this work. Conclusive chapters, *(Chapter 7* and *Chapter 8)*, are denoted by the red trapezoids and they consider the results and conclusions from all the previous chapters.

The second chapter discusses the development methodologies and procedures of ADAS. Here, the current state-of-the-art technology for Intersection Assistance is presented and future possible functionality is discussed. The common approach used for defining the functionality of ADAS is the classification of traffic scenarios. In industrial research, accident analyses serve as reference. They enable the classification of traffic scenarios that are then used to define the functionality of assistance. Scenarios in which many accidents happen are considered as potential application scenarios. Thus it is assured that developed assistance will provide high safety level and financial asset. As it is shown in *Chapter 2*, the standard accident analysis cannot provide sufficient information necessary for defining the functionality of Intersection Assistance. This chapter also explains why it is not enough to know only the dynamics of the task performance at an intersection in order to develop an ergonomic assistance, and why it is necessary to take the driver cognition into account as well.

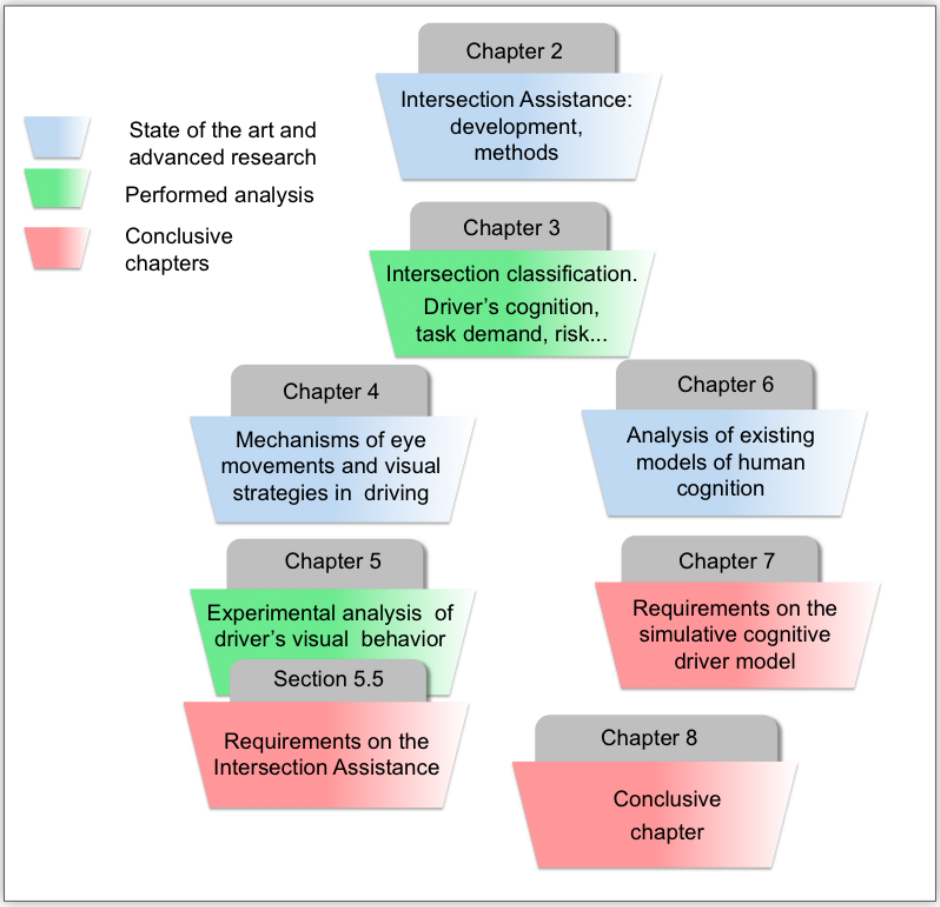


Figure 1.1: *Approach and the structure of the thesis*

The theoretical analysis of the driver performance at intersection is given in *Chapter 3*. The analysis starts with the classification of traffic scenarios and the definition of an intersection task. Relevant human cognitive processing is analyzed, in particular the way the information is perceived and processed. The separate sections include analysis on the influence that the demand of the task has on the drivers' performance and risk perception. In particular the discrepancy between the objective and subjectively perceived risk is elaborated. The parameters that have the strongest influence on the driver performance at intersection are identified.

The most relevant outputs of the resulting cognitive processes are applied visual behavior and strategies, which present the best source for the objective measuring of the underlying cognitive mechanisms. Hence, *Chapter 4* discusses the mechanisms of eye movements and presents the advanced research regarding the analysis of applied visual (searching and scanning) strategies. There are very few studies that analyze the drivers' visual strategies at intersections. The reason behind this is that the systematic control of factors in a real-life experiment is almost impossible to achieve, because of too many unpredictable factors. Also, up to recently, conducting such studies in driving simulators was inefficient as prevailing simulation software was not mature enough.

Therefore, within *Chapter 5* an experimental analysis of the drivers' visual behavior is presented. It was conducted in the fixed-base driving simulator of the Chair of Ergonomics, Technische Universität München. The objective of the study is an analysis of drivers' behavior in systematically changing conditions at intersections in a very realistic urban environment. The behavior of 24 test subjects has been analyzed in 10 different intersection scenarios. The experiments comprised of a baseline trial and a trial under the induced time pressure conditions. The results revealed the situations in which driver assistances are needed and provide safety and comfort benefits. Within *section 5.5* the requirements on the Intersection Assistance are defined and the possible functionality is suggested. Additionally, the results provided the base for the driver cognitive model, discussed in *Chapter 7*.

For defining the requirements on the driver model for the assistance development, already existent cognitive models are thoroughly analyzed in *Chapter 6*. Based on the conducted analyses, the requirements for the computer simulation of the cognitive model are made and the guidelines for its implementation are suggested in *Chapter 7*.

Thus the contribution of this thesis is summarized with the following:

- analysis of the methods for the human-centered development of ADAS,
- classification of intersection scenarios,
- theoretical analysis of the driving task in intersection scenarios,
- experimental analysis of the driver cognition in intersection scenarios,
- analysis and suitability of existing cognitive human models for the development process of driver assistances, and
- requirements and guidelines for an implementation of such a model.

The results of each chapter and contributions are discussed and summarized in *Chapter 8*.

Chapter 2

Methodologies for Development of Advanced Driver Assistance Systems for Intersections

This chapter presents procedures and methodologies for the development of Advanced Driver Assistance Systems. The objective of the chapter is to define the requirements and the human-centered approach for the development of Intersection Assistance. First, an overview of existing driver assistance systems is given and the problems resulting from the non-ergonomic development of these systems are identified. The ergonomic approach to develop assistance systems is further discussed. Accordingly, the corresponding work done within this thesis presents the determination of the ”Task-content” for the functionality of Intersection Assistance. Applicable technologies and advanced research regarding the Intersection Assistance are presented as well.

The major difficulty in designing the Intersection Assistance is the definition of the application scenarios. It is shown that the identification of appropriate application scenarios requires more information than available from accident statistics. Conclusively, an assistance system is suggested that has the knowledge of the driver normative and naturalistic behavior, both dynamic and cognitive, and is parallel-coupled to the driver. The first step in designing such an assistance is the theoretical and experimental analysis of the drivers' behavior during the negotiation of an intersection which is subsequently presented in Chapter 3.

2.1 Overview of Advanced Driver Assistance Systems

Advanced Driver Assistance System (ADAS) is a universal term used to describe all kinds of systems which support the driver in accomplishing the driving task. In other literature, they are also found under the term *Intelligent Transport Systems (ITS)*, whereby the term ITS includes a broader application field, like *Drive-by-Wire*. Many of driver assistances are already on the market and even more of them are under intensive development and research. ADAS is a generic and heterogeneous term as it occupies systems having a different level of automation, intervening in the driving task in a different way and supporting the driver on different levels. Some of them are giving additional information to the driver like *Parking assistance*, others are enhancing the drivers' view such as *Night Vision System* or issuing warnings in critical situations. There are also systems that aim to monitor the driver and detect the driver fatigue [Plavsic08a].

As there are no standards regulating the development and taxonomy of ADAS, the same systems can be found on the market under different names and even different systems can bear the same name. Problems of the non-systematic and non-uniformed development of ADAS was addressed in the [RESPONSE3] project. This project delivered the European *Code of Practice (CoP)* for supporting manufacturers in introducing new safety applications in all aspects, including legal issues. Within this project an agreement about ADAS definition has been reached and ADAS are defined as systems having the following properties:

- provide driver support in terms of the primary driving task,
- provide active support for lateral and / or longitudinal control with or without warnings,
- detect and evaluate the vehicle environment,
- use complex signal processing, and
- enable direct interaction between the driver and the system.

The first Advanced Driver Assistance Systems appeared on the market some thirty years ago. It was the *Antiblock-locking System (ABS)* brought up by Bosch in 1978 that began writing the first chapter of ADAS development. As depicted in Figure 2.1 during the last decade many other assistances appeared in mass production like *Active/Adaptive Cruise Control (ACC)*, *Collision Warning System (CWS)* or *Lane Departure Warning (LDW)*. The further improvement and adaption of these systems is expected in the future as well. Alone within EU cluster [ADASE] around 30 projects deal with various research for driver assistance systems. It is expected that future development will result in assistances, which can support the driver even in complex driving situations such as intersections. This is enabled by the rapid enhancement and steadily decreasing costs of on-board sensor technologies like long-range radar, laser scanner, 2D/3D cameras, different wireless communication technologies as well as techniques for their real-time fusion. Apart from Intersection Assistances, great success is also expected from systems that will be able to adapt speed control and optimize fuel consumption, so called *Eco-* or *Green Assistances*.

ADAS categorization. No generally accepted classification of ADAS exists and several categorizations can be made [Plavsic08b]. ADAS can be grouped into systems supporting the driver on the

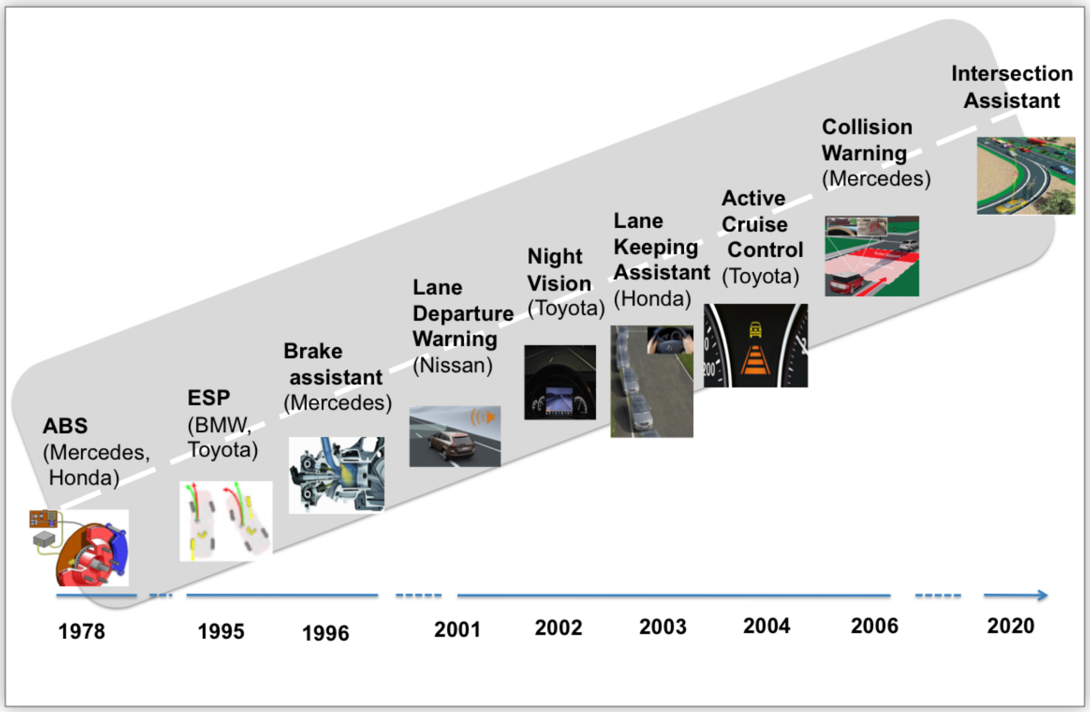
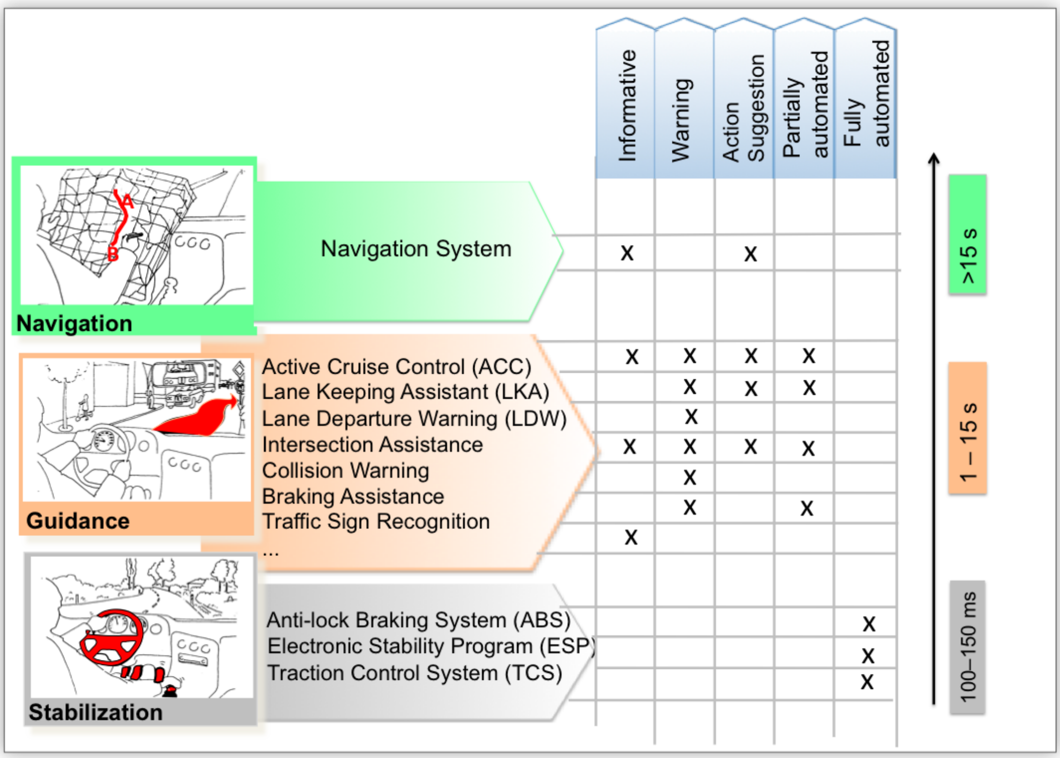


Figure 2.1: *Road map of the development of Advanced Driver Assistance Systems (ADAS). The year of the first appearance on the market and the producer of the respective system (Source: websites of manufacturers)*

navigation, *guidance* and *stabilization* level (see Figure 2.2). This classification of the driving task is suggested by [Bernotat70]. On the navigation level, the driver is supported with a *Navigation system*, which is often incorrectly categorized as solely *In Vehicle Information Systems (IVIS)*. On the guidance level, systems like ACC, LDW or CWS support the driver and systems like ABS or ESP provide support on the stabilization level. These three levels differ by the driving phase in which ADAS operate. Assistances on the stabilization level have the highest degree of autonomy and react in time range less than a second. Assistances on the guidance level operate in time span of several seconds to several minutes and on the navigation level the time span is measured in minutes and hours.

Another way to classify driver assistances is according to their degree of automation: anything from a simple information presentation to an autonomous interference of the driver control. ADAS can either inform, warn, give an action recommendation to the driver, and be partially or fully automated, or can operate in several modalities. Systems like ACC that allow the driver to transfer a part of the driving task to a system but cannot take over the complete driving task, are partially automated. Figure 2.2 shows the most relevant assistances and their modalities.

Problematic acceptance of emerging ADAS. For a system to be effective in preventing casualties, not only the reliable technology but also the acceptance of the user is highly relevant. Emerging ADAS, which aim to support the driver on the guidance level, like ACC or LDW, have stayed far behind acceptance expectations of car manufactures [Wolf06a]. Two reasons for this are inappropriate and



	Informative	Warning	Action Suggestion	Partially automated	Fully automated
Navigation System	X		X		
Active Cruise Control (ACC)	X	X	X	X	
Lane Keeping Assistant (LKA)		X	X	X	
Lane Departure Warning (LDW)		X			
Intersection Assistance	X	X	X	X	
Collision Warning		X			
Braking Assistance		X		X	
Traffic Sign Recognition	X				
...					
Anti-lock Braking System (ABS)					X
Electronic Stability Program (ESP)					X
Traction Control System (TCS)					X

Figure 2.2: *Classification of ADAS based on the classification of the driving task and the level of automation*

confounding functionality and technological imperfection. Systems like ABS and ESP, which are not interfering with the driver decisions and are not involved in the driver cognitive processing, are highly accepted. They operate in a way in which the driver is physically unable to react, like simultaneously braking all four wheels or bringing an overriding vehicle to a stable level again. Apart from that, the driver easily understands the intervention of these systems. As opposed to, assistances on the guidance level are ergonomically more sophisticated as they have to co-operate with the driver. If these systems do not have an understanding of the driver behavior, they can be irritating to the driver and will therefore not be accepted.

An additional problem is that the fusion of the state-of-the art sensors is technically still imperfect. Not only that advanced sensors do not have a $360°$ view, but they also can have less insight into the situation than the driver. This can cause an inappropriate assistance ”decision”; for example activation of *Emergency brake assistance* to prevent a forward collision can potentially cause a rear-end collision with even more casualties. Another example is *Lane Departure Warning (LDW)*, which nowadays can work only on good visible road lines. The light and the shadow areas can cause failures in the detection of the road postings. In many similar situations, it is easier for the driver to recognize the lane than for a system. Especially problematic are partly automated systems, which change the role of the human from the active to a supervisory. An example is the ACC system, already mentioned in the introductory chapter. Basically, currently available systems offer support in situations in which the driver can handle the situation himself but fail to do so in critical moments. One additional difficulty with current ADAS is that they are developed independent of each other and use independent sensors for detecting the environment. This can cause a simultaneous feedback of several assistances, which can be additionally increased by feedback of infotainment devices [Wolf06b].

For ADAS to be accepted, the drivers should know and understand the limits of the system. As number of systems in vehicles increases, this becomes more complicated. According to different studies and interviews, many drivers do not have sufficient understanding of how ADAS are working and have wrong expectations from them [Kassner06]. The biggest difficulty for drivers is to understand in which mode the assistance is in, and under which conditions it can change modes. The cause of such a problem can be traced to risky driver behavior such as relying on the system too much and failing to react when necessary [Saad06]. Other risks that assistance systems pose include negative influences on the state of the driver such as:

- *information overload*; may be caused by the lack of driver awareness regarding the systems functionalities, their current and desirable state and modality;
- *information underload*; can be caused by partly automated assistances like ACC. ACC can cause driver errors in critical moments like during transitions from non-automated to half-automated or fully automated modes;
- *loss of vehicle control/maneuverability skills*; can be caused by assistance performing some task instead of the driver. These skills may not be essential but in some critical situation they could be relevant, or
- *safety margin compensation* which stands for several phenomena. One of them is a riskier behavior of the drivers, when they expect that an ADAS is bringing additional security.

Because of all these reasons, drivers are loosing their trust and confidence in Advanced Driver Assistance Systems and are not ready to invest in them.

2.2 Ergonomic Approach for Development of Advanced Driver Assistance Systems

For dealing with the acceptance and behavioral issues of Advanced Driver Assistance Systems, it is necessary to consider ergonomic rules and to place the human in the centre of the development process. Driving should be seen as more than only the crash avoidance and driver assistances should be developed beyond solely safety aspects. The driver assistance system should be acquainted with the driver behavior and cognitive limits. Especially, subjectively underestimated risk has to be taken into account. No generic standards for such development exist, but a summary of these considerations is presented by rules defined in [Kompass06]. Accordingly, ADAS should:

- support the driver like a virtual co-pilot,
- increase a drivers' authority and competence,
- preserve a drivers' sovereignty by being supportive, but not patronizing,

- be overruled by the driver as necessary,
- be as intuitive as possible and be easy to learn,
- be designed to be switched on and off by the driver,
- be transparent with performance and expectation conformity of system properties,
- not exceed the intended load reduction benefit of the system by driver-monitoring system,
- keep the driver on a "mean activation level" in order to counteract overstress and fatigue, and
- not have functional gaps, inconsistencies and should be compatible among each other.

Additional important characteristic of ADAS is a learnability curve [Bengler07] as it influences user's long-term acceptance.

As mentioned in the introductory chapter, the approach that was, up to recently, mainly applied for defining the application of ADAS is the Bottom-Up method. Bottom-Up method starts from the available technology and develops functionality without considering the drivers' requirements. Just as the acceptance of systems developed in this way remained far behind expected, car manufactures started to take ergonomic aspects into account by primarily analyzing the demands for an assistance system. Such a method where the ideal ADAS functionality is first defined, followed by the definition of the technically realizable assistance is called *Top-Down* approach. The technically realizable assistance is then constructed, evaluated and iteratively improved. The difference between these two approaches is depicted in Figure 2.3.

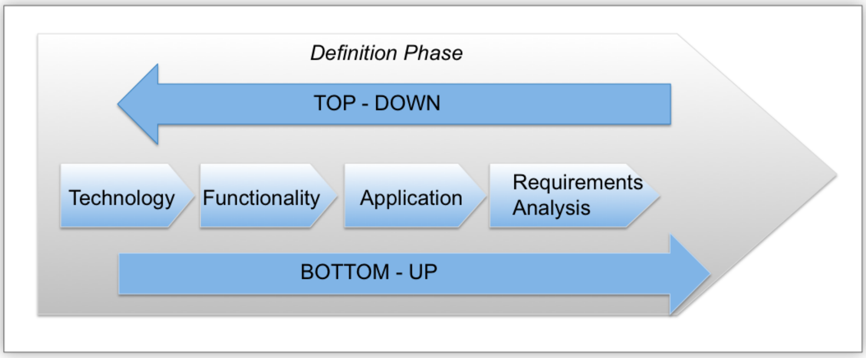


Figure 2.3: *Bottom-Up and Top-Down approaches for defining the functionality of ADAS*

To reinforce such trend but mainly to deal with problems regarding the non-standardized development and legal aspects, the already mentioned Code of Practice for ADAS has been initiated by many car manufacturers [CoP09]. CoP disseminated a generic development process of ADAS, presented in Figure 2.4. The process starts with a *Definition phase*, during which *Human Machine Interface (HMI)* and controllability safety concepts are drafted. In the *Best concept selection* phase, HMI concepts are compared and the most suitable one is chosen for the realization. Finally, the selected concept has to be specified in the *Proof of concept* phase.

Regarding the CoP phases of ADAS development, the work done within this thesis belongs to the *Definition phase* of the development of the Intersection Assistance. According to CoP, *Definition*

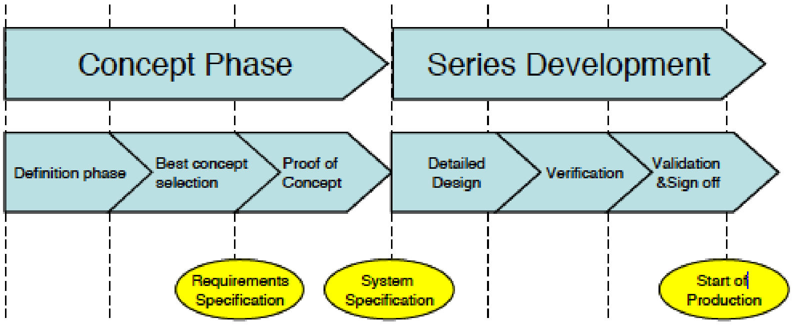


Figure 2.4: *Code of Practice (CoP) recommended phases of ADAS development presented in [CoP09]*

phase is divided into the following activities: *Functionality*, *HMI*, *Usage*, *Standards* and *Hazards analysis and risk assessment*. This is presented in Figure 2.5. In particular, the focus of this thesis lays within drafting the possible functionality of an Intersection Assistance but also with defining the requirements on the driver model that can be used in the development process of ADAS. CoP covers development topics only to the extent of describable controllability specifics. However, CoP does not suggest how to define the functionality. The CoP only advises that the definition of the functionality should include the definition of system states, modes, transitions and actions as well as situational limits and initial sensor requirements. It is not mentioned how to define the application scenarios.

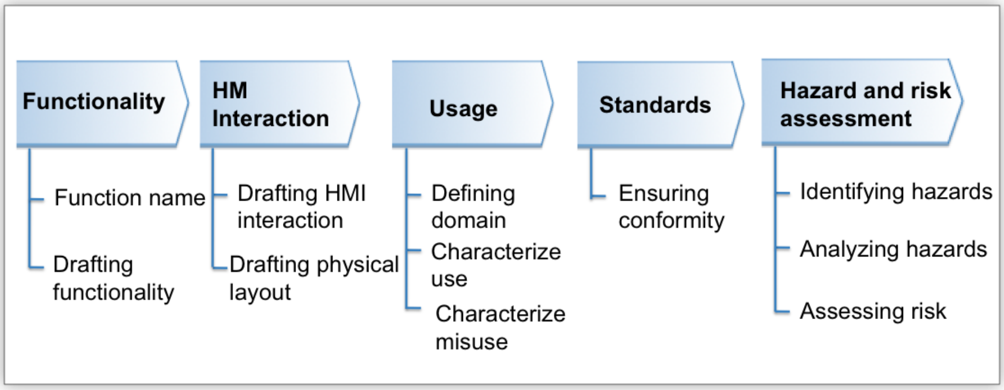


Figure 2.5: *Activities within Definition phase of ADAS development*

For drafting the functionality of the Intersection Assistance as presented in CoP, one step behind is necessary. This step is the identification of possible application scenarios, meaning the identification of situations in which the assistance system should offer the support. As defined by [Bubb93], *Functionality* is separated into the *Task-content* and *Task-design*. *Task-content* is defined by the temporal and spatial order of the activities, which are to be carried out to complete the total task. Concerning the driver assistance systems, the identification of application scenarios belongs to the definition of the *Task-content*. *Task-design* refers to the system structure. Mapped to the development of driver assistance system, to define *Task-design* means to define the modality, HMI, location or level of support. The work done in this thesis is therefore summarized as defining the *Task-content* for the Intersection Assistance. This is accomplished through theoretical and experimental analysis of the driving task at intersections, and by defining methods for modeling driver cognition in the development process of driver assistances.

As the functionality of the system should be defined taking into account the technical feasibility, the next section outlines the state of the art technology that can be used for Intersection Assistance.

2.3 Intersection Assistance Technology

This section gives a brief overview of the recently designed prototypes of driver assistance systems for intersections. The focus is on the feasibility and the state-of-the art sensor technology of Intersection Assistances. Hence, the section deals with the typical values, range and limits of applied sensors rather than with the Human-Machine Interface, which is discussed later in *Chapter 5*.

All presented prototypes are based on the wireless communication technologies named together Car2X technologies. Car2X is a common term used to describe technologies which enable a vehicle to communicate either with other vehicles, *Car2Car (C2C)* or with stationary traffic objects like traffic lights *Car2Infrastracture (C2I)*. For developmental purposes of these technologies the *Car2Car Communication Consortium* was founded [C2CC]. The mission of C2CC is to create and establish an open European industry standard for C2X systems and to enable the development of active safety applications by specifying, prototyping and demonstrating such systems. Its goal is not only to develop technologies but also to deal with respective marketing, legal and political issues. Also, plenty of other projects are supporting the evolution of C2X technologies like [IVHW], [FleetNet] or [NoW].

The development and testing of such preliminary, communication-based assistances is the goal of several projects like [KAS], [INTERSAFE] or [i2010]. In [KAS], a communication based Intersection Assistance was developed and analyzed. The aim of [KAS] project was to develop a system for avoiding potential collisions between a vehicle with right of way advantage and a vehicle in minor priority. Requirements and architecture for such an assistance, regarding the state of the art sensors, is defined within work of [Klanner06]. Basic components of the system are: *Position localization* and *Communication module*. For the completeness and to demonstrate the typical values, range and limits of the state-of-the art sensors, the short description of these modules is given.

The *Position localization* module is the system, which calculates the absolute position and the heading of the vehicle. Based on the position and the vehicle data, the future trajectory of the vehicle is predicted and the possible conflict points are estimated. [Klanner06] determined the maximum permissible deviation of relative position localization, with the assumption of the constant speed of both vehicles. This deviation depends on the speed: the lower the speed is, the more accuracy is required. Favorably, for lower speeds, on-board inertial sensors can additionally tune the position. For example, for a speed of 36 km/h, the maximum permissible deviation of the real position is calculated to be ± 5 m. The accuracy of differential GPS used in an urban scenario is just ± 10 m, but the sufficient accuracy is achieved by adequate sensor fusion algorithms: for example by using a Kalman filter on data from the differential GPS and their fusion with inertial sensors [Walchshäusl08].

Not only was the feasibility of a sufficient localization accuracy shown in this work, but also the feasibility of a *Communication module* by using state of the art sensors and WLAN Standard $IEEE$ $802.11b$. Requirements on the range, latency and update rate of the communication module were set. Minimum communication range is determined to be from 180 m for the speed of 70 km/h to 341 m for 100 km/h when no occlusion exists.

Another project that was dealing with an Intersection Assistance is [INTERSAFE], conducted within the EU project PReVENT. The goal was to develop and test a warning assistance, based on the precise relative vehicle localization, path prediction, and bidirectional communication with traffic lights (C2I). The functionality was demonstrated in form of assistances for left turn, turning/crossing, and assistance for traffic lights in two test vehicles: VW Phaeton and BMW 5 series. Relative localization was done using a video camera and laser scanner and by employing line matching and tracking algorithms. Detection and tracking of other road users was done based on the localization and comparison of measurements with a detailed ”feature-level” digital map, like reported in [Lindl06]. The exceptional achievement of this project is that it showed feasibility of an Intersection Assistance with state of the art sensors and prototype C2I communication technologies [Fuerstenberg07]. This finding was the reason for launching of the follow-up project [INTERSAFE2] in the middle of 2008.

[Benmimoun07] also presented one C2C-based Intersection Assistance, developed in the cooperation with the Japanese company DENSO. The communication range, equipment rate and data exchange are analyzed for the different traffic situations and conditions using the traffic simulation tool [PELOPS]. Afterwards, the assistance system was evaluated in the real world tests. In [Benmimoun07] a technical feasibility of an Intersection Assistance was shown, but it became obvious that for achieving efficiency and acceptance, a careful ergonomic analysis of assistance functionality is necessary.

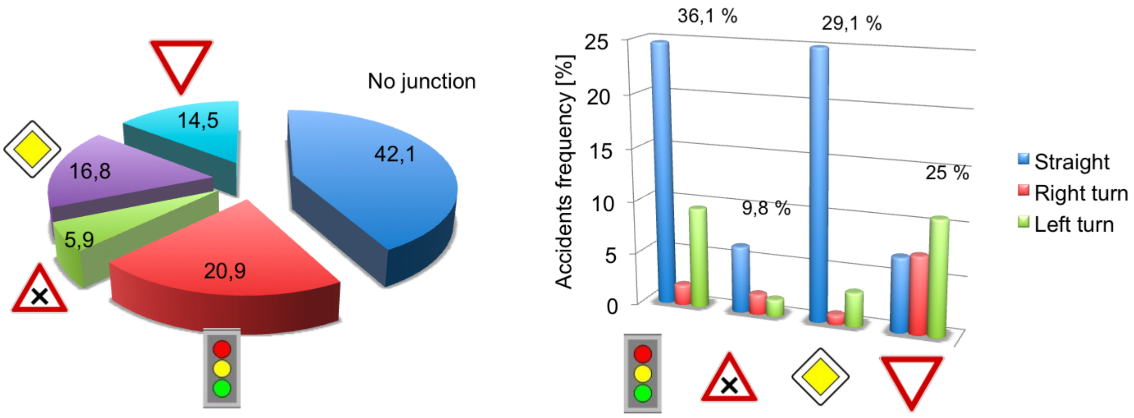
All these works proved that state-of-the art sensors allow the realization of an effective and reliable communication-based Intersection Assistance. Yet, the subsequent usability tests showed that defining the functionality of an Intersection Assistance based solely on the feasible technology is ineffective and confounds with drivers’ needs. The definition of the functionality presents a more complex problem than only sensor fusion because it involves the knowledge and prediction of a human as an extremely variable factor. The next section gives on overview of the applied methods to define application scenarios and gives an overview of several prototype-implemented functionalities.

2.4 Defining Applications of Intersection Assistance

The typical starting point for defining the application of Intersection Assistance in industrial applications is the statistic analysis of accidents. These analyses give salient information about the possible functionality of an assistance system. Therefore relevant statistical data are presented in this section. Still, for the functionality of an Intersection Assistance they do not provide enough information. This is shown by discussing the prototypes of Intersection Assistances that were developed based on the statistical analyses. Here it is also shown that the analysis of the driving dynamics only, does not provide enough results for the construction of an effective warning assistance system. Therefore, the solutionis suggested to additionally analyze and model driver relevant cognitive behavior in more detail and to design an Informative-warning Intersection Assistance system, which operates concurrently with the driver.

Analysis of accident statistics. The inspection of accident statistics at European intersections reveals a high dispersion between individual countries. Still, in all of them, the number is very high and ranges between 30% and 60% of all vehicle related accidents [INTERSAFE]. For defining the assistive function, it is essential to understand causes leading to such high numbers of accidents. Reports from EU and official statistic institutions give in the best case solely information about whether the accident happened inside or outside of urban area, and the day time. A detailed analysis of the type and the cause of accidents are missing in these reports. However, institutions carrying out in-depth analyses and providing detailed findings about collision types and causes, have been established in many countries. In Germany, one such institution is *GIDAS (German In-Depth Accident Study)* [GIDAS]. Parties having access to GIDAS databank can form arbitrary statistic analysis and deduct many relevant conclusions. Several such in-depth analyses, concerning accidents at intersections, have been distributed within different projects in previous years.

[Klanner06] used GIDAS database to find out the most common geometrical features of intersections involved in accidents in Germany. The analysis showed that 80% of accident-intersections have an angle between $80°$ and $90°$. Additionally, in 96% of cases, there was either no, or very low degree of curvature. This fact simplifies the considerations taken regarding possible assistance and the causes of accidents.



(a) (b)

Figure 2.6: *The distribution of accidents per intersection type in the city of Stuttgart, 1996 (data from [Wiltschko04]) (a) absolute frequency per junction type, (b) relative frequency per junction type and maneuver (data from [Wiltschko04])*

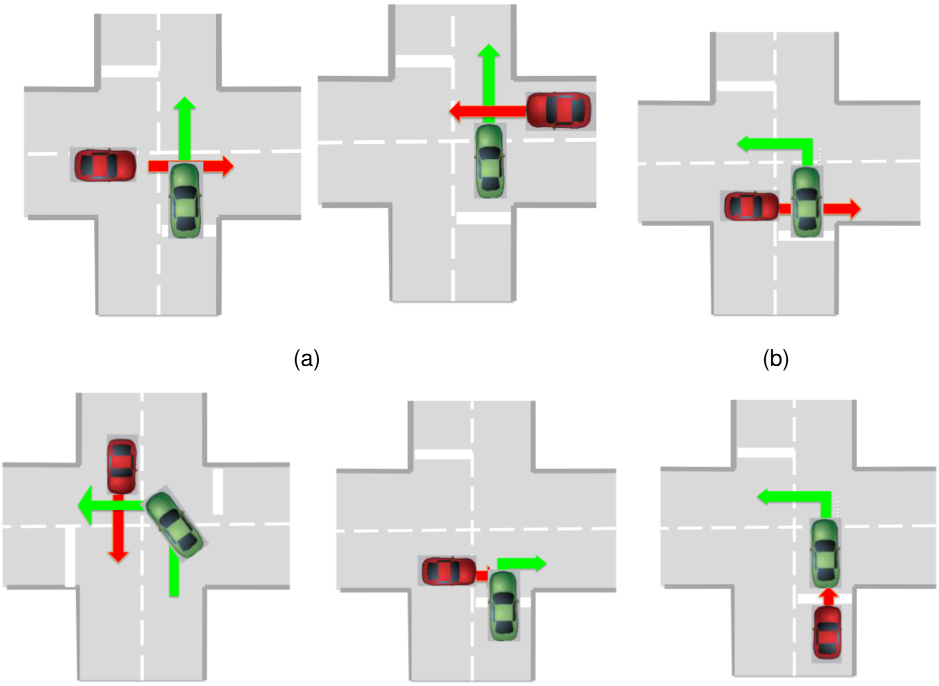
One of the most detailed, publicly accessible, in-depth analyses of intersection accidents has been published within the work of [Wiltschko04]. This analysis refers to the intersection accidents that happened in the year 1996 in the city of Stuttgart. The concentration and distribution of analyzed intersections can be considered as the representative for the other German cities. Figure 2.6(a) presents the visualization of the frequency of accidents regarding the different intersection types, based on the data from [Wiltschko04]. Altogether intersection accidents accounted for 58% of all injury-related accidents. This data complies with the data from INTERSAFE. Around 21% of accidents happened at intersections regulated by traffic lights, 31% at intersections regulated by traffic signs and 6% at unordered intersections. These data represents the absolute numbers of accidents. The absolute numbers depend on the concentration and frequency of the respective types of intersections in the city: smaller number of unordered intersections results in smaller number of accidents.

Figure 2.6(b) depicts the relative frequency of accidents, independent of the number of intersections in the city. The data is sorted according to the regulation type and the maneuver performed. Figure 2.6(b) shows that around 54% of all accidents happened at intersections regulated by traffic signs ($29,1\%$ when in right of way and 25% without right of way), 36% at intersections regulated by traffic lights and unordered intersections accounted for 10% of all accidents. Still it should be kept in mind that the accidents at unordered intersections happen mostly at low speeds (< 30 km/h) and often they are not included in any police report. Also, these intersections are characterized by a low daily traffic density, which also influences the accident frequency. Regarding the maneuver, the majority of accidents happen when driving straight 63% of the time, followed by the left turns with 25% of accidents and right turns with 12% of accidents. Another relevant fact that [Wiltschko04] found is that the majority of accidents happened on simple intersections with one lane for each direction. In complex intersections, with several lanes, collisions between vehicles moving in the same direction are major issues.

To investigate the typical accident constellation, an in-depth analysis from data from Germany, France and United Kingdom has been conducted within [INTERSAFE] project for the year 2004/2005. Five scenarios are identified, which represent between 60% and 72% ($71,8\%$ in Germany) of all injury related accidents at intersections. These scenarios are presented in Figure 2.7. The data comply to the analysis conducted by [Wiltschko04]. Figure 2.7(a) shows that around 35% of accidents are the collisions with crossing traffic when there is no change in the direction. Using the same database, [Klanner06] found that scenarios in Figures 2.7(a) and 2.7(b) account for 61% of all intersection accidents with crossing traffic.

Possible Intersection Assistance. A common approach followed, when designing an assistance system, is designing an assistance system based on the accident type. Such an approach has been applied in [Meitinger04], [Meitinger06] and [Klanner08]. These works developed an assistance systems based on the accident classification: *Stop sign Assistance*, *Left-turn Assistance* and *Crossing Traffic Assistance*, respectively. Their approach is to warn the driver during critical moments, for example when driver does not stop at the stop sign or just before a moment of possible collision.

Such warnings must be initiated with precision timing in order to make collisions comfortably avoidable and without irritating the driver with too early of a warning or an excessive warning of a danger that the driver has previously noticed. The warning is effective only if an appropriate time span exists.



(a) (b)

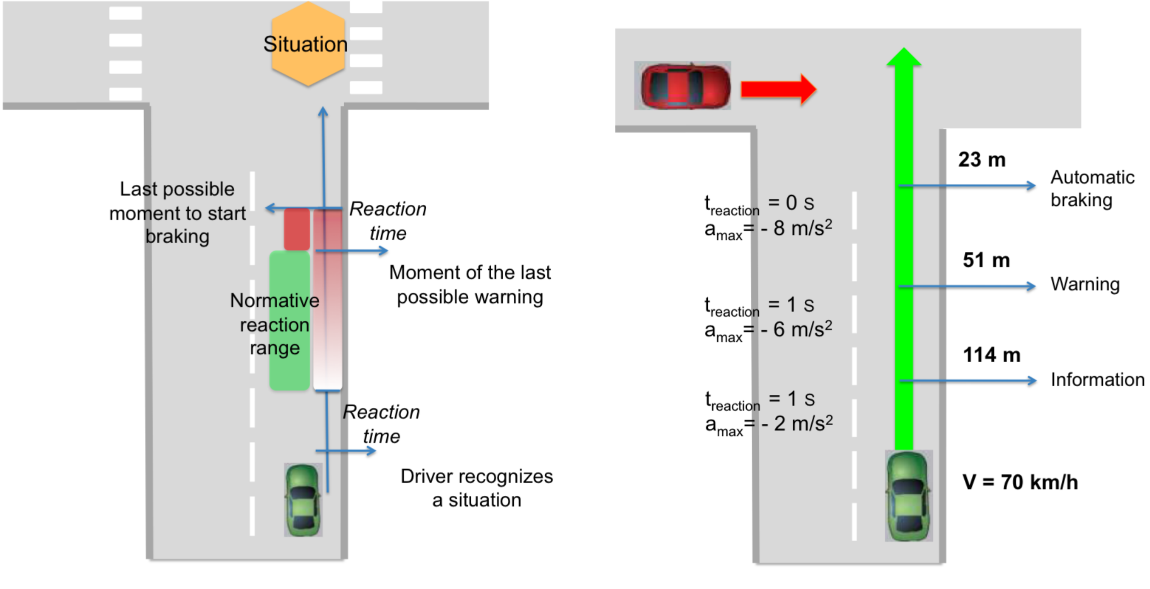
(c) (d) (e)

Figure 2.7: *Distribution of common accident intersection scenarios in Germany in year 2002/2003 [INTERSAFE] (a) Turn into/straight crossing path* (34%)*, (b) Turn into/straight crossing path* $(10,5\%)$*, (c) Turn across path* (10%)*, (d) Turn into/ straight crossing path* (2%)*, (e) Turn across path* (2%)

This problem is known as the *warning dilemma* and is depicted in Figure 2.8(a). When approaching a situation where the driver is required to stop, a particular distance range exists in which the driver can start decelerating. The warning is effective only if it is announced before the last possible braking point, the drivers' reaction time subtracted (see Figure 2.8(a)). Sporty and defensive drivers react differently. If the majority of frequent drivers' reactions are within green rectangle, a warning function is reasonable. However, if many drivers react within range of the red rectangle, a warning has no effect.

[Meitinger04] researched the possibility of a warning assistance for Stop sign by analyzing the drivers' usual reactions. He conducted field experiments for analysis of natural drivers' reactions when approaching a Stop sign, and found out that the majority of drivers, including sporty ones, react much earlier before the last moment of possible reaction. Additionally, he showed that the distinction between the drivers who are reacting and who are not reacting to the Stop sign could be made before the last possible warning point. This means that the Stop sign Assistance can be designed so to be effective and thus accepted by the majority of drivers.

The warning function is also effective in case of Crossing Traffic Assistance. [Klanner08] showed the feasibility and acceptance (in 95% of cases) of warning function for such an assistance. Additionally, he suggested the possible modality of an assistance depending on the distance to an intersection.



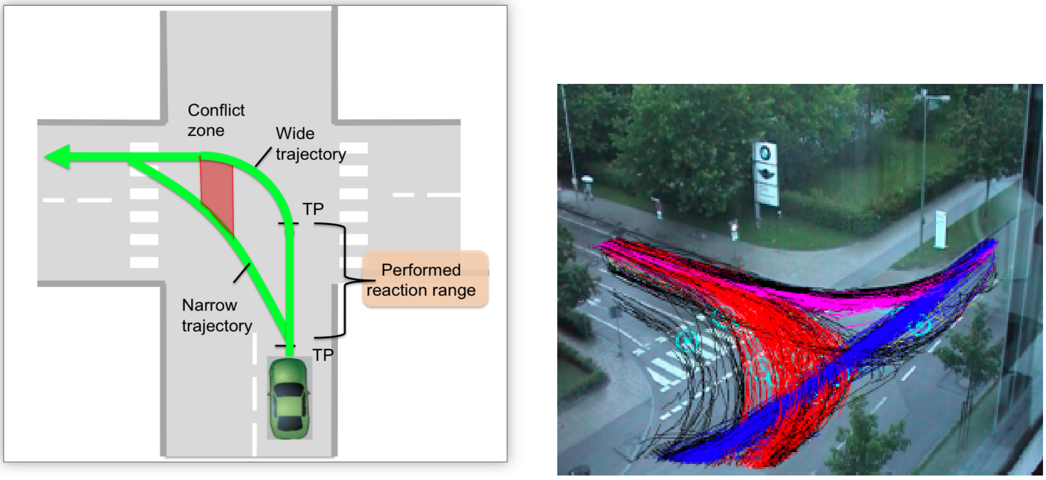
(a) (b)

Figure 2.8: *(a) Warning dilemma: If the majority of natural driver reactions are happening within the green rectangle, the warning is effective; within the red rectangle the warning has no effect, (b) The possible modality of Assistance for Crossing traffic, data from [Klanner06]*

Based on typical 1 s reaction time and deceleration values for comfortable (-2 m/s^2), critical (-6 m/s^2), and autonomous braking (-8 m/s^2), he calculated the appropriate distances for the Informative, Warning assistance and Autonomous braking assistance. An example of the modalities of Crossing Assistance for the speed at 70 km/h is presented in Figure 2.8(b). At this speed, information should be issued no later than 114 m, the warning no later than 51 m and the autonomous brake should be performed 23 m before the intersection at the latest.

In this manner, it is shown that the Stop sign Assistance and Crossing Traffic Assistance can be designed to be effective. However, the same does not hold true for the Left turn Assistance [Meitinger06]. The reason is explained in the following. A decisive characteristic of the left turn maneuver is the turning point (TP). This point defines whether the driver will stop to give way to oncoming traffic or drive through. Again there is a distance range in which this point still belongs to normative driver behavior. This is visualized in Figure 2.9(a). The sooner the turning point is, the narrower the trajectory. The earliest moment when the warning can be issued is exactly at this turning point, because just in that moment, whether the driver will stop to give way to oncoming traffic or drive through, can be detected. On the other side, the warning should be issued early enough, so that stopping is possible before the driver enters the conflict zone.

[Meitinger06] conducted experiments to analyze whether the warning can be issued between these two points and has found that the effectiveness of the warning assistance differs in case when drivers drive through and when drivers stop to yield to the oncoming traffic. In the first case, an effective warning system cannot be realized. The standard deviation of realized turning points and reactions



(a) (b)

Figure 2.9: *Left turn (a) Range of turning points (TP) within normative driver behavior, (b) Augmented trajectories of left turns at one intersection, courtesy of [Klanner08]*

times is too high, much higher than the deviation of reaction times to the Stop sign. In other words, when reacting to the Stop sign the behavior of the driver is far more uniform than when executing the left turn. The high deviation of the left turn trajectories is augmented in the video recordings of [Klanner08] presented in Figure 2.9(b). For drivers who choose the narrow trajectory, alarms would often be issued when no critical situation exists and for drivers with wide trajectory a collision could be avoided in only a very few cases. For stopping, a warning would have more effect, but it is disputable whether in that case the assumed reaction time of 1 s would be enough. Therefore the conclusion is that in both cases autonomous braking with the deceleration of -6 m/s^2 should be implemented. Of course, for such a solution it is necessary to have extremely high levels of sensory fidelity, and situation interpretation to avoid activation for non-critical situations, so called false-positives. Another major problem that needs to be solved for the application of an autonomous assistance is the responsibility and the liability issues concerning the traffic law. Anyhow, it is concluded that the Warning intersection assistance system cannot be designed in a way to be both efficient and accepted by the majority of drivers, at least not for all maneuvers and types of intersection.

Adaptivity of Warnings. One possible solution to the above mentioned problem are adaptively issued warnings. The system can be either adapted to the driving situation or to the driver [Plavsic08b]. The *situation adaptation* means that the assistance can recognize the traffic situation, classify it and adapt a reaction accordingly. However, drivers present a heterogeneous group of users, which makes the situation adaptivity insufficient, as shown in the previous examples. *Adaptation to the driver* means many things, for example adaptation to the drivers' individual preferences or to the drivers' current state or intention. The difficulty here is that the behavior of the same driver encompasses huge intra-individual differences. The driver can show different behavior in the same situation depending on the mental and physical state: fatigued, motivated, focused on current goal, or the current strain. The consequence is that the same warning in the same situation can at some time be perceived as helpful, but at some other time as irritating.

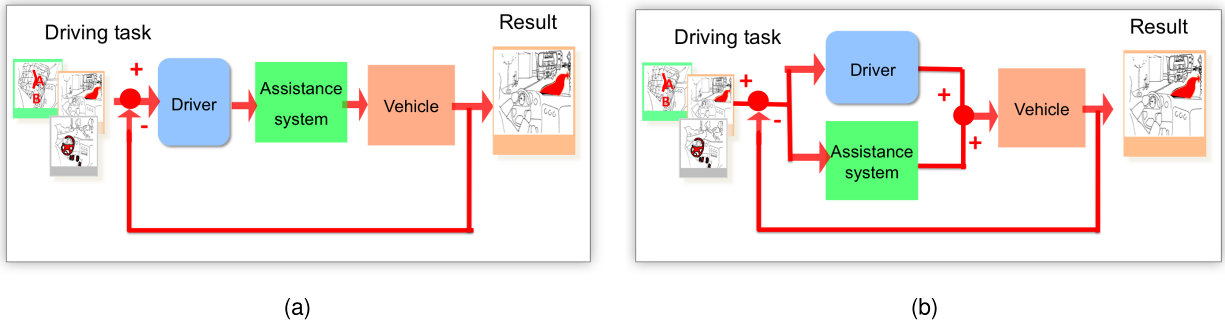
Even though the adaptiveness of driver assistances is a popular topic, current research deals mainly with the adaptivity of infotainment devices to the driver workload or the risk assessment of specific traffic situations [AIDE]. The adaptivity of the warnings depending on the drivers' state in the critical situations is a more complex issue. Several researchers are developing methods to deduce the drivers' state based on driving dynamics data like [Farid06] or [Schulz07]. Other authors are applying different techniques from the field of artificial intelligence to detect the drivers' state and intentions such as *Hidden Markov Models*, *Fuzzy logic*, or *Bayesian network*. Yet, none of the single solutions proved to be satisfactory [Plavsic08b]. Also, these approaches were applied only to the longitudinal scenarios up to now. The prediction of driver state and intentions in intersection scenarios, based on driving data only, is additionally complex.

The way to gain more useful data from the driver can be achieved by using on-board cameras. Such an approach is considered as too obtrusive for this work and will not be considered.

2.5 Conclusion: The analysis of the driver cognitive behavior and parallel-coupled assistance as a solution

The work carried out within this thesis is based on the suggested solution to extend the knowledge about drivers' dynamic behavior with the knowledge about drivers' cognitive behavior and to use it to develop Informative-warning Intersection Assistance. The previously discussed warning assistances act like a serial element between the driver and the vehicle. This is presented with the control-theory paradigm as in Figure 2.10(a). The driver perceives the environment and performs the driving task by commanding the vehicle: gas, brake pedal and the steering wheel. The assistance system observes the drivers' reactions and when it detects the critical behavior it issues the warning or intervenes in the process. Here, the assistance presents a serial element that resides between the driver and the vehicle and is therefore acting with a time-delay. This time-delay is causing problems previously described as the warning dilemma. The assistance system, which is on the other hand informing the driver in critical situations, operates simultaneously to the driver and can be even considered as a co-driver (see Figure 2.10(b)). Such system is parallel-coupled to the driver and there is no time-delay. The main difference between the systems on the Figure 2.10(a) and 2.10(b) is in the reliability of the system: the reliability of the parallel-coupled system is several orders of magnitude higher than the reliability of a serial-coupled system.

The development and design of an assistance that is parallel-coupled to the driver require extensive knowledge about the situation and the natural drivers' reactions. The assistance should be designed so to avoid the possible overload of information by giving the appropriate information at appropriate moment. The first step in the design process of such assistance is the determination of the ideal behavior in a particular situation and an analysis of the driver usual behavior and naturalistic reactions. By knowing these differences, the assistance can inform the driver about the normative behavior in situations which are assessed as critical.



(a) (b)

Figure 2.10: *Possible position of an assistance system within driver-vehicle control theory paradigm (a) serial-coupled, (b) parallel-coupled. The reliability of the parallel-coupled system is several orders of magnitude higher than of serial-coupled*

Currently available knowledge about the drivers' behavior at intersections is mainly focused on the behavioral dynamics. It is known that drivers have approximate reaction time of 1 s, that comfortable deceleration is around -3 m/s^2 and that the deceleration in critical situations can go up to -6 m/s^2. It is also known that drivers start decelerating around 3 s before an intersection or that typical entrance speed is around 17 km/h [VanderHorst07]. What is not analyzed in the satisfying extent, is the drivers' cognitive behavior when performing the task at an intersection. This behavior involves the distribution of attention, expectations, typical searching strategies and scanning behavior. Knowing the typical and the naturalistic cognitive behavior supplements the knowledge, necessary to develop the suggested assistance system. In this way a unique Informative-warning Intersection Assistance System can be designed.

It is important to understand here that typical driver behavior should not be analyzed only in critical situations which lead to accidents, but also in regular, every-day situations. The accident can be caused by either consciously committed or by unintentional error. The informative assistance should in the first place prevent the unintentional errors from happening. The accidents, which are the consequence of unintentional errors, are rare occurrences. Traffic scenarios leading to an accident are often very complex and are a combination of several factors. If other factors do not contribute, the committed error will stay without consequences. The factors, which are necessary to come together in order for an accident to happen, are depicted in Figure 2.11. An accident *(Topevent)* can happen if a traffic conflict and an inappropriate treatment of the conflict occur [Bubb05]. For an accident to happen it is necessary of the driver to commit an error and that neither he nor other road users can compensate for. Thus only an unresolved conflict leads to an accident. Therefore the pure accident analysis cannot reveal enough information about the underlying poor strategies. It is necessary to determine the ideal driver behavior for the particular traffic situation and to analyze the usual behavior and its variance. In this way the poor drivers' strategies, that are often applied, but in reality seldom lead to an accident, can be identified.

Ideal driver behavior can be described as the behavior that is regulated by the traffic law. For each traffic situation, there is a span of driver behavior that can all be correct. For situations such as intersections, there is less time in which the driver has to perform plenty of tasks and by that the

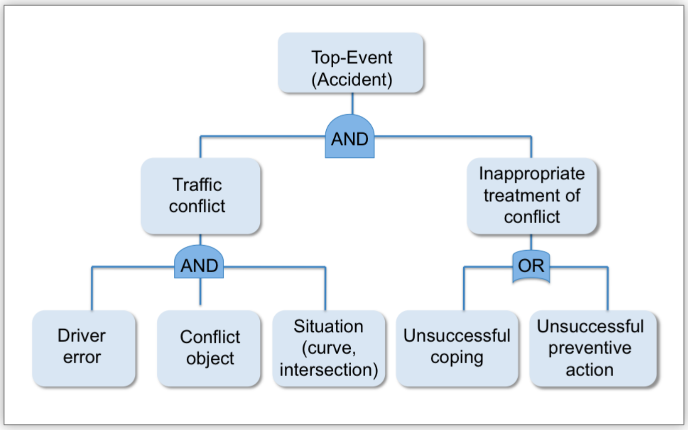


Figure 2.11: *The role of the human error in accident origin, adapted from [Reichart00]*

range of ideal behavior is decreasing. However, with the experience, the drivers develop strategies and techniques that differ from the ideal behavior. These strategies present the maximum of the function between the safety and efficiency for each driver, and can be labeled as naturalistic or usual driver behavior. For example, prior to entering a highway, the shoulder gaze is required for getting a driver's license. Still, after some time, the majority of drivers do not make this gaze because they pay attention to the situation behind the vehicle for several seconds before they enter the highway. The assistance system that would warn the drivers that they should do the shoulder gaze would not be accepted and would be irritating for the majority of them. Rather it should be assumed that drivers follow the situation behind the vehicle even though they did not do the shoulder gaze.

Figure 2.12 shows an example regarding intersections. This Figure presents two possible visual behavior strategies when driving straight and when in right-of-way. The blue arrows present the glance directions and the numbers attached give the sequence of the changes of glance directions. If the analysis of the usual drivers' behavior shows that in the majority of cases drivers do not pay attention to the crossing traffic not in right-of-way (Figure 2.12(a)) and the sensors detect the deviated behavior of the crossing traffic (for example too high speed), the driver should be informed. Such a situation is so rare that it does not even matter whether the driver has perceived the deviating vehicle himself or not, the driver is not irritated by such information. If however the analysis of drivers' behavior shows that the usual visual behavior is as in the Figure 2.12(b), the information about the crossing traffic should be left out.

With such an assistance there is less confusion about the functionality, and the legal issues can be solved easier. The major difficulty is the requirement of extensive knowledge about the drivers' behavior. Also extensive knowledge about situation assessment and risk evaluation of situations is necessary. Furthermore, it will also be necessary to test whether and under which condition would such system be accepted. The first step in design process is to find answer on the following questions: Does usual driver behavior differ inter-individually and/or intra-individually? Are the usually applied cognitive strategies similar among the drivers and among different intersection types? Does the same driver apply the same strategy under the same condition? Does the way the driver perform the task

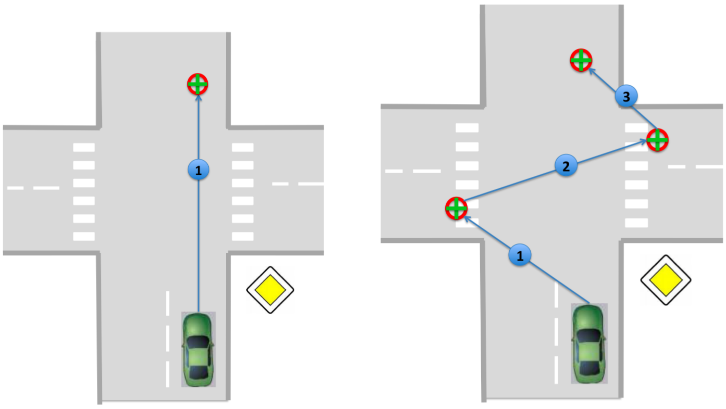


Figure 2.12: *Two possible visual behaviors of the driver at an intersection in the simplest intersection scenario of going straight when in right-of-way. Blue arrows present glance directions and numbers attached their sequence*

at simple intersection relate to the way the driver performs the task at a complex intersection? By knowing the answers on these questions, by knowing the normative behavior in a particular situation, and by being able to recognize or predict the poor driving strategy, the system increases the driver's competence in the best way. It can be considered as an on-board instructor and teaching assistance.

The first step is however, to analyze the driving task at an intersection, applied drivers' strategies, and to define the way in which the driver behavior should be modeled. The prerequisites for this analysis are the classification of traffic situations and analysis of drivers' cognitive processing relevant to the driving task. These two are accomplished within the next chapter.

2.6 Summary

In the last thirty years, plenty of Advanced Driver Assistance Systems have appeared on the market and during the last ten years the focus was on supporting the driver on the guidance level of the driving task. The emerging communication technologies enable development of assistances that can support the driver at intersections and they are expected to be the center of research in the next decade. This chapter has shown that an assistance system for intersections is technically feasible and reliable with usage of various C2X communication-based protocols. Prototypes of such assistances have already been developed and tested. The major issue that is still to be solved is the definition of the application scenarios. It has been shown that the non-human-centered development of assistances results in a series of problems and the drivers' rejections of the new systems.

For the industrial purposes, the typical determination of application scenarios starts from the accident analyses. It has been shown within this chapter that the accident statistics cannot give enough information for determining the application of Intersection Assistance, because it is not an accident type that should be addressed with an assistance, but the cause of human error provoking an accident. If the assistance is not adapted to the traffic situation, and to the driver state and intentions, it can be perceived as irritating and may not be accepted. For the prediction of the driver intentions almost absolute knowledge about the driver, vehicle and environment is necessary. To avoid these difficulties, the suggested approach is the informative, ”teaching” assistance that is parallel-coupled to the driver and that learns the ideal and the usual behavior of the driver. In such a way, it can inform the driver in situations which are objectively critical and in which there is a high probability of a deviation from the ideal behavior. To find out whether such an assistance system is feasible, the first step is to understand the range of applied driving cognitive strategies at intersections, their difference to the ideal behavior and to determine the most suitable way to model it.

Chapter 3

Classification of Traffic Situations and Driver Model for the Task Analysis of Driving

For the determination of ideal driver behavior at intersections and for systematical analysis of the range of applied driving strategies, it is necessary to have at call the appropriate classification of intersection scenarios. Another prerequisite is the appropriate model of human's cognition for the performance of the driving task on the guidance level. These two prerequisites of the task analysis present the objective of this chapter.

After discussing the possible classifications of traffic situations, information perception and processing mechanisms relevant for the driving task are analyzed. Driver's cognition is described in terms of cognitive states and corresponding processes, which are necessary for the achievement of particular states. This chapter considers the most relevant psychological models of driver cognition and maps them to the performance at intersection. In doing so, the recently popular term of Situational Awareness is described and connected with the traditional system-ergonomic view of human-machine control circle. Each of the processes necessary for achieving Situational Awareness and decision making are modeled in detail and presented on an example of driving through intersection. By this, the bottlenecks in human processing mechanisms are emphasized, which are of essential importance when considering the possible functionality of an assistance system. Subsequently, the terms of risk, task demand and workload are discussed regarding the influence on driver behavior at intersections.

The presented model uniquely merges and unifies the most relevant theories and aspects regarding cognitive driver behavior. It presents the theoretical basic for the simulation model of the cognitive driver behavior and as such it presents the fundamental step for solving the issues discussed in the introductory chapter.

3.1 Classification of Traffic Situations

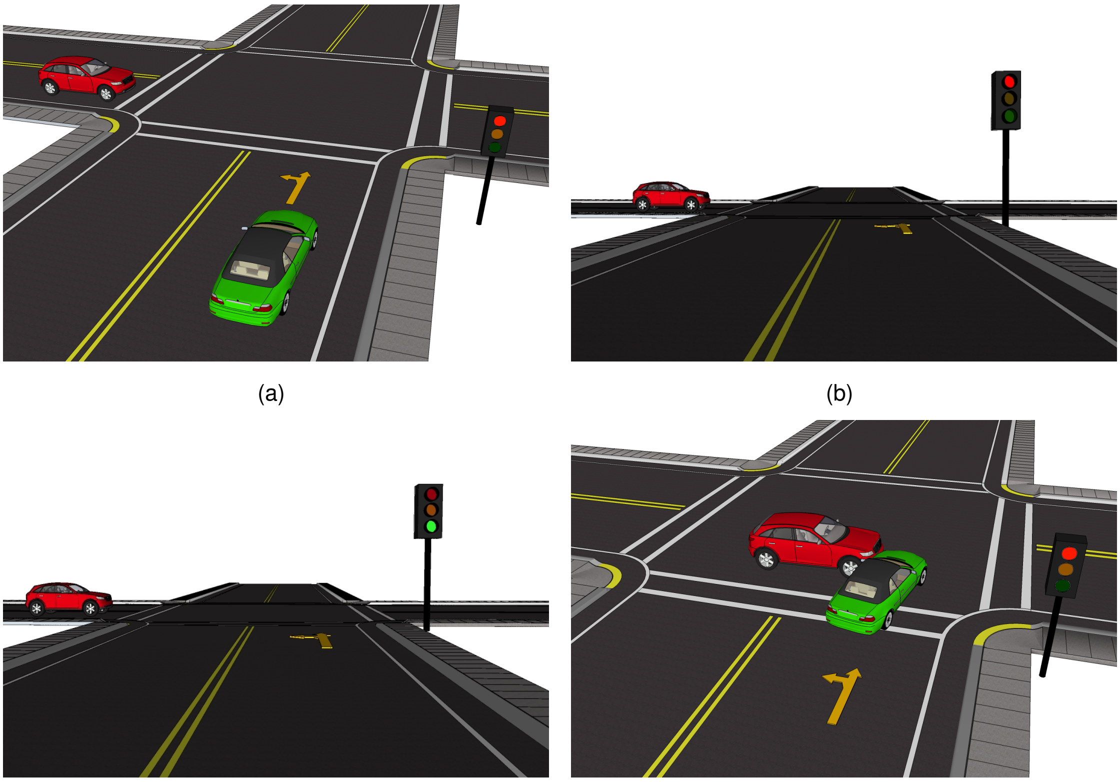
The unambiguous classification of traffic situations is essential for the successful modeling and analysis of the driving task. However, no standardized or generally accepted classification of traffic situations exists. Each of numerous, available classifications is developed for a specific purpose and as such they show huge variations and inconsistency. For the coherent classification of traffic situations, it should be first distinguished between the *road traffic situation* and the *driving situation*. The difference between these two is formulated by [Fastenmeier95] as: *traffic situation* is defined by the constellation of traffic parameters that are objectively existing in time and space. *The driving situation* presents the subset of the traffic situation and it is the traffic situation seen from the driver's perspective, or in the other words it is the part of traffic situation that the driver experiences in some unit of time and space. To this grading, [Reichart00] introduces one more aspect: *driver situation*. The driver situation additionally depends on the individual characteristics of the driver like motivation, experience or vision ability.

An example in Figure 3.1 clarifies the difference between these terms. In this example, the *traffic situation* is an inner city X-intersection regulated by traffic lights, connecting two-lane roads via a separating strip, without a dedicated lanes for turning and without dedicated bicycle path. The traffic situation is sketched in Figure 3.1(a), where the green car presents the subject vehicle. In contrast to the *traffic situation*, the *driving situation* is presented in Figure 3.1(b). The *driving situation* in this example is described as an approach to the intersection regulated by traffic lights during the red phase, with no leading vehicles and one vehicle approaching from the left. It can happen that the driver does not perceive the red traffic light because the lights are blended by the sun and the driver falsely assumes that the traffic lights are green or out of order. In such a case the *driver situation* differs from the *driving situation* and can be described as an approach to the X-intersection with having right of way. Such *driver situation* is presented Figure 3.1(c). This mismatch between *driving* and *driver situation* can have the fatal outcome and explains the reason for the necessity to distinguish between these terms.

In the following, available classifications of road traffic situations and of driving situations are discussed with the purpose of selecting the appropriate classification of intersection driving situations.

Classification of traffic situations. There are many classifications of road traffic situations, especially from an engineering point of view. They describe the physical nature of the situation regarding the four aspects: constructional characteristics (intersection, curve, width of the lane), infrastructural characteristics (regulation of the right of way), characteristics of the traffic flow (daily traffic road records) and local characteristics (bicycle roads). Such classifications are used by state's institutes for the road constructions like [RAS95] in Germany.

Another type of the road traffic classifications are classifications for accident analyses. Such classifications are made by the insurance companies or police for the legal regulation of the accidents. They are important to mention here in more detail because they are often used for the definition of application scenarios for driver assistance systems. For example, the German institute for road constructions [GDV88] applies the following classification of accident scenarios:



(a) (b) (c) (d)

Figure 3.1: *The exemplary visualization of the difference between traffic, driving and driver situation: (a) Road traffic situation, (b) driving situation, (c) driver situation (misinterpreted driving situation), (d) the possible consequence of the mismatch between driving and driver situation*

- *Run-off-road collision*, caused by either loosing the control over the vehicle or colliding with another object,
- *Turning into collisions*, caused by the vehicle that is turning and the vehicle from the same or oncoming direction,
- *Turning/Crossing collisions*, caused by the collision between the vehicle without right of way and the vehicle in right of way,
- *Collision with the vulnerable road users*, including all collisions with pedestrians and bicycles unless they do happen in junction areas,
- *Impact with parked vehicles or infrastructure*, and
- *Collision in longitudinal traffic*, like rear-end or head-on collisions.

Another popular classification of the road traffic situations has been developed by [Fastenmeier95]. The classification is based on the street type, roadway, and traffic characteristics. Hereby, the visibility and traffic density are considered as factors that characterize the individual drive and not the situation. The resulted classification is presented in Table 3.1. It distinguishes between three types of the road: motorways, rural and city roads. Regarding the road layout, the difference is made between

Table 3.1: *The classification of the road traffic situations developed by [Fastenmeier95]*

Main Elements	Type of Category	Code	Description of categories
Highway type, Road design	Motorways	A1	Dual-three-lane motorway, modern type; broad marginal strip: parking and queing lane or at access points acceleration and deceleration lane
		A2	Dual-two-lane motorway, modern type; broad marginal strip: parking and queing lane or at access points acceleration and deceleration lane
		A3	Dual-three-lane motorway, older type; slim or no marginal strip, no parking lane or acceleration and deceleration lane
		A4	Dual-two-lane motorway, older type; slim or no marginal strip, no parking lane or acceleration and deceleration lane
		A5	Parking and service areas
	Rural roads	L1	Two-lane rural road: modern profile and cross-section, road markings and paved verges, wide shape of curves
		L2	Country road, older type, and side roads: lack of road markings unpaved verges, narrow shape of curves
	City roads	C1	All inner-city roads with two carriageways and separating strip: ring roads etc.
		C2	One carriageway, broad at least 4 lanes
		C3	As C2, with fixed-guideway transit system
		C4.1	One carriageway, broad, 3 lanes
		C4.2	One carriageway, 2 lanes, in case speed limit of 30km/h
		C5	As C4.1 and C4.2, with fixed-guideway transit system
		C6	Residential streets, narrow carriageway, narrow thoroughfares,
		C7.1	One-way roads, broad, 2-3 lanes
		C7.2	One-way roads, narrow, 1 lane, in case of speed limit of 30km/h
Road layout	Horizont. shape	H0	Without curve
		H1	Curve
	Vert. shape	V0	Even, straight course
		V1	Incline
	Type of junction and junction control	K0	No junction
		K1	Signalised junction with traffic lights
		K2	Unsignalised junction with priority to the right
		K3	Signed junction with priority (including access points on motorways from the driver's point of view on the motorway)
		K4	Signed junction, minor priority or give-way line (including access points on motorways from the driver's point of view approaching on the motorway)
Traffic flow	Lane closures	E0	Straight course
		E1	Lane closures, bottlenecks, narrow tunnel, narrow bridges, etc.
	Driving direction	F0	No direction change
		F1	Right turn
		F2	Left turn
		F3	U-turn

curvatures and straight roads, and even and inclined courses. Also, four types of junctions are distinguished: signalized, priority to the right, signed junction with priority, and signed junction with minor priority. Having this taxonomy on call, intersection scenario is combined as a type of junction and type of accessing road. For example, C1- K2 presents an unordered intersection connecting two carriageway roads (see Table 3.1).

Classification of driving situations. Restricting the classification to the physical nature of traffic conditions is not sufficient for the situational analysis of the driving behavior. The same attributes may cause different driver reactions and different attributes may result in the same behavior of the driver, depending on what the driver perceives. To avoid this difficulty, the classification of the traffic situations for analysis of driver behavior should refer to the *driving situations* and not to the *road traffic situations*.

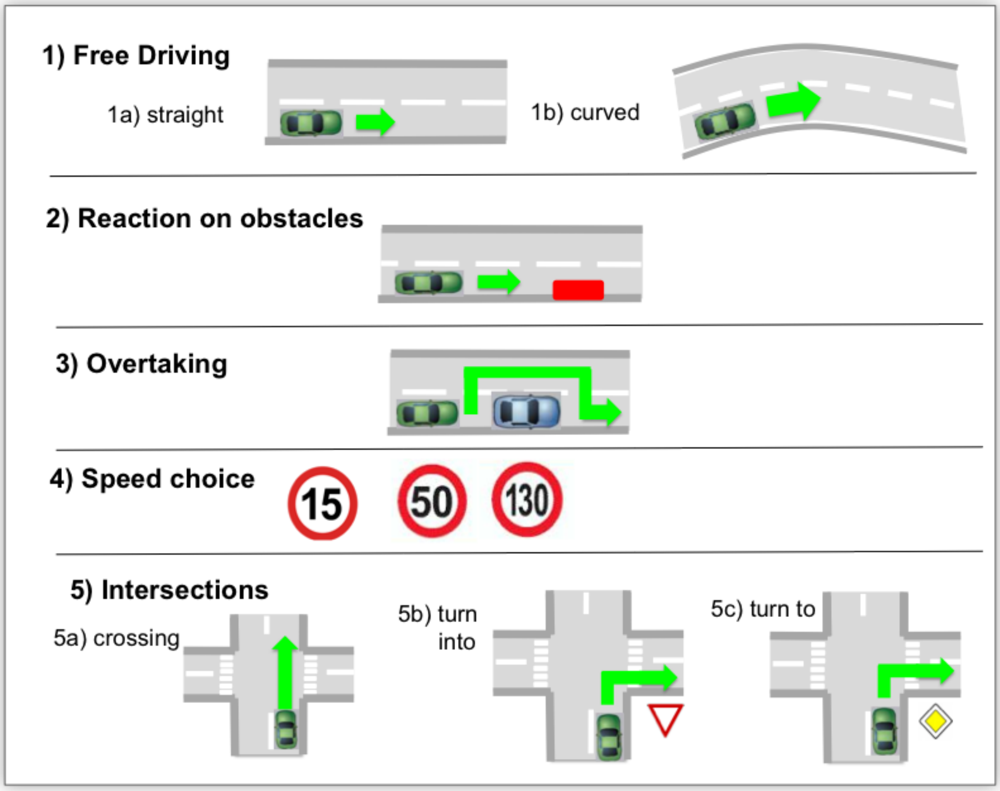


Figure 3.2: *The classification of driving situations according to [Reichart00] (the green vehicle presents the subject vehicle)*

Driving situations are however more complex to classify because of the high number of influences. This is resulting in even more abundant classifications of driving than traffic situations. The reason is again an inconsistency in these definition of the driving situation and the driving task. One driving situation may imply several driving tasks to be committed. As a consequence some of the classifications define the driving situation on the lowest level of the tasks to be committed like the popularly quoted classification from [Benda77] that resulted in even three millions of different driving situations. Other classifications occupy larger set of single tasks, like classifications from [Klebelsberg70] and [McKnight70]. For example, within some classifications the driving through an intersection is a driving situation where within other classifications the driving through an intersection is divided into several driving situations like approach, deceleration or crossing of an intersection.

More practical approach has been suggested by [Schemmerer93]. She takes into account an information-processing model of the driver and distinguishes between the situations depending on the requirements that each task has on the driver. [Reichart00] adopted this classification, reshaped it further and suggested the classification of driving situations which consists of five categories: three refer to the longitudinal traffic, one category to the intersections and one is the speed choice. These categories are presented in Figure 3.2.

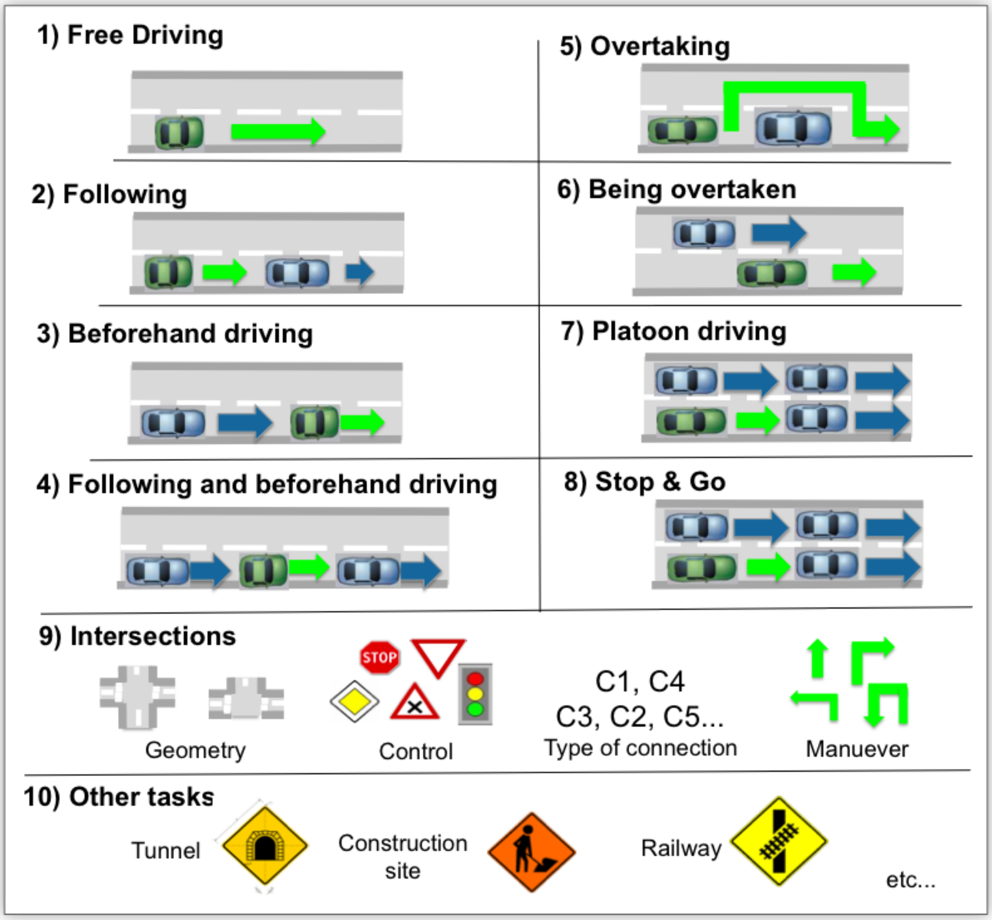


Figure 3.3: *The classification of the driving situations suggested by [Fastenmeier07]*

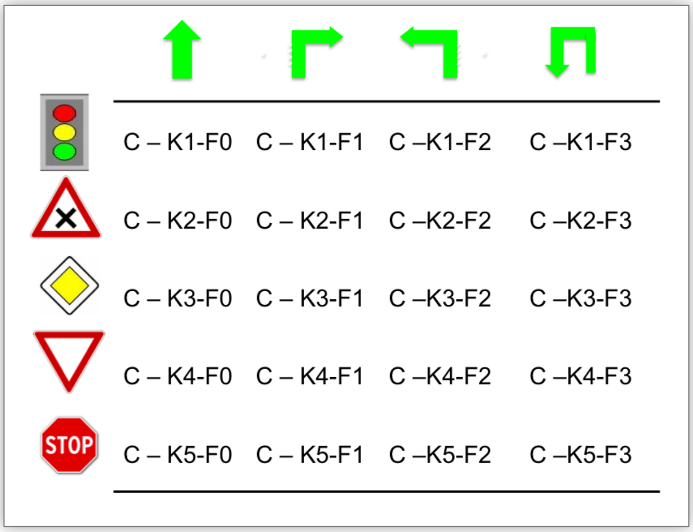
A similar approach has been suggested by [Fastenmeier07]. The resulting classification is presented in Figure 3.3. This classification takes both static and dynamic features into account. It distinguishes between eight situations in the longitudinal traffic, intersection situations and other situations. The situations are precisely distinguished from each other by a specific situation element. For example *Free driving* turns into *Following* when the headway to the leading vehicle becomes smaller than 2 s. The same is with road traffic classification (see Table 3.1), these situations cannot be analyzed independently of the type of the road: motorways, rural and city roads.

According to all these classifications, the driving task at intersection differs qualitatively from the driving task in the longitudinal traffic. Intersections are areas where the driving speed should be changed in order to change of the driving direction safely. Each intersection can be described as a combination of the specific static and dynamic parameters. Static parameters are:

- Regulation type (traffic lights, road signs or implicit rules)
- Maneuver (right, left, straight, U-turn)
- Type of intersection (X, Y, T)
- Type of connection (type of the road, C1 to C7 coding)

The dynamic parameters occupy the parameters regarding the presence and the behavior of the other road users. The classification of the situation in the longitudinal traffic presented in Figure 3.3 takes into account the traffic density and the behavior of other traffic participants, and by that, both static and dynamic parameters. Such a classification resulted from the numerous field studies whose purpose was to observe and classify relevant driving situations [Fastenmeier07]. The corresponding analysis for intersection scenarios, which systematically analyzes the influence of other road users, has still not been carried out. Therefore the classification, which takes into account for example the leading vehicle or the presence of pedestrians and other users, can still not be made, at least not based on the experimental data.

Table 3.2: *The classification of the driving situations at intersections. A modified version from [Fastenmeier95]*



	↑	↱	↰	⮍
🚦	C – K1-F0	C – K1-F1	C –K1-F2	C –K1-F3
⚠	C – K2-F0	C – K2-F1	C –K2-F2	C –K2-F3
◆	C – K3-F0	C – K3-F1	C –K3-F2	C –K3-F3
▽	C – K4-F0	C – K4-F1	C –K4-F2	C –K4-F3
STOP	C – K5-F0	C – K5-F1	C –K5-F2	C –K5-F3

For the task analysis conducted in this thesis and the definition of experimental scenarios, the classification of intersections scenarios presented in Table 3.2 is used. It distinguishes between intersections regulated by traffic lights (K1), priority to right (K2), major intersections (K3), minor intersections (K4), and intersections with *Stop sign* element (K5). The letter C (see Table 3.1) indicates the type of the city road and hereby it is not relevant what kind of the road it presents and F0, F1, F2 and F3 denote going straight, right, left and turning, respectively. This is the classification of road situations from [Fastenmeier95] with an additional *Stop sign* element. *Stop sign* requires different behavior than the *Yield sign* and is therefore put in the separate category. Additionally, roundabouts also belong to the categories of intersections and are their alternative. However, they are out of the scope of this work and will not be considered.

3.2 Relationship Between Driving Task and Driver Model

As discussed, the prerequisites for the task analysis of the driving at intersection are appropriate classification of driving task and appropriate driver model. This section explains the connection between these two.

The driving task, independent of the driving situation, can be classified into one of the following groups: [Bubb93]:

- *primary tasks* - serve to keep the car on the course and can be divided into tasks of *navigation*, *guidance* and *stabilization* level,
- *secondary tasks* - tasks either required only in the specific situation (wiping, dimming headlights) or tasks of giving an information about own intentions to the other drivers (blinking), and
- *tertiary tasks* - occupy all the tasks which have nothing to do with the driving like operating the air-condition device or changing a radio station.

With the control theory paradigm, the particular categories of driving task are presented as in Figure 3.4 [Bubb02]. Each of the three categories of primary tasks puts different demand on the driver. Navigation refers to making a route choice and adapting to the traffic boundary conditions. Within the guidance level appropriate control parameters are selected in around the next 200 m, such is the choice of the desired course, speed or maneuver [Bubb02]. The interaction with other road users also happens on this level. On the guidance level it is determined whether the driver can perceive all the information that is relevant for the task, how is this information processed, whether the correct decision is made and how is this communicated to the other road users. The reason for accidents at intersections lay primarily on the guidance level of the driving task. On the stabilization level, the focus lies on the translation of the driver's desire into appropriate vehicle movements by steering, accelerating or braking. At intersections the driving task is performed on all three levels: navigation, guidance and stabilization level.

The connection between the driving task and the driver model is given by *Knowledge-, Rule- and Skill-based model* from [Rasmussen87]. This model explains the level of cognitive resources necessary for specific task. Each task can be accomplished on one of three levels: knowledge-, rule-, or skill-based level. On the knowledge-based level the task is managed almost completely consciously. This can be the performance of the task by a beginner or the performance of an experienced person in an unfamiliar situation. In both cases, cognitive resources are required and performance is likely to

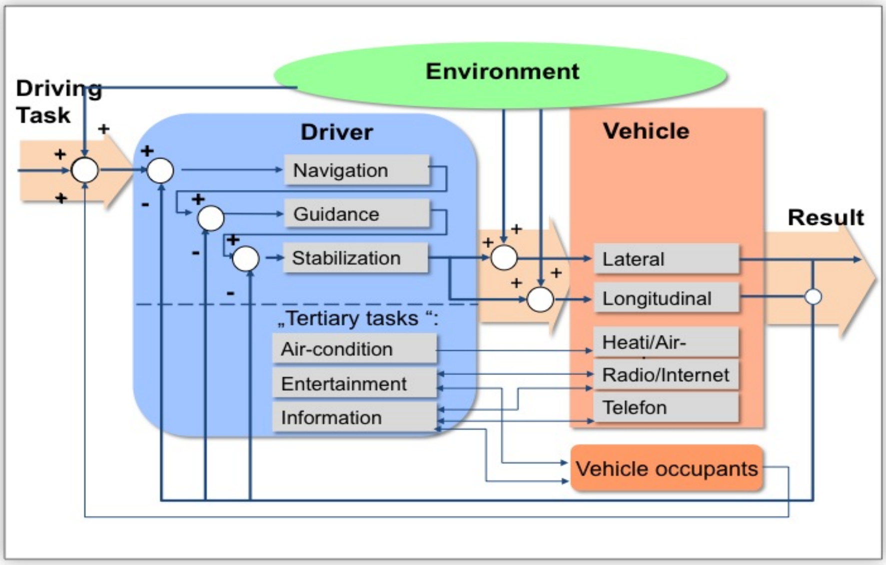


Figure 3.4: *Control circuit presenting driving subtasks from [Bubb02]. Navigation, guidance and stabilization present the primary and the secondary driving tasks; they influence the lateral and longitudinal control of the vehicle. Tertiary tasks are not in the direct connection to the driving task*

be slow. Regarding driving, the task that is mainly managed on the knowledge level is the navigation task (see Figure 3.5). When looking for a way through a new city, the drivers have no access to the rules or routines to conduct this task but have to rely on the active search. Knowledge level can also include the tasks on the guidance and stabilization level. An example is the stabilization of the vehicle in the first few driving lessons or executing a maneuver on icy roads.

A level underneath the knowledge-based level is the rule-based level. The required cognitive resources lay between knowledge- and skill-based level. The activities on the rule-based level are based on rules that can be learned as a result of interaction with the machine. Driving tasks on the guidance level belong for the most part to the rule-based behavior. This level is of the interest for the topic of this thesis.

The skill-based level occupies highly practiced activities, which can be executed largely without conscious thoughts. Mainly, the stabilization task is conducted on the skill-based level. The guidance tasks can also be managed on the skill-based level if the route is known to the driver very well and this task has been done many times already.

Longitudinal tasks are mainly managed on the skill-based level. Even though the driving task in the longitudinal traffic consists of many activities such as steering, speed control, observing the vehicle state, self-assessment and search for hazards, for experienced drivers this mainly happen automatically, without too much of conscious control. On the contrary, the tasks at intersections are primarily managed on the rule-based level and require the driver attention. Even experienced drivers perform the task at intersections consciously.

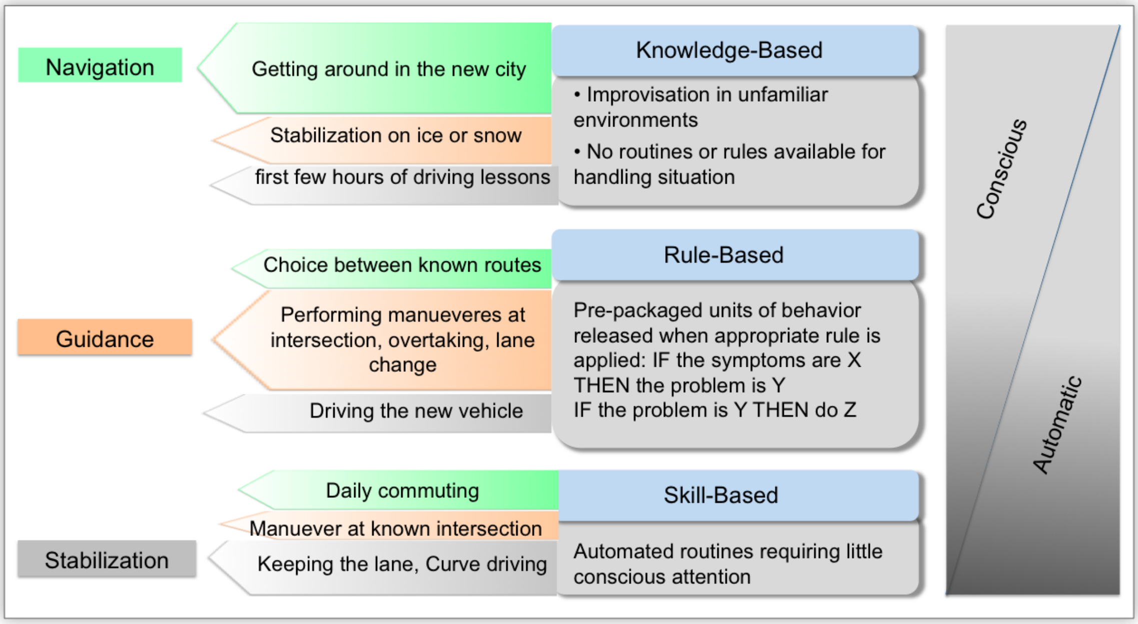


Figure 3.5: *Mapping of the driving task on the driver behavior; Knowledge-, rule- and skill-based model of [Rasmussen87]*

Also, what's specific for the intersection task is that available time is shorter than it is the case with the longitudinal tasks. There is a narrow time span in which many activities should be completed and the driver does not have too much time and possibilities for compensation when the demand gets too high. In longitudinal traffic, driver compensates the high task demand for example by decreasing the speed. However, at intersections there is not much time and possibilities to compensate, which can result in the driver error, and if the other factors contribute the outcome is fatal. This means that the driver cognition and learned and applied rule-based behavior present the crucial elements when negotiating intersections.

Therefore the next section presents the basic of human cognition involved in the performance of the driving task at intersection.

3.3 Cognitive Representation for the Performance of Driving Task on the Guidance Level

For safe accomplishments of the driving tasks, the driver should perceive all relevant information from environment, process it in a correct way, decide on the driving action, and then flawlessly execute it. This process can be modeled by the control circle paradigm of driver-vehicle-environment. The elements of the control circle are presented in Figure 3.6. Resulting position and orientation of the vehicle and new elements from environment are again perceived by driver and are the input for the cognitive processes.

The parameters of environment like traffic situation, weather, or visibility define the driving task and influence the perception of information. The information perception and processing is also strongly influenced by the driver's characteristics. Driver behavior in Figure 3.6 refers to the steering and regulation of the longitudinal control on the stabilization level, and eye movements on the guidance level.

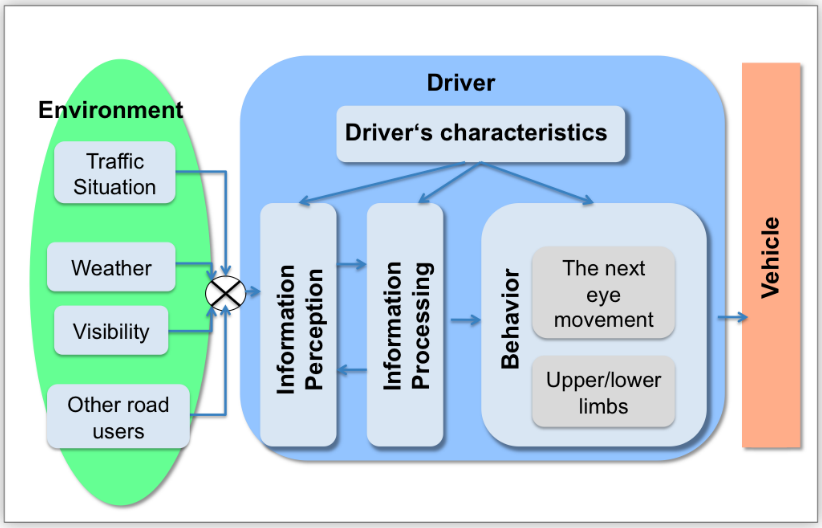


Figure 3.6: *Simplified elements of the driver-vehicle-environment circle with unfolded Environment block*

In this following, separate elements presented in Figure 3.6 will be analyzed in detail.

3.3.1 Information Perception

Perception refers to the process of reaching awareness and understanding the sensory information. Whether an object is perceived depends on:

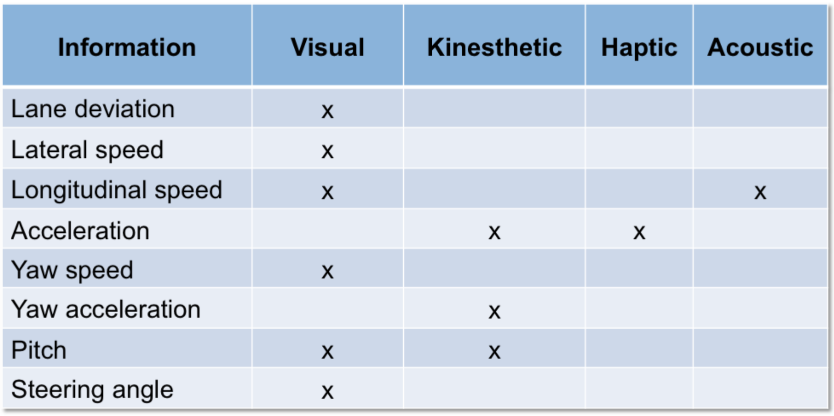
- physical stimuli (its intensity, features, duration, ...),
- environment (visibility conditions, presence of other stimulus, ...),
- receptors (the characteristic of the human perception system, quality of vision, sight, ...),
- driver's characteristics (knowledge, motivation, emotions, current state,...), and
- information processing (driver's expectations and goals, ...).

Traditional five senses singled out already by Aristotel are: sight, hearing, touch, smell and taste. Nowadays neurologists do not agree about the number of senses because of the different definition of what the sense represents. It is generally considered that the following senses also belong to humans: kinesthetic (proprioception) sense, balance, temperature, pain and according to some authors even the sense for time. For the timely critical, dynamic tasks, such as driving, the experience of time is of essential importance for safe performance and is discussed here shortly.

[Pöppel00] found out that humans experience time in temporal units of about $2 - 3$ s, which is responsible for our feeling of *Now* or so called *psychological present*. The time window of *Now* may be extended, which depends on the mental capability of an individual. This means that there is a specific anticipation horizon in which drivers perceive the elements relevant for the driving task. For example, for the speed of 50 km/h *Now* corresponds to the horizon of about 26 to 39 m. Connected to the feeling of *Now* is human's simultaneous perception of events, which are objectively non-simultaneous. For example, as showed by Pöppel, if audio signals are separated by less than 6 ms, humans experience them as simultaneous. For visual stimuli this range is from 20 to 30 ms.

Apart from the sense of time, for the driving, the optical sense is decisive, followed by acoustic, kinesthetic, and haptic sense. The Table 3.3 gives an overview of information relevant for the driving and the importance of each of the senses for the particular information. As shown, the most relevant information drivers perceive visually, according to [Cohen90] up to 90%. For the driving task at intersection, this ratio is even higher.

Table 3.3: *Human senses and their importance for the particular element of the driving task from [Lange08]*



Information	Visual	Kinesthetic	Haptic	Acoustic
Lane deviation	x			
Lateral speed	x			
Longitudinal speed	x			x
Acceleration		x	x	
Yaw speed	x			
Yaw acceleration		x		
Pitch	x	x		
Steering angle	x			

The visual perception is the complex process and involves several individual subprocesses: seeing, detection and recognition. For each of these processes, specific elements of human cognition are responsible: receptors, sensory memory, processes of feature integration, and cognitive processes of recognition. This is sketched in Figure 3.7. Understanding the process of visual perception is essential for understanding the perceptual errors, which may often lead to accidents. Further explanation of information perception mechanism is limited to the information perceived visually, but analog mechanisms do exist for each of the senses.

When the light enters the eye, it is transformed into neural signals forming so-called *early or rapid vision*. These processes last around 200 ms and are characterized by application of filters that measure the image properties and form an abstract image of the scene, so-called *gist*. They are believed to operate automatically, without any need for attention [Marr82], and are called *preattentive processes*. Secondary processes are applying non-linear operations to the image, which are than an input for subsequent *attentional processes* [Rensink07]. How long is the information available for the

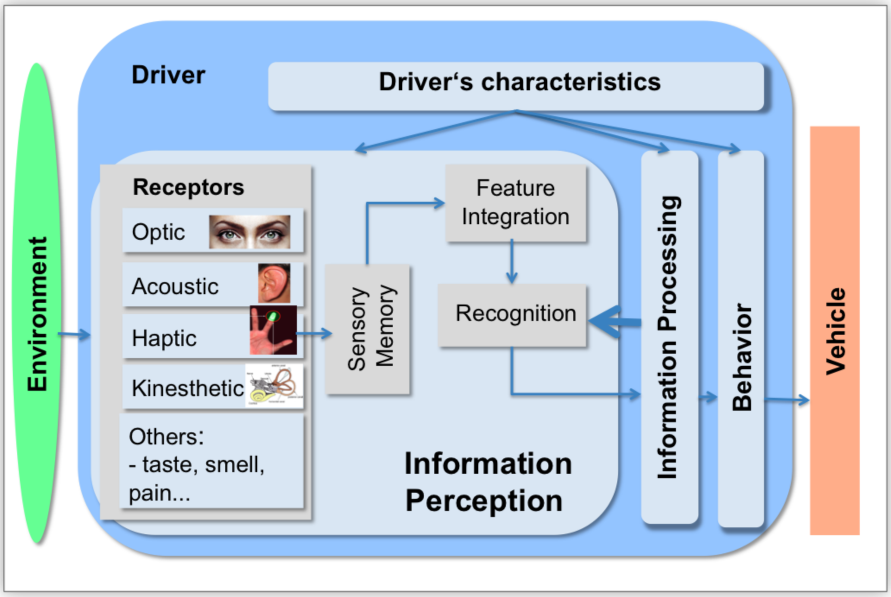


Figure 3.7: *Unfolded Information-processing block within driver-vehicle environment circle*

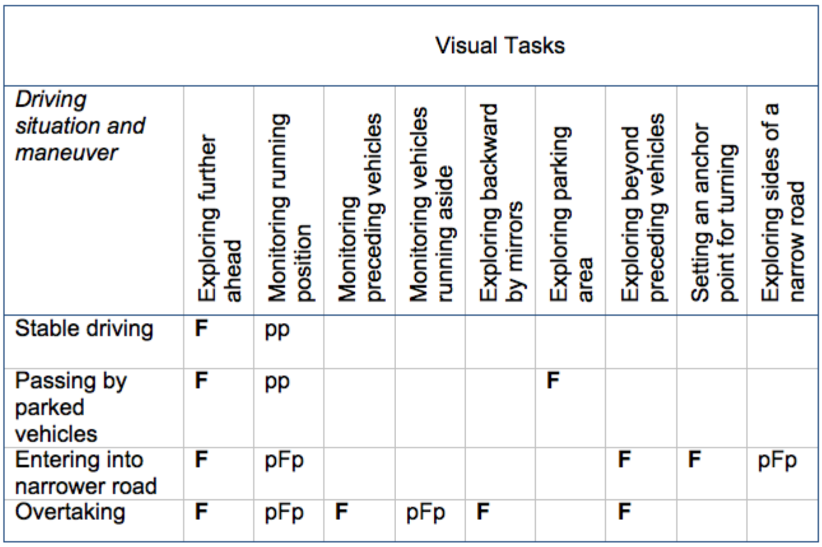
attentional processes depends on the capacity of sensory memory. Sensory memory presents the ability to retain sensory information after the original stimulus has ceased. Visual sensory memory is called *iconic memory* and lasts around 250 ms [Sperling60].

Attentional processes can be described as ”glue” that puts together the features of the observed scene. The way this happens is explained by the rules of *Feature integration theory* from [Treisman80]. Respectively, several primary visual features of objects are processed. To these belong edges, orientation, width, size, color, but also dynamic presentation. This processing is represented by the separate *feature maps*. During attentive processes, they are integrated into a *saliency map*, which can direct the attention to the most conspicuous areas. By that, the attention determines which information will be moved from sensory to the short-term memory and thus be incorporated into the *mental model* of the scene.

To the information perception belong several processes: *monitoring*, *cue detection*, and *simple recognition* of situational elements. The driver is monitoring the surroundings by either bottom-up (data-driven) or top-down (knowledge-driven) mechanisms. Bottom-up mechanism is driven by occurrences and objects in the environment and the top-down mechanism indicates controlled strategies and eye movements that are the result of information processing. By monitoring, the driver detects cues in environment and by categorizing them the information is advanced to the information-processing mechanism. This is described in more detail in the following subsection.

Perception Limits. The perception of environment is limited by the structure of humans' sensory system. Human perception mechanisms allow parallel perception of many information, but the limits of perception lay in physical limits of receptor organs and information-processing mechanisms. The physical limit of the human vision refers to the acuity of the *foveal vision*, determined by *fovea*. The fovea is the region of the retina where light is focused when it comes straight through the eyeballs optical axis. The area we see with fovea is called foveal vision and outside this cone humans perceive objects by *peripheral* vision. Sharp perception is possible only in the foveal field of view, about 2° in a cone. Not only the acuity but also the ability to distinguish colors is decreased in the periphery.

Table 3.4: *The importance of foveal and peripheral vision for specific visual tasks.* F *stands foveal,* pp *for peripheral perception and* pFp *for both peripheral and foveal perception, according to [Miura86], quoted from [Rötting01]*



	Visual Tasks								
Driving situation and maneuver	Exploring further ahead	Monitoring running position	Monitoring preceding vehicles	Monitoring vehicles running aside	Exploring backward by mirrors	Exploring parking area	Exploring beyond preceding vehicles	Setting an anchor point for turning	Exploring sides of a narrow road
Stable driving	**F**	pp							
Passing by parked vehicles	**F**	pp				**F**			
Entering into narrower road	**F**	pFp					**F**	**F**	pFp
Overtaking	**F**	pFp	**F**	pFp	**F**		**F**		

The importance of peripheral vision for driving is a disputed topic. There are experiments providing evidence for both the importance and the insignificance of peripheral vision. In general, peripheral perception enables static and dynamic orientation as well as the perception of size, movement and changes in brightness. It has been proven that detection of abrupt changes depends a great deal on peripheral vision and that the major difference between novices and experience drivers lays exactly here [Schieber94]. [Miura86] gave an overview of driving tasks depending on the importance of the peripheral vision for the driving. These are presented in Table 3.4. In general, the more the situation is complex, the more important foveal vision becomes. This is exactly the case with intersections in which the majority of information has to be perceived foveally.

Humans have also limited capacity for the perception of the movement of objects. [Lindsay72] defined perception threshold for static world as one angular minute (1 ’/s) and for dynamic two angular minutes per second (2 ’/s).

3.3.2 Information Processing

The perceived information is further processed and either advanced to the plan for an action or disregarded. Depending on the performed task, information can be processed on one of the three levels: knowledge-, rule-, or skill-based level. As explained in *section 3.2*, for performance at intersections the highest relevance has the processing within the rule-based level. Such behavior refers, for example, to the behavior of an experienced driver at an unknown intersection.

The processes and the structures involved into transforming information into the behavior are in psychology referred to as *cognition*. Cognition can be defined as *"large class of so-called higher-level processes, that is, processes not directly driven by the sensory and motor systems"* [Pfeifer99]. The cognition is *"the process of thought"* and studying the cognition means studying mental processes of thought, its possibilities and limits [Anderson98].

Regarding driving, it is efficient to distinguish between cognitive states and cognitive processes leading to particular states and to analyze them individually. Also, human capacities and mechanisms of these processes are important to understand. In the first place the way the human working memory functions should be understood. In the following, cognitive states, memory storage and cognitive processes are analyzed. The traditional system-ergonomic view on human as a subsystem in human-machine circle is explained in the terms of *Situational Awareness (SA)* and mental models. As such, a theoretic base for the computer simulation of the driver cognition is set.

Cognitive States

Information processing, relevant for the task of driving, starts with the perception of the current situation. After being perceived, the situation is comprehended and the development of the current situation is anticipated in the future. The last two processes belong to information-processing and are also known as the processes of achieving Level 2 and Level 3 of Situational Awareness [Endsley95]. Situational Awareness is useful and increasingly popular concept because it occupies relevant aspects of human cognition regarding operating task. Therefore the information-processing mechanisms will in the following be explained in the terms of achieving SA.

Having appropriate SA is essential for correct decision making. So far, information processing is described as the process of achieving Situational Awareness and consecutive decision making. Studies analyzing the reasons for erroneous driver behavior have shown that when having all appropriate information, the driver is rarely deducing a wrong decision [Gruendl05]. This means that the reasons for the drivers' erroneous behavior lay mainly in the process of achieving situational awareness.

[Endsley95] defines Situational Awareness as *"the perception of the elements in the environment within a span of time and space, the comprehension of their meaning and the projection of their status in near future"*. Three stages of SA formation are distinguished:

- *Perception (Level 1):* involves monitoring, cue detection and simple recognition, which leads to the awareness of situational elements and their current status; This level belongs to information-perception and has been discussed in *section 3.3.1*;
- *Comprehension (Level 2):* involves synthesis of separate elements through the processes of pattern recognition, interpretation, and evaluation. It also requires understanding of how will the new information impact an individual's goals and objectives;

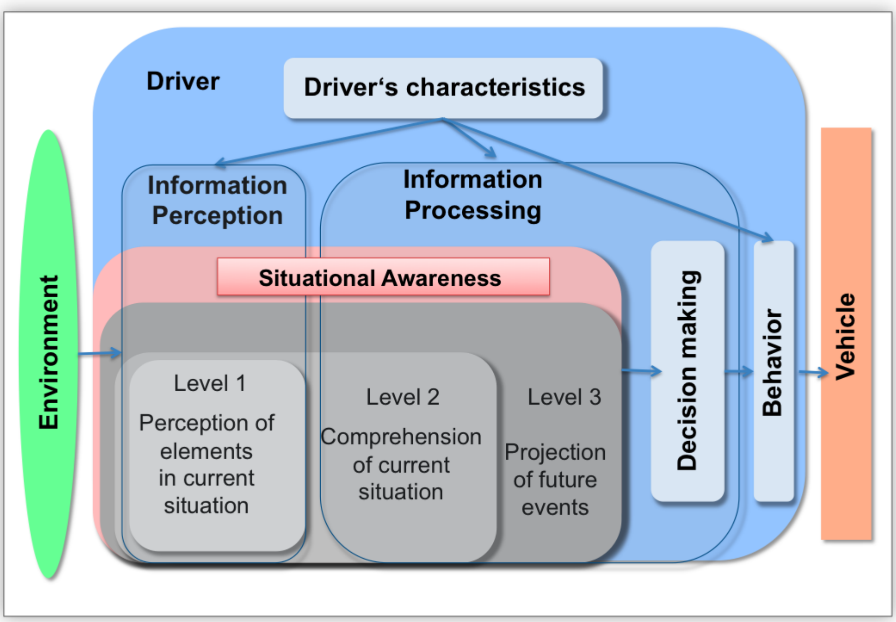


Figure 3.8: *The relationship between Endsley's model of Situational Awareness [Endsley95] and traditional system-ergonomic driver-vehicle-environment circle*

- *Projection (Level 3):* occupies extrapolation of gained information from Level 2 forward in time and determination of how it will affect current state and environment.

Thus the concept of SA includes perception, comprehension, and projection of situational information (*anticipation*). The decision making is based on the successful performance on all three levels. How these levels correspond to the previously presented Driver-Vehicle-Environment structure is presented in Figure 3.8. Having appropriate Situation Awareness means being in an appropriate cognitive state. Each of the SA levels presents a state in which the driver can be while performing the driving task.

Achieving the Level 1 is done by information perception mechanisms described in the previous section. For achieving Level 2 of SA, the key elements are *Mental or inner models*. Mental models present a key of human cognition. They are also known as mental schemes or mental representations. The term is originally coming from [Craik67]. He defined mental models as mind's representation of real or imaginary situations. The mind is building a model of the reality and using it to reason, expect and anticipate events. Mental models are built based on perceptive information, the driver's characteristics, and results of information processing. The decision making mechanism is not based on the objective state of the world, but on the base of mental models, which can be fatal in critical situations like driving. The characteristic of mental models is that they are incomplete, constantly evolving, not accurate and simplified. For the modeling, it is beneficial that they can be represented in production system, by *if-then-else* rules.

Even though mainly associated with problems appearing in the process of software development of future systems, the comic in Figure 3.9 is a paradigm clearly illustrating the mental model problem.

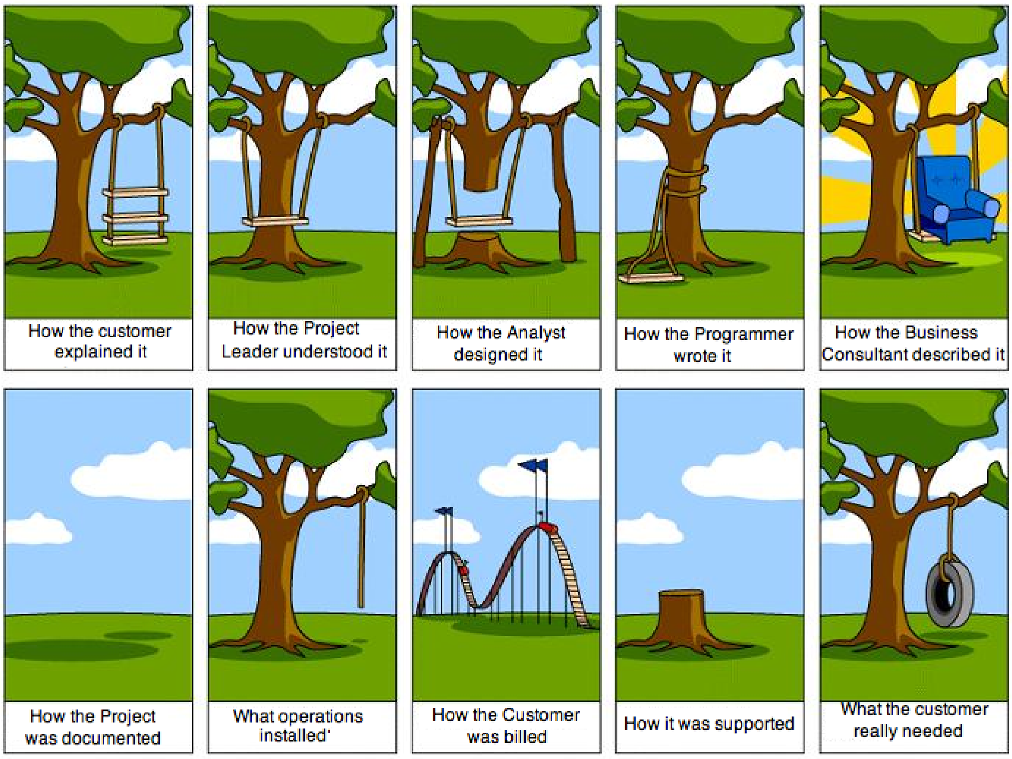


Figure 3.9: *Popular software engineering comic depicting the paradigm of the mental models. Mental models present the incomplete representations of the reality and are used to reason, expect and anticipate events*

Each human has a mental model of some particular situation in the reality. Depending on the experience and human's characteristics, these models may drastically differ and for each human is his mental model presenting a meaningful interpretation of the reality. Figure 3.9 refers more to issues in communication between humans having different mental models, but it also depicts the possible discrepancy between the objective situation and corresponding mental model. Among driver's characteristics, which influence the creation of mental models, it is distinguished between: permanent attributes and the current state. The driver's characteristics block within Driver-Vehicle-Environment circle is unfolded and presented in Figure 3.10. Among permanent attributes the most influential are experience, general health state, age, and gender. The experience refers to the content of the long-term memory and it plays an imperative role for the quality of retrieved mental models. But also the current state of the driver, involving motivations, emotions and health, contributes to the quality of mental models. The attitude towards risk is singled out as the separate characteristic because of its high influence on the driver behavior. Additionally, the general and the local goals also affect the formation and maintenance of mental models. The general goals are the goals set on the navigation level and on the guidance level they are transformed into local goals.

The creation of the good quality mental models is essential for the achievement of Situational Awareness. However, it should be noticed that SA is a state of knowledge and should be distinguished

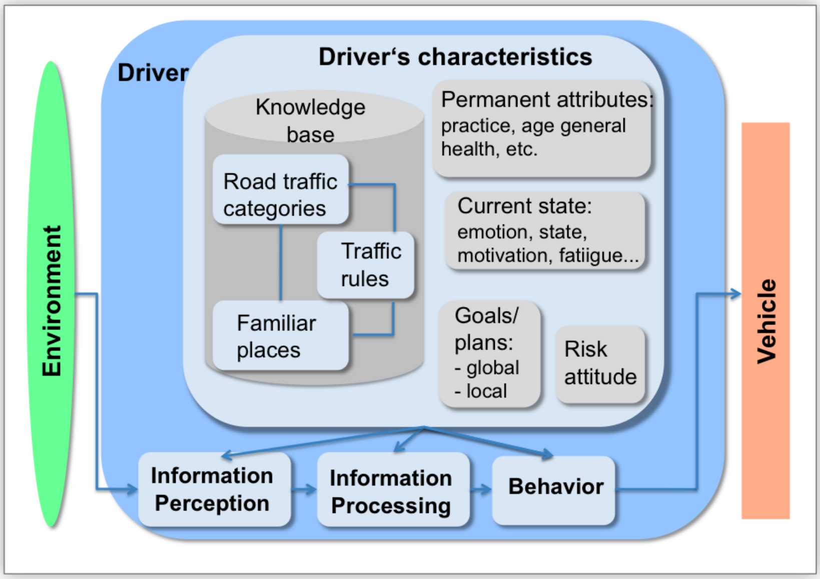


Figure 3.10: *The unfolded driver's characteristics block. Elements that influence the quality of the mental models as well as their selection process in the particular situation*

from the processes used to achieve this state [Endsley95]. Before focusing on the processes, the mechanisms for storing information are described.

Memory storage. Even though there are recent attempts to explain human memory as a single system [Neath98], an analysis of human behavior gives evidence of a distinct and separate retentiveness behavioral systems. This implies the existence of different memory based storages. [Baddeley09] distinguishes between *Sensory Memory (SM)*, discussed in the previous section, *Working Memory (WM)*, *Short-Term Memory (STM)* and *Long-Term Memory (LTM)*. He gives the neurophysiological arguments that these storages are controlled by different brain areas and have evolved separately for different purposes. The working memory is the concept introduced to replace and better explain the older term of short-term memory. Short-term memory presents storage involved in keeping and recalling small amounts of information in the span measured in seconds. Oppositely to STM, working memory is the memory that is not used only to temporarily store information but which also allows their manipulation and processing like reasoning and learning. This theory is supported by patients who suffer from STM deficiency, but have otherwise no problem reasoning or performing other cognitive processes [Baddeley09].

Long-term memory does not have limited capacity and contains driver knowledge (presented in Figure 3.10). It is distinguished between *declarative* and *procedural* knowledge. Declarative knowledge occupies generally known facts, and this is the knowledge that humans are aware of. It is often referred to as passive knowledge or description of what to do. In contrast, procedural knowledge is often referred to as applicable knowledge or a description of how to do something; it is the knowledge humans are not aware of. To the declarative knowledge belongs for example the classification of the driving situations (each driver has one for himself), traffic rules and familiar places. The more experience the driver has, the more his knowledge matches the objective state of the world. To the procedural knowledge belongs for example, how to drive, how to steer, how to accelerate, or move the eyes to look in some direction.

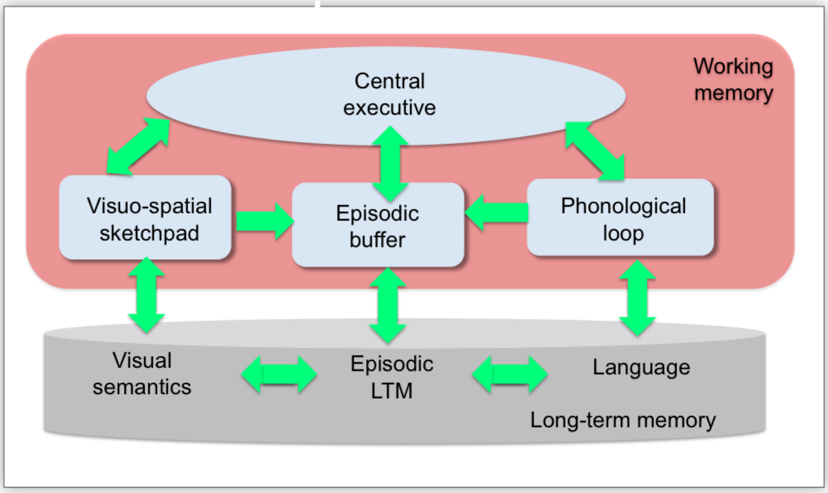


Figure 3.11: *The structure of Working memory from [Baddeley09]*

As working memory plays the essential role for the cognitive processing, it will be discussed in more detail. Baddeley elaborated the concept of the working memory and suggested its model as in Figure 3.11. Accordingly, working memory has *central executive* element, which works as an attention based controller rather than a memory based storage, and three memorial elements: *phonological loop*, *visuo-spatial sketchpad*, and *episodic buffer*. A phonological loop is involved in language acquisition and in all tasks that can be done with the help of verbal coding. It complies with the limits of the STM. The visuo-spatial sketchpad is responsible for the spatial and visual memories, which are separate, even though connected systems. Episodic buffer serves to take an advantage of the LTM and makes sense of information contained in phonological loop and visuo-spatial sketchpad. The episodic buffer is also the element that is influenced by the driver's state like emotions or motivations. Central executive is responsible for switching attention between tasks and can work in regimes that correspond to skill-based, rule-based and knowledge-based behavior.

Cognitive Processes

Processes for achieving Situational Awareness belong to the concept of *situation assessment*. Situation assessment refers to the short-term objective and it happens on the guidance level. The corresponding long-term objective, which is happening on the navigation level, is usually named *sense-making* and the resulting output is named *understanding*. In cognitive science, cognitive processes refer mainly to comprehension, inference, decision making, planning and learning. In the following, cognitive processes relevant to the driving task at intersections are discussed and explained in an example. The relevant cognitive processes are presented in Figure 3.12. They are named: *Categorization*, *Retrieval*, *Anticipation*, *Mental model creation*, *Risk assessment* and *Decision making*.

Acquisition refers to learning and *Planning* is the process on the navigation level. As the focus of this analysis is the guidance level, these two processes are not further discussed.

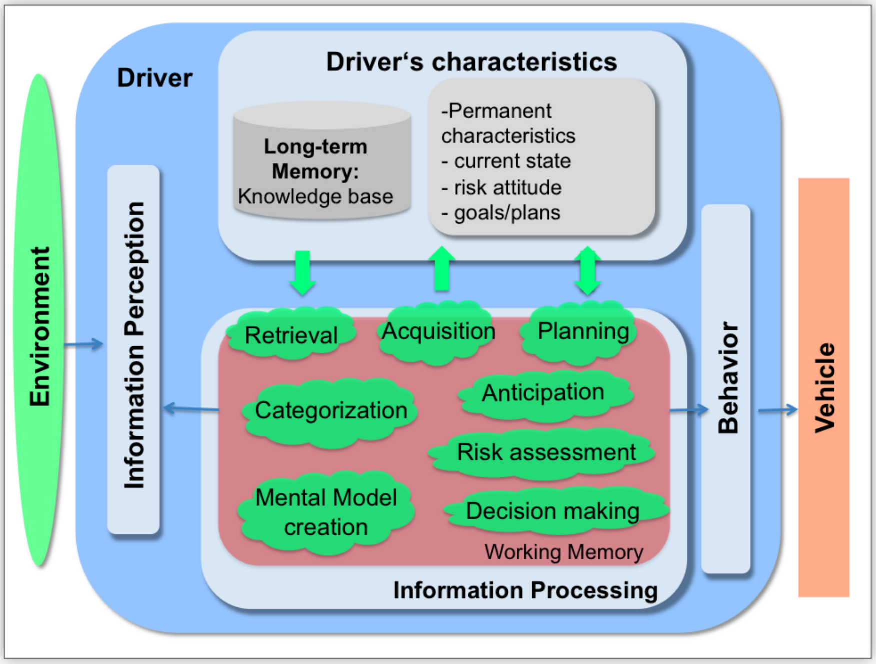


Figure 3.12: *Unfolded Working memory block with sketched processes for achieving Situational Awareness in driving*

Processes for achieving Level 1. To have Level 1 of Situational Awareness means to have awareness of objects present in the scene and their current state. Processes for achieving the first level are *monitoring*, *cue detection*, *simple recognition* of situational elements and their *categorization*. As already mentioned, the *monitoring*, *cue detection* and *simple recognition* belong to *Information perception* and have been described in the previous section. Even though belonging in already explained information perception, the process of *categorization* is emphasized here as an essential part of the mental model creation and the driver cognitive model.

When the driver detects cue in environment and recognizes it, like for example the crossing roads, it leads the driver to the conclusion that he is approaching an intersection. This conclusion belongs to the process of *categorization*, which is the first element of information-processing mechanisms. The process of categorization is described in Figure 3.13. The green cloud presents the process of categorization, and blue rectangles that present the input for this process are connected with appropriate arrows. The outputs of this process are *Category* and *Top-down search command*, presented by the dark blue bordered rectangles. The same notation will be used for the visualization of the rest of the cognitive processes.

In Long-term memory the driver keeps the knowledge of how particular situation looks like, for example, that the crossing roads indicates an intersection. In the process of categorization the driver is

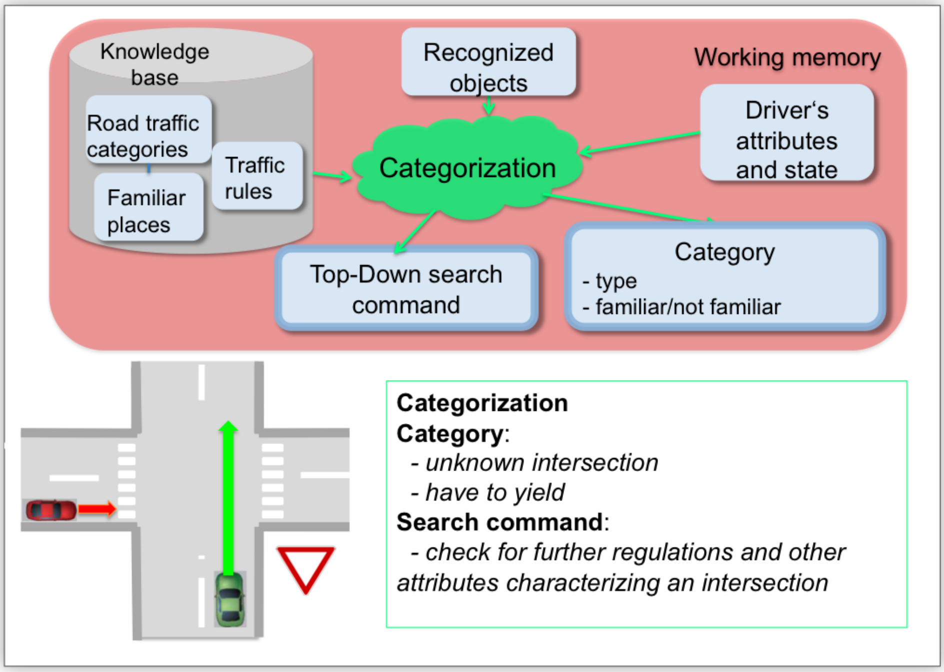
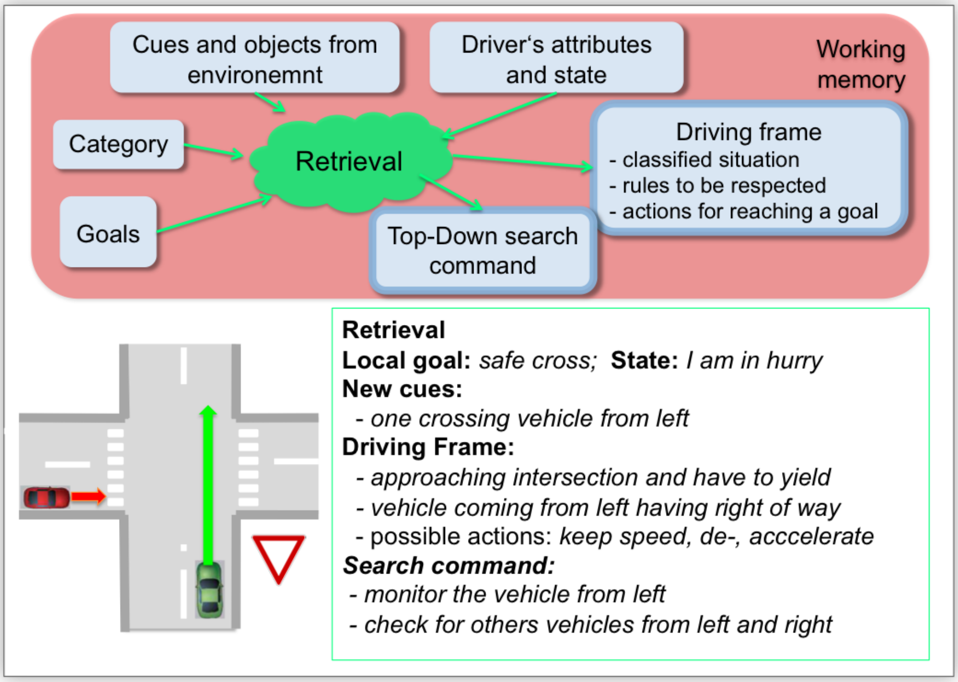


Figure 3.13: *Process of Categorization of the driving situation. The process for achieving the first level of Situational Awareness. This process belongs to the previously explained Information Perception block*

matching the characteristics of the observed scene to the structured knowledge he has. This knowledge has to be retrieved from LTM. In environment with many cues, categorization occurs by reducing the environment to some features salient for the current goal. How the categorization happens depends also on the available time to perceive these salient features. Based on the perceived features, the driver sorts the situation to one of the categories (intersection, curve...) and categorizes it either into familiar or non-familiar places. An output of categorization is also the command for an action, which has as its goal to either prove whether the categorization was correct or to further assess the situation. For example, imagine that the driver is seeing the crossing street. This is presented in the lower part of Figure 3.13. He categorizes the perceived road scene as an unknown intersection. He is then looking for regulation signs and after perceiving them the driver categorizes the intersection to the minor intersection regulated by traffic signs. In this example an output of the categorization process is an unknown intersection with minor priority. The resulting command is to check for further regulations and further cues characterizing the intersection.

Processes for achieving Level 2. The second level is characterized by the creation of the so-called *driving frame* of the current situation. The driving frame is a term coming from *Frame theory* of [Minsky75]. The process of driving frame creation is named *Retrieval*. In this step appropriate rules for the categorized situation are retrieved from the long-term memory. This is presented in Figure 3.14. Figure 3.14 shows that inputs for the process of *Retrieval* are: categorized situation, driver's goals, his attributes and current state, and new cues and objects from environment. The situation and its type have already been retrieved in the process of categorization and now the behavioral rules for this situation are additionally retrieved as well as possible actions. Which rules and actions are retrieved depend highly on the local goals. The categorized situation, appropriate rules, and possible actions form the *driving frame*, which presents an output of the retrieval process.



Retrieval
Local goal: *safe cross;* **State:** *I am in hurry*
New cues:
- *one crossing vehicle from left*

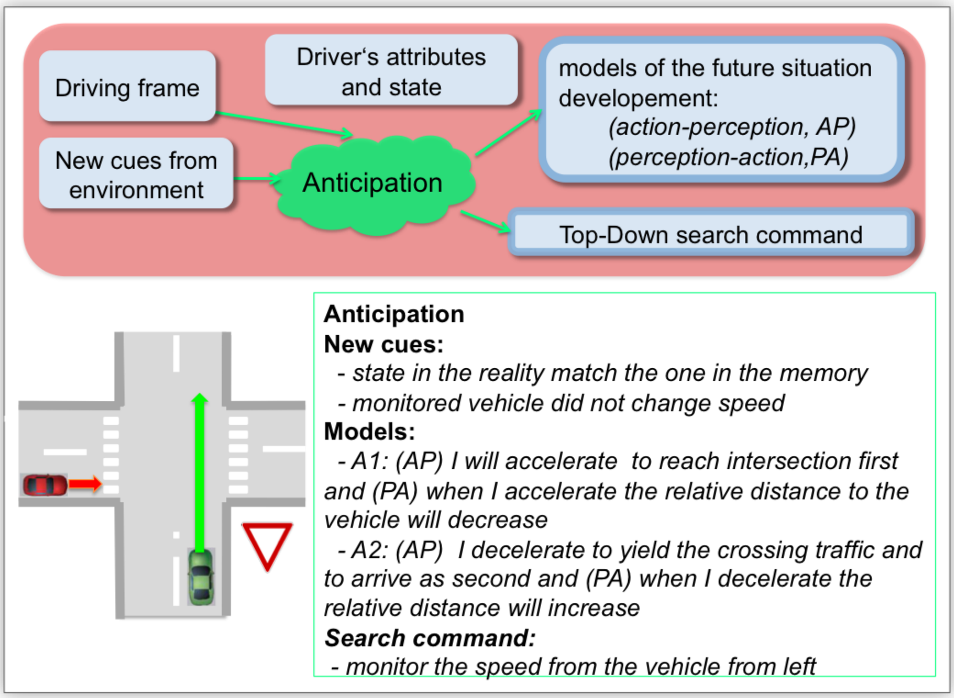
Driving Frame:
- *approaching intersection and have to yield*
- *vehicle coming from left having right of way*
- possible actions: *keep speed, de-, acccelerate*

Search command:
- *monitor the vehicle from left*
- *check for others vehicles from left and right*

Figure 3.14: *Process of Retrieval of the driving frame. The driving frame is created and the corresponding commands are issued*

In our example, the driver is under time pressure and in a hurry and there is one more cue: the vehicle from the left is recognized. The driver’s local goal is to safely cross the street as fast as possible, which corresponds to the global goal set on the navigation level and his current motivation. In the presented example the retrieved rule is that crossing traffic has right of way. The possible actions for fulfilling this rule are: to decelerate and admit the crossing vehicle from left first, to keep the speed, or to accelerate and reach the intersection as first. In any case the command for checking for other crossing vehicles from both left and right is issued.

Processes for achieving Level 3. The creation of the driving frame is followed by the generation of several anticipation models. This is illustrated in Figure 3.15. In the anticipation process the driver is generating expectations about the further development of the situation. The driver anticipates the possible actions and evaluates their possible development. Each of anticipated models consists of two parts. Based on [Bubb93], they are here named *Action-Perception (AP)* and *Perception-Action (PA)* parts. The Action-Perception part corresponds to deducing an action based on the perception of the situation. The Perception-Action part is the mental representation of the consequences of the hypothetically performed action. In our example one AP of the anticipation model could be: *I* *will accelerate, to reach the intersection first* and corresponding PA would be: *when I accelerate the relative distance to the crossing vehicle will increase*.



Anticipation
New cues:
- *state in the reality match the one in the memory*
- *monitored vehicle did not change speed*

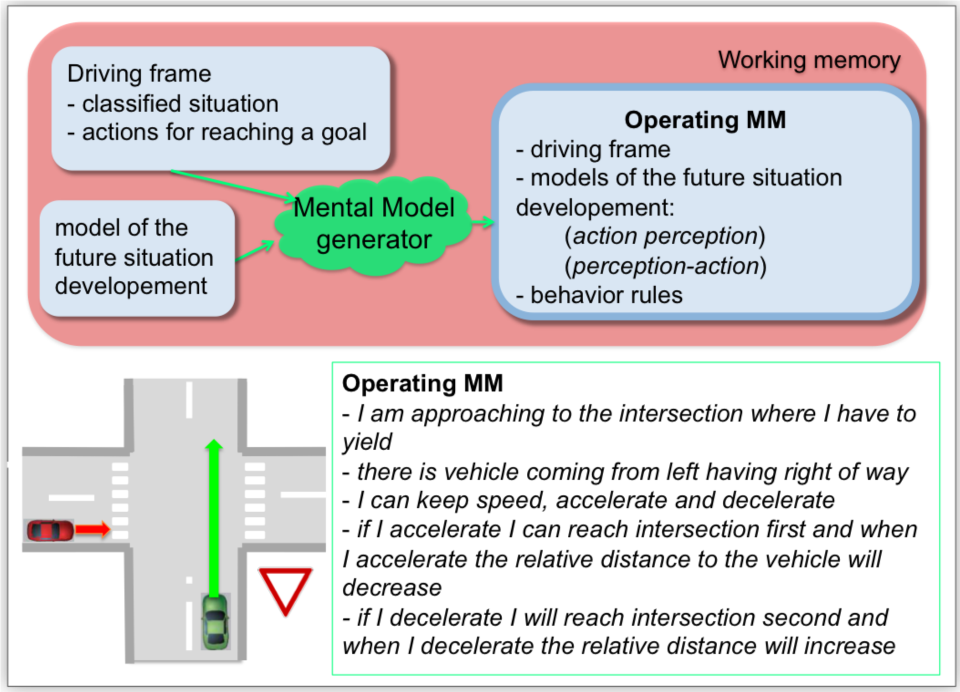
Models:
- *A1: (AP) I will accelerate to reach intersection first and (PA) when I accelerate the relative distance to the vehicle will decrease*
- *A2: (AP) I decelerate to yield the crossing traffic and to arrive as second and (PA) when I decelerate the relative distance will increase*

Search command:
- *monitor the speed from the vehicle from left*

Figure 3.15: *Process of Anticipation. The possible future developments of the current situation are created, each of them consisting of Action-Perception and Perception-Action parts. Top-down search commands for the control of future development of situation are issued*

The outputs of *Retrieval* and *Anticipation* processes constitute an *Operating mental model*. The process of its creation is illustrated in Figure 3.16. When talking about mental models, it is predominantly referred to this level of model; to an operating mental model, which is subsequently an input for the decision making. The quality of this model is essential for the correct decision making. For example, the content of an operative model may not be directly available in reality, like the vehicle that is currently hidden, but it is still in working memory. On the other side, the objects that exist in reality may be missing in the model, either because of the bad top-down strategies or perception issues like hidden vehicle or look-but-not-see phenomena [Rensink07]. The more the situation is complex and the less time is available, the quality of the model is more important. [Bailly03] has shown that the quality of chosen mental model is significantly influenced by the amount of cognitive resources available, this being more important for novices than for experienced drivers. Refreshing the operating model with cues from environment is very important for safe driving. The difficulties of elderly drivers at intersections can be explained by the fact that vehicles in their memory ”starts to drive slower” with increasing age and degradation in cognitive functions. To be aware of how fast this process is decreasing the elderly drivers should practice more.

The creation of the operative mental models is followed by the selection of one of them within *Risk assessment* and *Decision-making* processes. These processes evaluate the risk and the benefit



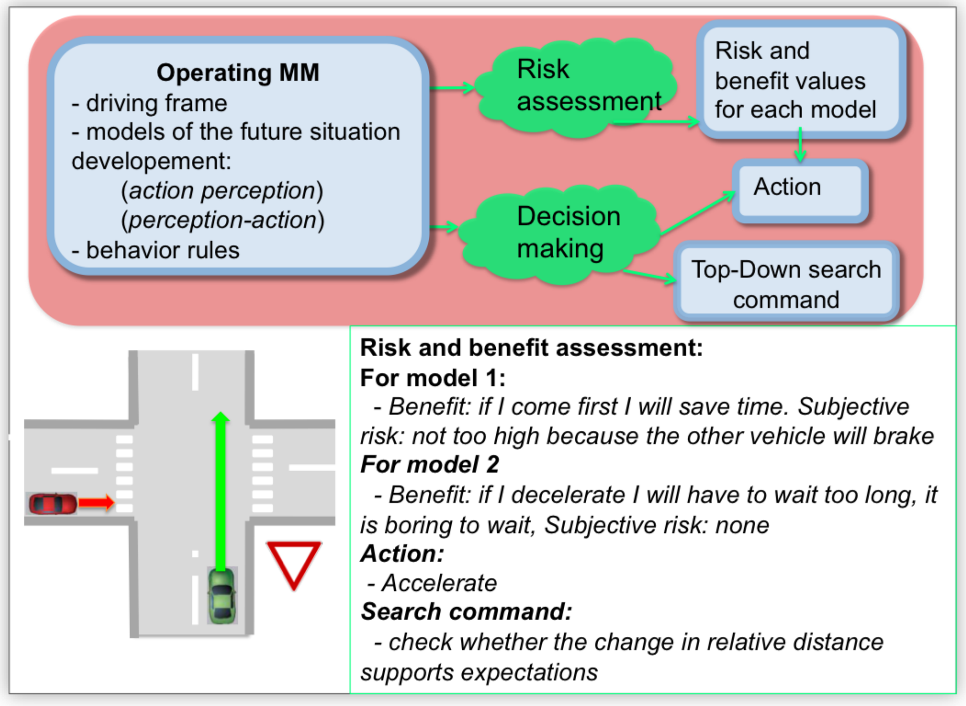
Operating MM
- *I am approaching to the intersection where I have to yield*
- *there is vehicle coming from left having right of way*
- *I can keep speed, accelerate and decelerate*
- *if I accelerate I can reach intersection first and when I accelerate the relative distance to the vehicle will decrease*
- *if I decelerate I will reach intersection second and when I decelerate the relative distance will increase*

Figure 3.16: *Process of Mental model creation from Driving frame and the anticipated future development of the situation*

of each of the models and deduce the model with the highest benefit and the lowest risk (see the illustration in Figure 3.17). In the given example, the benefit of the first model (accelerating and reaching the intersection first) is evaluated as high because the driver is under time pressure and the risk is evaluated as low because the driver expects the crossing vehicle to brake a critical situation. Therefore the driver in our example decides to accelerate.

Decision making is an iterative process and can be processed on the knowledge- , rule-, and skill-based level. How this iterative process happens is transparently presented by the model from [Bubb93] in Figure 3.18. The driver chooses between several operating mental models. The selection of an inner model and the comparison with sensory memory happens on the skill-based level. Only the result of an action, which deviates from the mental representation, is perceived on the rule-based level or in the more critical case on the knowledge-based level. The higher the level is, the more time does the driver need for the decision and the situation becomes more critical. In our example, the driver decides to accelerate. As long as the relative distance increases as expected by his mental model, the driver is not deciding upon acceleration and deceleration again. Only when the driver perceives that the relative distance is not enough to avoid the collision, he re-chooses another model of the situation on the rule-based level and starts to decelerate.

Cognitive Limits. Information processing mechanisms are in the first place limited by the capacity of the working memory. The working memory capacity reflects the efficiency of maintaining relevant representations in the face of distractions and irrelevant information [Engle99]. Each of the working memory elements presented in Figure 3.11 has its limitations and intervenes with each other in



Risk and benefit assessment:
For model 1:
- *Benefit: if I come first I will save time. Subjective risk: not too high because the other vehicle will brake*

For model 2
- *Benefit: if I decelerate I will have to wait too long, it is boring to wait, Subjective risk: none*

Action:
- *Accelerate*

Search command:
- *check whether the change in relative distance supports expectations*

Figure 3.17: *Process of Risk and benefit assessment of the models and the Decision making process. The most appropriate Mental model of the situation is chosen.*

different way. The phonological loop complies with the limits of the short-term memory and has a different span for different elements: digits, known, or unknown words. [Sternberg66] found that the capacity of STM is linear, and as the length of the elements to be kept in STM increases, the length of time required to scan STM increases as well. Information is maintained through rehearsal as long as rehearsal continues; otherwise information is inaccessible after 12 to 30 s. The loss of information can happen by trace decay or because of interference; that is when new information displaces the older one. The more similar the new information is, the more probable the loss is.

The well known quantification of the capacity of the STM is 7 ± 2 *chunks* theory of [Miller56]. This denotes the number of elements that can be kept in the memory at the same time. A chunk presents an independent item of information. It was shown that the number of chunks depends on the type of element. By grouping elements in chunks, the number of information within the memory can be increased. By doing so, only the highest-level chunk needs to be held in the short-term memory and upon retrieval each chunk is "unpacked". For example, for the novices, the steering, pressing the gas pedal, and clutching present separate chunks. The capacity for receiving additional information is around four elements. In the learning process, these three activities become one chunk and the capacity for receiving new material is increasing. However, even though it is possible to expand the number of elements in short-term memory in this way, the capacity of working memory cannot be expanded.

For driving, the visuo-spatial memory is more influential than the phonological one. Still the phono-

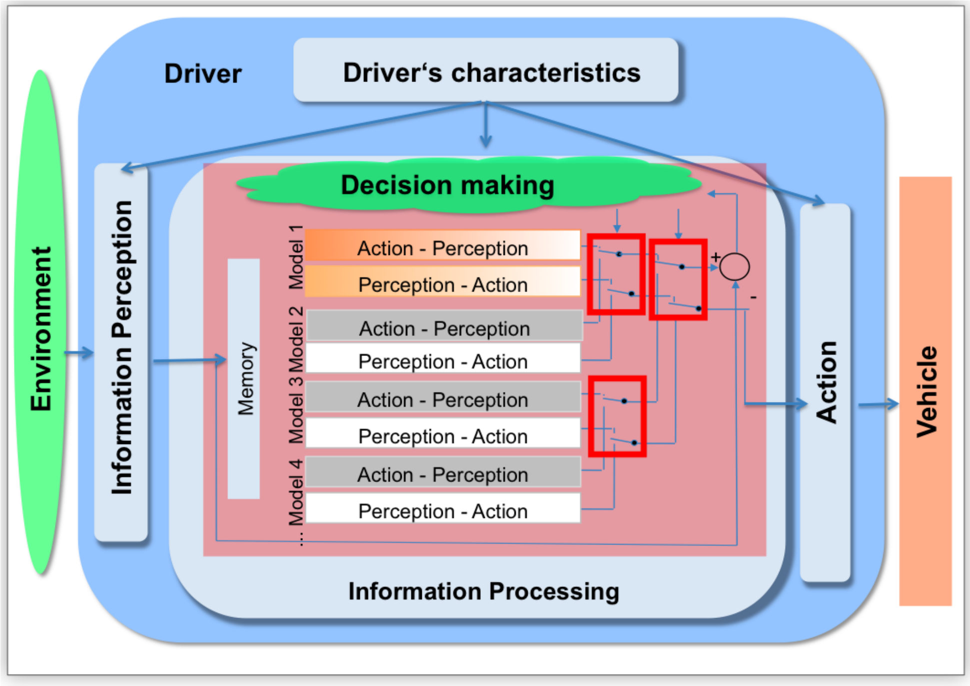


Figure 3.18: *Model of decision making from [Bubb93] in the context of illustrated processes for achieving Situational Awareness*

logical memory interferes with the visual memory. For example, phoning during maneuver increases the chance of forgetting the seen vehicle or object. The limit of the visuo-spatial memory is considered to be around four objects (when their verbal coding is not possible) [Baddeley09]. This is important because at intersections drivers do not verbally encode what they see. [Vogel01] showed that it does not matter of what kind these objects are and how many features they have (up to 16 features were tested). It appears that four objects, does not matter how complex they are, can be remembered and do not decline over a few seconds period even when disrupted with other activity. With respect to the driving, [Ungerer94] claims that up to 5 objects can be held in 2 s span (quoted from [Schweigert03]). Also, the visual scanning while driving impairs the spatial memory more than the visual memory. [Woodman04] found that the memory for spatial relations is impaired by scanning but the object memory is not. This explains why evaluations of distance and speed are more frequent errors than forgetting the seen object.

The episodic buffer has limited capacity as well and it is evaluated to be about four chunks of information [Baddeley09]. Different experiments have shown that the functioning of episodic buffer is not impaired by the limits of the other two memory based elements: *phonological loop* and *visuo-spatial sketchpad* on the skill-based level, but it is impaired on the rule-based level. For example, concurrent verbal reasoning does not impair the drivers' steering (skill-based level), but it disrupts the judgment (rule-based levels) - drivers were choosing gaps of smaller size than the size of their cars [Brown69]. This means that the activity of the phonological loop did not affect the activity of the episodic buffer on the stabilization level but it did affect it on the cognitive-guidance level.

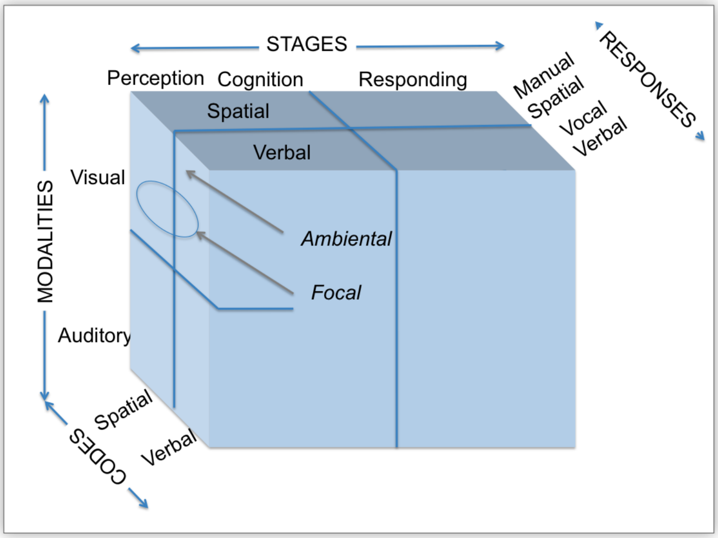


Figure 3.19: *Multiple-resource theory explaining the distribution of attention in multi-tasking activities[Wickens02]*

For the modeling purposes, the driver's ability to handle the multi-tasking is described by the *Multiple-resource model* from [Wickens02]. This model sums up the previously discussed limitations of working memory and presents them in the simple, engineering form. The model is not focused on the low-memory level, but it abstracts the results of cognitive processes by allowing the prediction of which tasks can be conducted concurrently and which tasks interfere with each other. This theory explains the phenomenon that the combination of some tasks is easier to do simultaneously than the combination of some other tasks. Multiple-resource model propose that there are four categorical and dichotomous dimensions that account in time-sharing whilst performing some task. These dimensions are: *processing stages*, *perceptual modalities*, *visual channels* and *processing codes*. Each dimension has two levels. This is presented in Figure 3.19. The evidence for the dichotomy is experimentally proved and also resembles different brain regions. Depending on the task, the processes can be conducted sequentially if they require same resource, or simultaneously if they require different resources. When two tasks, that are to be conducted simultaneously, demand equal level of a given dimension than they will interfere with each other more than two tasks that demand separate levels of one dimension. For example, perceptive and cognitive stages use the same resources, where action and reaction are on the separate levels. This model can be directly used as simple prediction of the driver's capacity when performing the driving task without going into detail of human's memory characteristics.

This section has modeled the process from visual focus on information to the action performance regarding the driving and has illustrated the process on an example of driving through intersection. The input and output parameters for each of the relevant cognitive processes have been discriminated as well as their relation to each other. The next section throws additional light upon the risk assessment process as one of the essential processes for the selection of action and is therefore discussed in more detail.

3.3.3 Risk Assessment

As pointed out in the previous section, risk assessment plays an essential role in the decision making. To avoid misunderstandings, the ambiguities connected with the term risk will be first cleared. The term of risk is often used as a synonym to all following terms: hazard, accident probability, dangerous situation and subjective evaluation of the risk. According to normative standard DIN 19 250: *the risk linked to a specific technical event or state is described in summary by a probability statement that takes into account the expected frequency of an event occurring that will lead to damage and takes into account the extent of the damage to be expected on occurrence of the event.* The similar definition is given in the safety standard EN 1050.

In the scientific field of traffic psychology the more appropriate definition of risk is the one which disregard the extent of the damage and considers only the probability of an accident occurring. This term is in industrial applications connected to the exposure to the specific traffic situations and can be calculated only ”a-posteriori” from accident statistics. This means that in the city with few unordered intersections, the risk of accidents at an unordered intersection is respectively low.

However, the risk in the cognitive science and the risk considered in this work is the risk of having the collision in the current traffic situation independent of the possible damage and independent of the exposure or the frequency of such traffic situations. It is the measure of how some situation is dangerous and can theoretically be evaluated in advance and expressed in terms of probability. It is named further as the *objective risk*.

Opposite to so-defined objective risk, there is a *subjective risk*. The subjective risk is the risk that influences the driver behavior and does not have to match the objective risk. Subjective risk occupies *subjectively perceived risk* and *subjective evaluation of the possibility for the collision*. Subjectively perceived risk is connected with the reaction of human body and with the fear that the collision can happen. An evaluation of the risk is the consequence of human reasoning and does not have to match with subjectively perceived risk.

The model from [Bubb93] in Figure 3.20 visually illustrates the association between objective and subjectively perceived risk. The dashed green horizontal line presents the individually accepted level of subjective risk. This line presents the target risk from the *Risk-homeostasis theory (RHT)* from [Wilde82]. The target risk is the maximum of the benefit-cost ratio and the driving around the target risk presents the highest joy for an individual. If perceived risk is higher than the target level, the driver is trying to reduce perceived risk by slowing down or abandoning the tertiary task like phoning. If the experienced risk is too low, the driver tries to bring it up by, for example, increasing speed.

In situations in which subjective risk of the planned action is lower than the objective and at the same it is below the target level, the situation is described as dangerous (red area in Figure 3.20). In this area the action is performed because the driver is not aware of the consequences of the action. The cognitive state of the driver which implies that the subjective risk is lower than the objective risk is also named *prejudice* [Kokubun05]. Assistance support should offer help in this area as well as in areas where subjective and objective risk match but the driver is reaching his limits while performing the task. If the subjectively perceived risk of performed action is higher than the objective risk, the action is not performed. These are the blue areas in Figure 3.20.

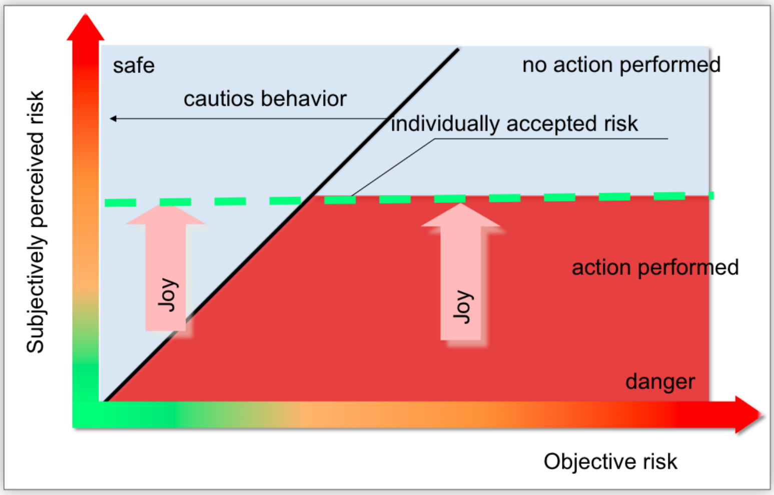


Figure 3.20: *The relationship between subjectively perceived and objective risk and their consequence on performed action [Bubb93]*

A more elaborate theory of how subjective and objective risks depend on each other and on environmental and driver characteristics is given by the *Task-Capability Interface model (TCI)* from [Fuller00]. This theory gives a relationship between the task demand and risk. It presents a reconciliation of two popular theories: *Zero-risk theory* from [Näätänen76] and already mentioned *Risk-homeostasis theory* from [Wilde82]. According to Zero-risk theory, the perception of the risk is a dichotomous variable. The driver either perceives or does not perceive the risk (zero-risk condition). Opposite to this theory, the theory from Wilde defines the risk target level (dashed line in Figure 3.20), which differs individually. This theory states that the counter-measures cannot bring a decrease in accidents because they decrease the subjectively perceived risk and the drivers show more risky behavior when knowing about the counter-measures.

TCI model combines these two theories and suggests that under typical driving conditions the driver is in the zero-risk state, but under exceptional conditions the driver is consciously accepting higher risk and higher possibility of a collision. This happens because the certain positive reward of doing so outweigh the uncertain negative consequence.

TCI model refers mainly to the speed choice and states that the driver selects the speed depending on the perceived task difficulty. Perceived difficulty depends on the task demand and driver capability. The relationship between the task demand and driver capability is shown in Figure 3.21. [Fuller07] proved experimentally the theory behind TCI model by showing that the ratings of task difficulty correlate highly to the speed and that subjectively experienced risk and subjective evaluation of risk do not correlate with each other up to speeds at which drivers feel comfortable. This state corresponds to the zero-risk conditions form [Näätänen76]. With higher speeds, subjectively experienced risk and evaluation of the risk correlate and the model complies with the Risk-homeosthasis theory.

Even if not experimentally confirmed, it is reasonable to consider that this theory account for cor-

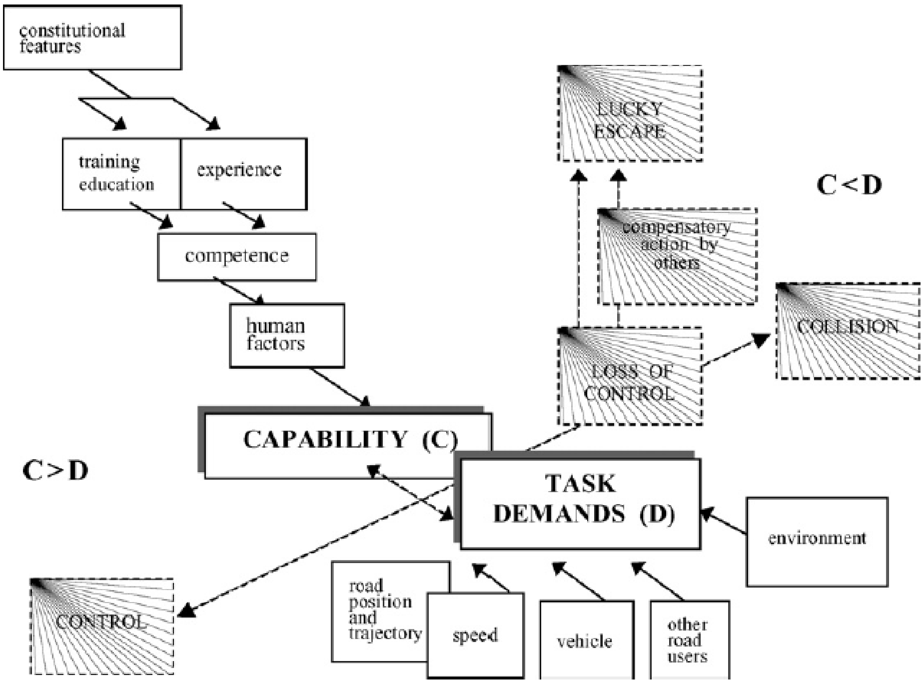


Figure 3.21: *Task-Capability interface model (TCI) model from [Fuller00]. The relationship between driver capability and task demand*

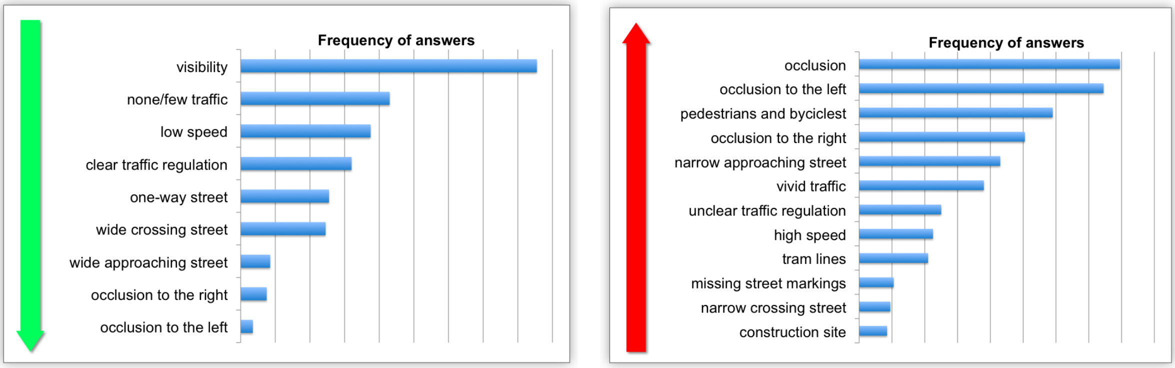
responding behavioral aspects at intersections as well. The relationship between task demand and driver capability determines the perceived task difficulty. This influences the subjectively perceived risk, but does not match to the subjective evaluation of the probability for an accident. Compliant with the previously conducted analysis, task demand has an influence on the quality of the mental model. The more the task is complex, the greater the number of mental models are appropriate. The greater the number of mental models and the greater the complexity of every model, the possibility for the choice of the wrong one is higher.

Regarding the relation between task demand, driver's characteristic, subjective and objective risk, there are several questions of interest to the work done in this thesis:

- which factors influence subjective and objective risk and is it possible to quantify them?,
- which of them are independent and can therefore be considered as additive?, and
- is it possible to isolate specific situations in which objective risk is higher than subjectively perceived risk?

The majority of works about the subjective risk refer to motivations and attitudes towards risk. There are also works that analyze how different speed, weather conditions or road-design elements influence the subjectively perceived risk like the works from [Kebeck99], [Aarts06], or [Kanellaidis00]. Within [AIDE] project, a detailed review of risk-influential factors has been given and it has been shown that speed, speed variability, headway measures, lateral position keeping, and driver awareness can be considered as independent and therefore additive factors that contribute to the objective risk. Regarding intersections, in [Plavsic09a] has been shown that the traffic density increases subjectively perceived risk. Also, it is shown that the subjectively experienced risk correlates more with vulnerable traffic participants and occluded objects, than with the complex driving tasks.

Regarding the third question, there are relatively few works. One of them, the work from [Glaser94], was analyzing the intersection scenarios. Within his work, video clips of 14 intersections in the city of Vienna were shown to participants. Seven of selected intersections were accident-prone and seven have been restructured and accident-free since. Subjects evaluated the danger level of each intersection by means of four-level scale and additionally justified their evaluations in a written form. The analysis identified the elements that predominantly contribute to the increment and decrement of the subjectively perceived risk. They are shown in Figure 3.22(a) and 3.22(b), respectively. As shown, the visibility conditions and moving objects play the decisive role and there are some elements like pedestrians whose presence increase risk but its absence does not decrease the risk.



(a) (b)

Figure 3.22: *Elements which (a) decrease and (b) increase subjectively perceived risk at intersections, based on data from [Glaser94]*

The subjectively perceived risk of each of the intersections was compared to the statistical risk of collision. No intersections were found in which subjectively perceived risk was higher than statistical risk but two were found in which subjective risk was lower than the statistical one. Distinctive for these intersections is that participants named more parameters that increase the risk than those that decrease them. The conclusion is that drivers do recognize the risk elements but they do not give them enough importance. [Glaser94] also found the same for other situations: decreasing parameters are normally given higher importance than the increasing ones. However, a fixed pattern, which enables the prediction of situations where subjectively perceived risk is lower than it should be, could not be found, neither in this nor in other available works.

The modeling of risk assessment is essential when modeling driver cognition. As seen from the presented argumentation, the direct measurement and by that the modeling of the subjective risk is impractical and the precise evaluation of the objective risk is hardly possible. As an alternative, the concept of task demand can be applied instead and is therefore discussed in the next section.

3.3.4 Task Demand and Workload

As seen in the previous chapter, task demand has a direct influence on the driver's risk perception. In direct connection with the concept of task demand is the concept of task difficulty and the workload. Task demand is independent of the driver's characteristics and task difficulty. The workload can be described as the task demand regarding the driver's characteristic.

The TCI theory from [Fuller07] defines a relationship between task demand and driver's capability as the *task difficulty*. TCI model says that task demand depends on environment, other road users, vehicle, speed and position on the road, and trajectory (compare Figure 3.21). Task difficulty is related to, but not the same as *task complexity*. However, there is no clear distinction between these two terms. [Sweller06] defines the complexity as interactivity between elements. In complex tasks many elements simultaneously interact and in the difficult tasks the elements are demanding but they do not necessarily have to be conducted simultaneously. [Kantowitz87] describes the difference between complexity and difficulty as a property of the task in isolation versus the interaction between task and individual. [De Waard96] explains that the complexity increases with an increase in the number of processing stages that are required to accomplish a task, where the difficulty increases with the processing effort (amount of resources) that is required.

The other concept used to describe the ratio between task demand and driver capability is the concept of the *Workload*. [De Waard96] defines mental workload as *the amount of information processing capacity that is used for task performance*. Workload can be understood as an experienced load that the task demand puts upon operator in relation to the stages that are used in information-processing. Workload has an effect on the driver behavior by influencing the distribution of the mental resources. This is in direct connection to the previously explained Wickens's *Multiple-resource theory* and as such it is suitable for modeling of driver cognition. For example, concept of workload explains the increased responses time to the sudden obstacles or reduced situation monitoring ability [Greenberg03]. Therefore the analysis and the modeling of workload in the first approximation can replace the analysis and modeling of the perceived risk.

The connection between workload and performance is explained with the help of Figure 3.23, modified from [De Waard96]. The figure presents the run of the workload curve depending on the task demand. Six regions of task demand are distinguished and task is increasing from left to the right. The minimum demand is in the area D (deactivation) where the task is monotonous for the operator. Low demand tasks increase the workload: "in case of boredom a reduction in capacity requires that a larger proportion of the capacity is used for performance of the same task, thus increasing mental workload." [De Waard96]. Sustained low workload (underload) leads to boredom, loss of situation awareness, and reduced alertness. The optimal performance is in the region A2. In regions A1 and A3, the operator has to exert an effort so to preserve the same performance level. In the region B, the task demand gets so high that the performance declines. However, the increment of workload may not decrease the performance as the operator may have a strategy for handling the task demand.

Parameters Influencing Workload at Intersections

For the modeling of driver cognition regarding intersection tasks, the influences on the workload

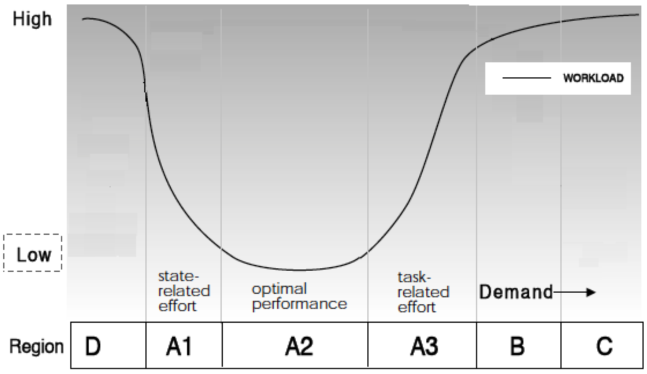
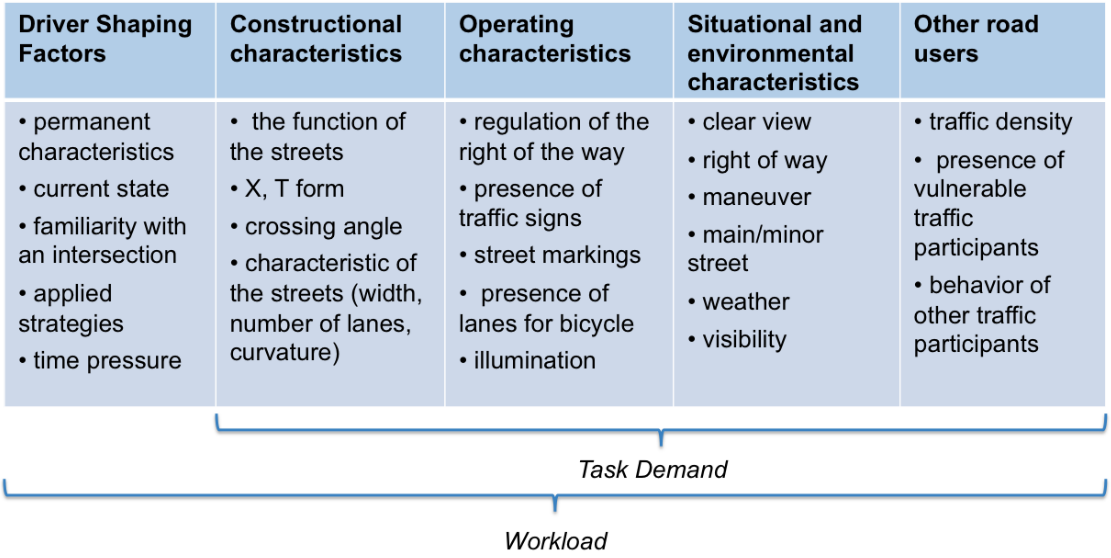


Figure 3.23: *Six regions of the relationship between workload and performance by increasing task demand [De Waard96]*

should be known. This is the topic of the current subsection. Additional question of interest here is whether and how can different intersection tasks be compared regarding their demand.

Based on the literary overview, the primary parameters that influence workload and task demand at intersections have been extracted within this thesis and their overview is given in Table 3.5. The parameters are grouped into five categories: *Driver Shaping Factors*, *Constructional characteristics*, *Operating characteristics*, *Situational and environmental characteristics* and *Other road users*. *Driver Shaping Factors* influence the perceived workload, where the others influence the objective task difficulty. Each group is shortly discussed in the following.

Table 3.5: *The most relevant factors influencing workload and task demand at intersections*



Driver Shaping Factors	**Constructional characteristics**	**Operating characteristics**	**Situational and environmental characteristics**	**Other road users**
• permanent characteristics • current state • familiarity with an intersection • applied strategies • time pressure	• the function of the streets • X, T form • crossing angle • characteristic of the streets (width, number of lanes, curvature)	• regulation of the right of the way • presence of traffic signs • street markings • presence of lanes for bicycle • illumination	• clear view • right of way • maneuver • main/minor street • weather • visibility	• traffic density • presence of vulnerable traffic participants • behavior of other traffic participants

Task Demand

Workload

Driver Shaping Factors. Driver Shaping Factors present the *Performance Shaping Factors (PSF)* concerning driving. These include both the driver permanent characteristics like age, gender, experience, and the current state, which is influenced by fatigue, motivation, or emotions. Other influential shaping factors are the familiarity with the situation, applied strategies, and time pressure. [Williams08] researched which of the permanent driver's characteristics have the highest influence on the behavior at intersections. She found that the decisive factors are the age and experience. The number of km driven in the city and the gender are only of the second-rang importance. That the age is one of the most influential factors, especially at intersections, is also supported by [Fastenmeier05]. The reasons are different strategies used among elderly and young drivers. On the one side is the degradation of the visual acuity and motoric processes of elderly drivers as well as the downshift of the speed of information-processing. On the other side, the aged drivers have experience with which they can compensate for the deficiency of cognitive functions. It has been shown that experienced drivers have better strategies to detect hazardous objects and that they benefit from the peripheral vision more than inexperienced [Underwood03], [Langham06]. Experience of the drivers regarding intersections can already be observed in approaching segment: they reduce the speed significantly in comparison to non-experienced drivers [Williams08].

The question of how applied visual strategies depend on the driver was also studied by [Williams08]. She showed that there is no correlation between driver's characteristics and applied visual behavior and that the visual behavior depends mainly on external factors.

One of the most influential Driver Shaping Factors is time pressure. Under time pressure the drivers have to prioritize information and to focus on the most relevant ones. Time pressure is causing the driver to increase the driving speed as well as to prioritize information even further and leave out all the tasks not considered as essential. As such, time pressure can be used for exploring the way the drivers prioritize information, as the simulation of high workload, and as a mean to provoke unintentional cognitive errors.

Constructional characteristics. For the improvement of the traffic safety on the organizational, meso level, the constructional characteristics of traffic situations have been well researched. The constructional features that decrease the task demand at intersections are: [Gambard88]

- good visibility conditions in approach segment (This is however disputed because the good visibility may increase the approaching speed. The countermeasures of occluding the view at intersections to provoke the reduction of speed are not rare in Germany.)
- simple geometrics,
- not too wide lanes as they lead to the choice of high speeds and attention deficits, and
- crossing angle of $90°$.

The opposite parameters are systematically increasing the task demand. With respect to the constructional characteristics, the best choice present roundabouts, followed by T-intersections and intersections with one-way roads because they simplify the decision processes that the driver has to make [Preusser98].

Operational characteristics. It is often said that the best driving assistance is a good traffic infrastructure. Extensive analyses have been conducted for increasing safety by improving operational characteristic in the field of traffic psychology [Klebelsberg82]. The important measure is the transparency of the traffic signs [Shinar03]. Expectations of the intentions of other road users at intersections are mainly based on the traffic signs. Traffic lights and dedicated turns immensely simplify the decoding and judging of the time gaps and are recommended for the intersections with busy traffic. They are often brought up to improve safety. Anyhow, this measure did not always lead to an improvement [Williams08]. She explains this fact with the ambiguity of the duration of yellow lights. The recommended duration of yellow phase is $3 - 4$ s [VanderHorst86]. The introduction of blinking green light when changing to the yellow can also increase safe performance [Köll04]. Also a lot of discussions exist about the exchange of *Yield-signs* to *Stop signs* because the *Stop signs* increase the taken time gaps. This measure, as well, did not prove to bring improvements [Williams08].

Situational characteristics. Occluded view, bad weather and visibility are the factors that systematically increase the task demand. They are also hardly controllable. However, the accident analyses from the [ConnectedDrive] and [INTERSAFE] projects have shown that accidents with crossing traffic mostly happen with no occlusion and no or low curvature, and at very simple geometrics. This shows that even though good visibility presents a crucial factor when it comes to the improvement of traffic safety, it can also cause the driver to execute more risky actions. It seems like that especially at complex intersections, conscious risky actions take little account for accidents: the more demanding the situation, the more attention the driver allocates [Mages06].

A theoretical analysis of how does the right of way and street type influence the task demand has been conducted by [Fastenmeier95]. He analyzed intersection scenarios based on the requirements on information processing and vehicle stabilization. For each situation indexes evaluating information processing and vehicle stabilization demands were determined and by that the complexity of situation was estimated. The full quantification is given in *Appendix A*. Within this classification also factors like presence of the curves (H), slopes (V) or narrow places (E) were included. These factors have a systematically negative influence on the difficulty of the task. The result of sorting intersection scenarios for each type of road when neglecting these influences is presented in Table 3.6. The higher the index is, the more the task is demanding.

To interpret the results from Table 3.6, the taxonomy of the different roads and junction types from Table 3.1 can be used. The table shows that for all types of roads except for C1 and C2, the most demanding situational characteristic is when having minor priority, then priority to the right, followed with priority by traffic sign, and the simplest is the regulation with traffic lights. Though, this analysis does not include the type of maneuver except for generally stating that turning left or right is more difficult than keeping the direction. This analysis does also not include other relevant factors such as the traffic density and the presence of other road users.

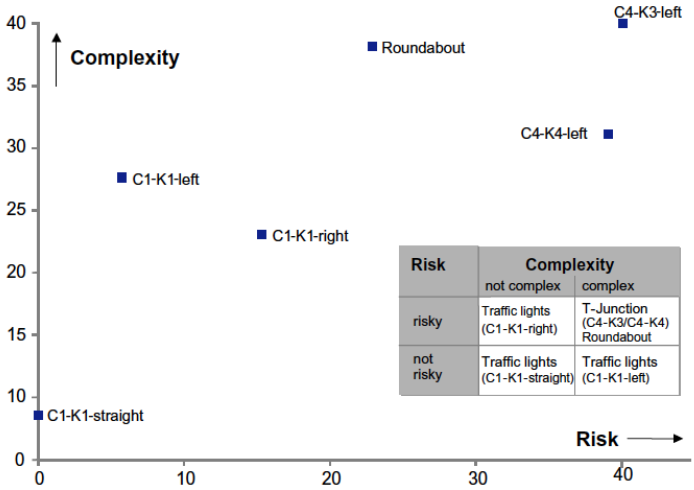
Based on this work, [Fastenmeier07] developed a SAFE method *(Situative Anforderungsanalyse von Fahraufgaben)*, the theoretical method for requirement assessment of the driving task. Even though the principles of this method are not fully published, some results are available and are presented in Figure 3.24. This Figure presents the distinction between four categories of intersections: not complex and risky, not complex and not risky, complex and risky, and complex and not risky, and gives an example for each of them.

Another theoretical evaluation of situational characteristics was conducted by [Vollrath04] in the form

Table 3.6: *Intersection scenarios sorted by requirements on information-processing from [Fastenmeier95]. Presence of curves, slopes and narrow places is omitted because of having systematical negative influence on the task demand*

Nr.	Taxonomy	Inform. Process index	Nr.	Taxonomy	Inform. Process index	Nr.	Taxonomy	Inform. Process index
50	C1-K4	92	65	C2-K4	91	75	C3-K4	88
42	C1-K1-F	78	60	C2-K2	82	73	C3-K3-F	78
41	C1-K1	76	56	C2-K1-F	81	72	C3-K3	66
49	C1-K3-F	72	62	C2-K3-F	78	71	C3-K2	82
46	C1-K3	68	55	C2-K1	73	70	C3-K1	76
			61	C2-K3	65			

Nr.	Taxonomy	Inform. Process index	Nr.	Taxonomy	Inform. Process index	Nr.	Taxonomy	Inform. Process index
92	C4-K4	90	106	C5-K4	97	119	C6-K4-F	90
89	C4-K3-F	81	103	C5-K3-F	80	118	C6-K4	90
88	C4-K3	75	102	C5-K3	79	115	C6-K3-F	78
86	C4-K2	78	101	C5-K2	84	114	C6-K3	75
82	C4-K1-F	83	99	C5-K1-F	86	112	C6-K2	80
81	C4-K1	79	98	C5-K1	88	110	C6-K1	80



Risk	Complexity	
	not complex	complex
risky	Traffic lights (C1-K1-right)	T-Junction (C4-K3/C4-K4) Roundabout
not risky	Traffic lights (C1-K1-straight)	Traffic lights (C1-K1-left)

Figure 3.24: *Risk and complexity evaluations of selected intersections scenarios based on the SAFE analysis from [Fastenmeier07]*

of a pairwise questionnaire. The objective was to find out the relationship between the following parameters influencing the task difficulty at intersections: maneuver, type, regulation, geometry, and right of way. These present both operative and situational characteristics. The parameters showed not to correlate with each other and therefore, the subjectively perceived task difficulty of one intersection can be evaluated as the sum of these factors. The result is the following rank of factors, the first one being the most influential:

- maneuver
- right of way
- regulation type
- type of intersection
- street direction

Even though the presented studies explained the relationship between the most relevant situational characteristics and task demand, there is still a question of which parts of driving task are the most demanding for the driver. This is highly relevant for the definition of an ergonomic assistance system.

Other Road Users. The presence of the other road users, its number per time interval, and density of objects in the road scene affect driver behavior as much as they compete for the driver's visual attention. However, there are no available works which systematically analyze these influences at intersections. To analyze this issue the driving behavior should be specifically researched by a systematic increase of the number of present road users. This is a scientific question that should be analyzed under controlled conditions in the driving simulator and presents the continuation of the work done in this thesis. By answering these issues, the classification of intersection road traffic situations from Table 3.2 can be supplemented by the classification of intersection driving situations.

3.4 Summary

This chapter discusses the classification of intersection scenarios and delivers the theoretical model of the driver's cognition regarding the task performance at intersection. The model of the driver cognition presented in this chapter presents the foundation for the computer simulation of driver cognition, which can be used for the development of driver assistance systems for the guidance level.

Within the classifications of road traffic situations, it is distinguished between *traffic situations*, *driving situations*, and *driver situations*. For the analysis of the task performance, the most applicable is the classification of *driving situations*. For the driving situations in longitudinal traffic, abundant experimental data enabled the classification of situations, which include the presence and the behavior of the other road users. For intersections, such systematically collected data do not exist and for the work done in this thesis the classification of intersection traffic situations from [Fastenmeier95] is used.

The intersection task presents a qualitatively different task from the tasks in the longitudinal traffic. Intersection presents situation in which the driver has to reduce the speed and to communicate with other road users to safely execute the planned maneuver. It is mainly conducted on the rule-based level. This means that the task is performed based on the learned rules and procedures and that it is conducted on the conscious level. Therefore the analysis and modeling of driver cognition present the essential aspects of modeling the driving task at intersections.

While accomplishing the subtasks at intersections, the driver goes through several cognitive states, which is described with the three cognitive levels in the process of achieving Situational Awareness. The cognitive processes for achieving the Situational Awareness are modeled in the following sequence: *Categorization*, *Retrieval*, *Anticipation* and *Mental model creation*. The limitation factor for driver cognitive performance is mainly the capacity of the working memory, which cannot be increased. The key elements for achieving appropriate Situational Awareness are *Mental models*. Mental models present the constructions of the reality, which the mind uses to reason, expect and anticipate events. For the particular situation, the mental model presents a meaningful interpretation of the reality. Mental models are an input for the consecutive *Decision making* processes, which are based not on the objective state of the world, but on these mental models.

The *Risk assessment* process has also a significant influence on the resulting behavior. It evaluates the risk and benefit of each of the mental models and chooses the most appropriate one to work further with. The attitude towards risk and its perception play essential roles for the decision making. Therefore the quantification of the objective and subjectively perceived risk of a particular situation is highly beneficial. The current chapter shows that this is ambiguous. Therefore the concept of the task demand and workload are presented as they can substitute the concept of risk. The task demand influences the subjectively perceived risk (which is not the same as the subjective evaluation of the risk of collision) and it is affected by the driver's capabilities. The resulting experienced workload dictates the quality of the performance and can be straightforwardly modeled.

Finally, the most relevant parameters influencing the task demand and workload at intersections have been singled out and selected for the experimental evaluation. These are: maneuver, right of way, regulation type, and type of intersection; and as the most influential driver shaping factors: experience and time pressure.

Chapter 4

Eye Movements and Visual Strategies in Driving

Within the previous chapter, a developed driver cognitive model for the performance of driving tasks at intersections has been presented. Up to now, information perception and processing mechanisms have been discussed. This chapter deals with the resulting action upon the information processing regarding the driving task at intersection. The performed actions present the only way to observe and measure the previously analyzed cognitive processes; anticipation, decision and evaluation processes cannot be directly observed. Even though there are efforts to develop techniques for measuring information processing mechanisms by measuring Situational Awareness with different techniques, these methods are still not developed enough. On the contrary, the eye movements, which present the performed action on the guidance level of driving tasks, can be quantified and by that, their analysis can give an objective measure of human performance. In spite of many drawbacks, the measurement of eye movements presents at the moment the best single tool for getting an insight into drivers' cognitive states. New eye-tracking systems enable recording of gaze movements with high frequencies, in orders of milliseconds. In that way, it is possible to gain insight not only in general driving strategies, but also in more detailed levels of human cognition like control of attention and processing times.

Therefore, this chapter is dedicated to advanced research about eye movements and resulting visual strategies in driving. However, there are surprisingly few works analyzing and measuring eye movements in driving, especially at intersections. Additionally, they do not provide information beyond the fixation distributions. With decreasing costs and weight of eye tracking systems, such analyses are becoming technically more feasible and are expected to become more widespreaded.

4.1 Mechanisms of Eye Movements

The analyses of driver visual behavior give salient clues for the identification of cognitive mechanisms, which are leading to erroneous actions [Salvucci99], as well as information about applied driving strategies, like anticipation horizons, distribution of attention and sources, and prioritization of information used for orientation [Bubb00]. [Theeuwes93] even argues that eye movements can be considered as a result of attention oriented selection processes preceding the actual eye-shifts.

In the previous chapter it is discussed that there are two mechanisms of eye movements: *intended* and *triggered (involuntary)*, which correspond to the top-down and bottom-up mechanisms, respectively. Intended eye movements are also named endogenous and they are controlled by the driver search demands. The next fixation or even next several fixations are consciously decided upon. Involuntary or exogenous movements are provoked by conspicuous stimuli like a blinker or a flashing light and are hard to suppress. There are no external cues about when a driver is in an exogenous or endogenous control, which is the problem encountered for the analysis of visual patterns.

The analysis of mechanisms, which control the eye movements, has become increasingly popular with the need to provide robots with the cognition. The majority of known models for predicting the next eye movement consist of organized *saliency maps* [Rötting01]. The saliency maps have been explained in the previous chapter when discussing the Feature integration theory. The prediction of the next eye movement with a saliency map presents a probability approach. The scene is transformed into a saliency map in which each area or object has a particular value. The probability that one point in the retina will be the goal of the next eye movement depends on this value and is increased if there is a sudden spatial activation or if there is additional stimulation of other modality, for example sound. Depending on the current task, the value of the objects in the saliency map can be increased and decreased. The higher the sum of activation on the map is, the easier a movement is activated. The goal of such models is to predict of the next eye movement. Such predictions have been achieved for the robot systems when taking into account only the characteristics of the scene. The necessary precondition is almost the absolute knowledge of the scene. [Torralba06] has developed a model of attention that combines bottom-up saliency, scene context, and top-down mechanism, and can predict driver's fixation in the early stages of vision processing before the decision phase arises.

The problem with the deterministic prediction of the next fixation is that perception does not only depend on the characteristics of the objects in the scene, but also on the driver's characteristics, current state, and active task. Activated mental model in the particular situation influences not only the decision that is to be made, but also what is perceived from the scene. Figure 4.1 is illustratively showing factors that influence where the eye will move next. Clearly, the deterministic prediction of the next eye movement is at the moment almost impossible to make. Additional problems appear when trying to predict the next eye movement in dynamic scenes.

The majority of research about eyes movements focus therefore on the descriptive analysis on visual strategies applied when driving. This chapter presents relevant research from this field, with focus on visual strategies applied at intersections.

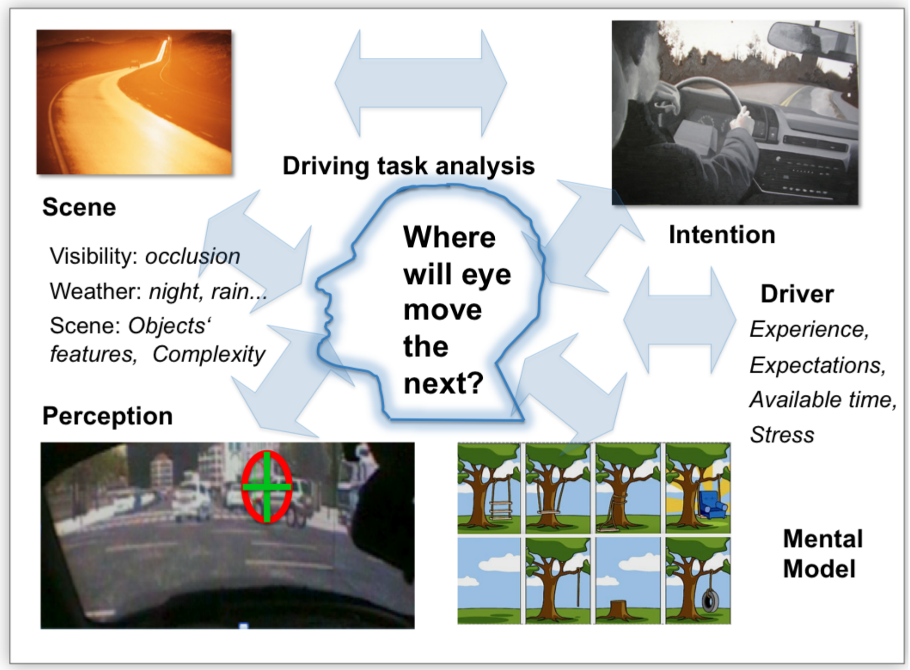


Figure 4.1: *Eye movements are influenced not only by features of objects in the scene but also by the mental model of the situation and the intention of the future action, deduced from an analysis of currently conducted driving task*

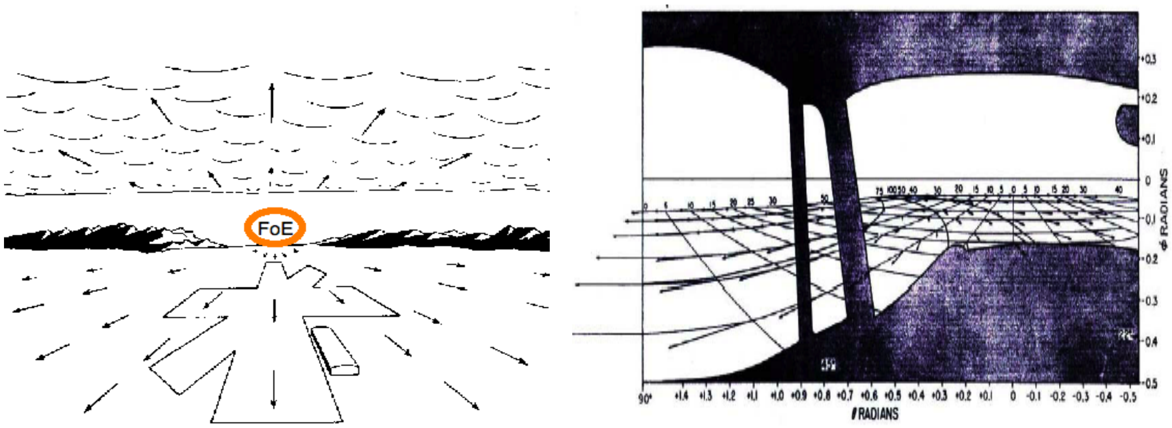
4.2 Visual Strategies in Driving

For achieving the cognitive driving task on the guidance level, the cognitive task on the stabilization level has to be first accomplished. Therefore, first some basics about visual strategies on the stabilization level are discussed, such as perception of distance and speed, followed by discussion of visual strategies at intersections.

4.2.1 Visual Perception of Distance and Speed

To stabilize and keep the vehicle in the lane, the driver has to perceive visual cues, which give information about the position of the vehicle in both longitudinal and lateral direction. For the longitudinal control, so called *optical flow* presents the main cue. This term was introduced by [Gibson73] and it presents a continuous deformation of the surface for relative movement, arising from a gradient of movement [Goldstein99].

Optical flow has an invariant point called the *Focus of Expansion (FoE)*, which presents a center of fluxation and from which it seems that optical lines are *flowing out* (see Figure 4.2(a)). With an absolutely straight movement and a constant speed, this point is in frontal center and is in the middle of the driver's field of view, in the height of the road, increased for the height of the driver's seat. In curves, visual vectors show the shift of crossing points of an imaginary grid: vectors closer to the vehicle are longer than the vectors further away. Speed vectors for the left curve driving are illustrated by [Gordon66] in Figure 4.2(b). Vectors along the ideal course look shorter than vectors in the same height and straight direction. The shifting is the same for the levels at the same distance below and above the height of the eyes and at the same lateral direction. This shifting of the gradients of the vectors is essential cue for the evaluation of the speed. [Gibson73] claims that human visual system does not have to be too sensitive to perceive the ”flow”, but perception can be done peripherally. Additionally, FoE and crossing of image vectors give information about the pitch angle, lateral distance, and over- and understeering; the FoE point sinks during the braking and comes up during the acceleration.



(a) (b)

Figure 4.2: *Optical flow: (a) Motion perspective in the visual field ahead with Focus of Expansion (FoE) point [Gibson73], (b) hypothetical speed vectors when driving in the left curve illustrated by [Gordon66]*

What are cues that are used to estimate the position of the Focus of Expansion? [Donges75] found that these are the lane markings with poles and middle road markings. Newer findings from [Chatziastros99] give to so-called *Splay angle* the highest importance for the perception of the optical flow. The splay angle is formed, not only from the lane borders but also from the surface textures, which are marked by lines parallel to the direction of a motion. That is the angle in the optical projection between a straight line and the line perpendicular to the horizon. During lateral displacement, an optical rotation of this angle occurs. Additional visual cues for the perception of FoE are disparity, occlusion of objects, relative sizes, and shadows. They are also essential for the estimation of distances.

[Chatziastros99] showed that the pivotal areas for lane keeping are areas between 3° and 9° under the horizontal plain of eye level. [Summala96a] also showed that the detection in upper part of the visual field is worse than in the lower. Therefore drivers achieve higher quality of driving when focusing on FoE because in that way, both vehicle control and anticipation of hazards are better. [Diem04] found that for straight roads the middle focus distance is around 120 m and lateral distance is $\alpha = 1.7°$ on average. The gaze distribution changes for curves with radius $R > 500$ m. [Bailly03] showed the difference in a focal point of novices and experienced drivers. Novices are mainly focused on the nearby environment and for experienced drivers this distance is between 2 and 3.5 s. [Diem04] found that the focusing distance even goes up to 150 m when driving on the straight road without distraction, which is for the speed of 80 km/h around 6 s.

Driving in curves. For controlling vehicle in curves, not only FoE but also the *middle point* of the curve is necessary for orientation [Wolf09]. Figure 4.3 shows two possible constellations of these two points for the right side driving: (a) when they are over each other, and (b) when FoE is to the left of the middle of the curve. [Land74] argues that driving curves comes up to match FoE with the middle of the curve. With the constant curvature and optimal lane keeping, a constant visual pattern is built. When the curve appears, drivers first notice that there is a change in the pattern. Just afterwards, the driver gets enough information about the direction and the size of the change. According to [Land74], the physical size that is evaluated is the curvature, whose deviation can be estimated pretty accurately when it is between $0.5°$ and $1°$.

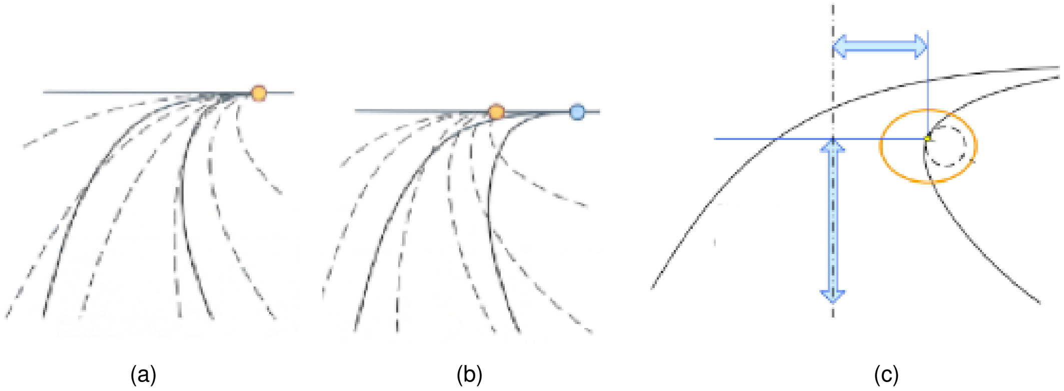

(a) (b) (c)

Figure 4.3: *Two possible constellations of Focus of Expansion (yellow circle) and the middle of the curve (blue circle) for the right side driving [Wolf09] (a) FoE and centre of the curve are over each other, (b) FoE is to the left of the middle of the curve, (c) Tangent point (yellow circle) of the right curve with constant radius from driver's point of view*

Frequently the centre of the curve is not visible. In that case, so called *Tangent point*, depicted in Figure 4.3(c), is used for orientation [Land74]. [Boer01] argues that the most important cue for curves negotiation is the optical density between *Tangent point* and *Focus of expansion*. The angle between long axis of the vehicle and line connecting the vehicle and the tangent point is giving the cue for the evaluation of the curvature. With the constant curvature, the tangent point stays always at the same distance to the driver. Experimental analysis from [Bengler96] showed that when driving curves the predominant pattern is shifting of eye movements from left to right. [Land74] found that drivers rely particularly on the tangent point on the inside each curve, seeking this point $1-2$ s before each bend and returning to it throughout the bend. [Shinar77] showed that drivers mostly focus the left side of the curve $(0,3°$ to the left) in left curves and right side of the curve $(3,6°$ to the right) in right curves. For left curves, [Diem04] found focusing distance to be from 59 m to 26 m for radiuses of 250 m to 110 m, respectively. For right curves these distances are 49 m and 35 m. With the presence of the leading vehicle in less than 75 m, applied strategies change and drivers start orienting according to the leading vehicle [Diem04]. Regarding the difference between novices and experienced drivers, [Cohen77] found that experienced drivers have significantly shorter fixation durations than novices, but only for curves to the right.

It is concluded that there is not one visual cue for the stabilization control of the vehicle but plenty of them. Their importance depends on the driving situation (whether it is a highway, tunnel or urban road), on the driving speed, but also on the driver himself. In [Plavsic10b] is discussed how are these visual cues transformed into actions for the steering behavior by different drivers in different situations.

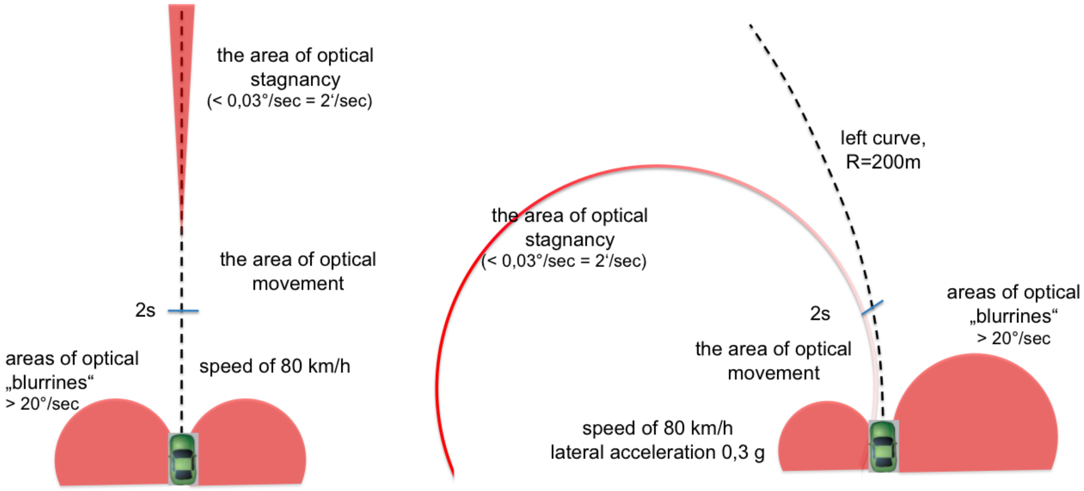


Figure 4.4: *Illustration of areas of optical stagnacy, optical movement and local blurriness for (a) straight driving, and (b) driving in a left curve. The illustrations are based on the [Remlinger10] work*

The perception of visual cues for both lateral and longitudinal control are restricted by human perception limits and laws of physics. In his dissertation, [Remlinger10] determined driver's limits to perceive objects and speeds. He calculated and illustratively presented the areas of optical stagnancy (static world) and areas of optical movements (dynamic world) (see Figure 4.4). The area of optical stagnancy is marked by a red triangle for straight driving and a half-circle line for the driving in curves. The position of this line is not the same for all humans as it depends on the individual vision acuity. The borderline between static and dynamic world presents as well the visual cue for the evaluation of relative position of the vehicle and speed. The distances and relative speeds of objects is harder to evaluate in the area of optical stagnancy. The most difficult estimation of speeds and distances is close to FoE point because of the small vectors shifts in this area and movement falls easily under the threshold of 2 '/s. For example, drivers approaching a traffic jam can hardly notice whether the vehicles in front are moving and, if so, how fast. Near the static and dynamic perception threshold, there is another relevant phenomenon, which limits the driver's perception of longitudinal parameters. [Remlinger10] named it *Local blurring* and is also presented in Figure 4.4. The area of local blurring is increased by increased speed.

4.2.2 Visual Strategies at Intersection

It is considered that the majority of experienced drivers manage the driving tasks on the stabilization level without too much conscious control. Oppositely, the tasks at intersections are mainly managed with the full conscious control. The driver has to assess the objects in the complex scene, to recognize them, evaluate their status, anticipate the further development, and apply one of the established strategies for performing the task. In the majority of intersections the driver has to simultaneously perceive several traffic signs and independently moving objects and to adjust his performance according to them. This has to happen in a narrow time span and the driver has to execute in parallel at least five discrete motor operations per second when negotiating an intersection. Already by perception of traffic signs, the driver can be overwhelmed [Diem04].

To perceive an object, it is necessary that the object falls close to the foveal area, which is designated as a *Fixation* of the object. Minimal *Fixation duration* necessary for the perception is about 80 ms and beneath this value no information can be perceived. [Velichkovsky99] distinguishes three types of fixations in a static environment: fixations shorter than 90 ms, which can be understood as corrections on the way to the actual fixation; fixations between $90 - 140$ ms, which belong to the pre-attentive phase and serve to localize but not to identify the objects in the scene, and fixations longer than 140 ms, which arise from the attentive processing. The fixation duration in driving rarely exceeds 2 s. [Schweigert03] found that the portion of fixations that last longer than 2 s is less than 5% and in 90% they are either fixations on the leading vehicles or on the road ahead. *Saccade* presents a brief movement of the eyes between fixations, during which no perception can happen. Several fixations of one object are building a *glance*. In contrast to a *gaze*, *glance* is a measurable parameter. *Glance duration* is defined as a time from the moment at which the direction of gaze moves towards a target to the moment it moves away from it [ISO-15007-1:2002]. It presents the total amount of successive fixations and micro-saccadic movements including saccadic jump to the object.

Glance distributions in driving are positively skewed [Schweigert03]. More complex segments are having narrower distributions. [Schweigert03] found that glances close to the vehicle (road, traffic signs, oncoming vehicles) all have identical distributions and modal values between $0,3$ and $0,4$ s. The exceptions are leading vehicles, which have a higher modal value of $0,4$ s.

The presented parameters are sufficient for describing the distribution of the driver's attention. Still, they refer only to the objects, which are foveally focused. It has been discussed that for the perception of an information not only foveal but also peripheral vision can be used. This is what experienced drivers usually do. [Knappe07] proved that without peripheral vision, when limiting the field of view down to 5°, the lane keeping performance is highly deteriorated. [Summala96b] found that novices do not scan far away and do not recognize hazards in the peripheral view. He showed that experienced drivers fixate the lane in a less extent than novices, which means that experienced drivers rely more on the peripheral vision and instead use the foveal vision to scan for hazards. [Aasman95] also found that experienced drivers search for the relevant objects in a more systematic fashion, but this is becoming obvious only in more complex and critical situations. In non-critical situations the majority of movements are idle movements. Still, at intersections the majority of information can be perceived only foveally and relying on the peripheral vision can provoke fatal situations. For example, [Uchida01] showed a case of clear intersection where many accidents happened with the crossing traffic. He found that this happens when the crossing vehicle approaches with the same relative speed to the subject vehicle. This case has been experimentally examined in the dissertation of [Remlinger10]. In such a scenario, the opponent vehicle builds a constant position in the driver's retina and there are no relative movements that can be perceived peripherally. The consequence is that if the driver does not foveally focus the crossing vehicle he may not see it even though there are no visual obstacles.

In the short time in which the driver has to execute the maneuver at intersection, it is impossible to get the detailed image of the scene. The proportion of the scene that can be taken into account is limited and frequently crucial decisions have to be made based on the perceived proportion of the scene. [Langham06] found out that the approximate time the drivers took to look for hazards at intersections was less than $0,5$ s. This is an indication that drivers check only parts of intersections which they consider relevant. The same as with perception of the static pictures, the first few fixations give an essential picture of the scene and remaining fixations are used to fill in details. In the first, pre-attentive phase, individual objects are concurrently localized and the environment is roughly scanned with 0,8 up to 5 fixations per second [Schweigert03]. In that way, a subjective impression of the whole scene is created. In the second, attentive or the focal phase, separate objects are consciously identified. When an object attracts attention, it is fixated and processed. The duration of a stimulus can be kept 3 to 4 s in the short-term memory. In more dynamic scenes this information is lost even earlier because the new content can suppress the old. As discussed, the capacity of the working memory limits the amount of simultaneously kept objects up to four. [Bailly03] showed that under lack of cognitive resources event modification is more robust information than the infrastructure information. This means that the infrastructure features will be forgotten sooner than the event.

The filtering of information that has to happen while conducting the intersection tasks leads to the sensibility of drivers towards particular stimulus. The ideal driving behavior at intersections is to successively scan all the directions from where the dangers can potentially come from. As discussed in the previous chapter, with increasing experience, drivers develop strategies with which they compensate for deficiencies and which serve to predict where the crucial information will be. Such strategies have the highest efficiency-safety function and information of lower subjective risk is neglected. In [Plavsic09a], it was observed that in complex driving situations, after being confronted with one's own eye movement, drivers did not recognize them and were surprised to notice that they did not scan some particular direction. [Summala96b] found that the majority of driver's visual strategies at intersections are appropriate for the detection of usual and frequent objects like trucks and vehicles but are inappropriate for the detection of rarely present objects like bicyclists and pedestrians, which are moving parallel to the driven vehicle. [Schweigert03] found that drivers in almost 65% of cases do not check for vehicles which do not have right of way. In [Plavsic09a] this finding is confirmed and it is also shown that drivers mainly focus on the further trajectory path and expect to see the illegal road behavior peripherally.

When having to perform so many tasks at once, it may happen that the driver does not only fail to look in some direction but also that the object that is fixated is not perceived. Such phenomenon is named *Change blindness* or *look-but-not-see error*. This is the phenomenon of not noticing the sudden change that was made simultaneously with an eye movement. Change blindness phenomenon occurs under a variety of conditions and can occur even when the changes are large, repeatedly made, and in full knowledge that they will occur [Rensink07]. [Rensink07] reports about experiments where operator was following indicator needle on display and if a transition occurred somewhere else in the display, operators were often not seeing it even in full state of alertness. Stimulus with strong emotional impact (for example a child on the street) can increase the probability of this phenomenon happening. [Grimes96] and [Velichkovsky02] were analyzing this effect by changing the scene during saccade and by using *blank screens* and found that in 67% the changes were not perceived even when they included changing of the quarter of the complete scene. In [Plavsic09a] this phenomena accounted for 3 of 14 accidents in a complex intersection scenario.

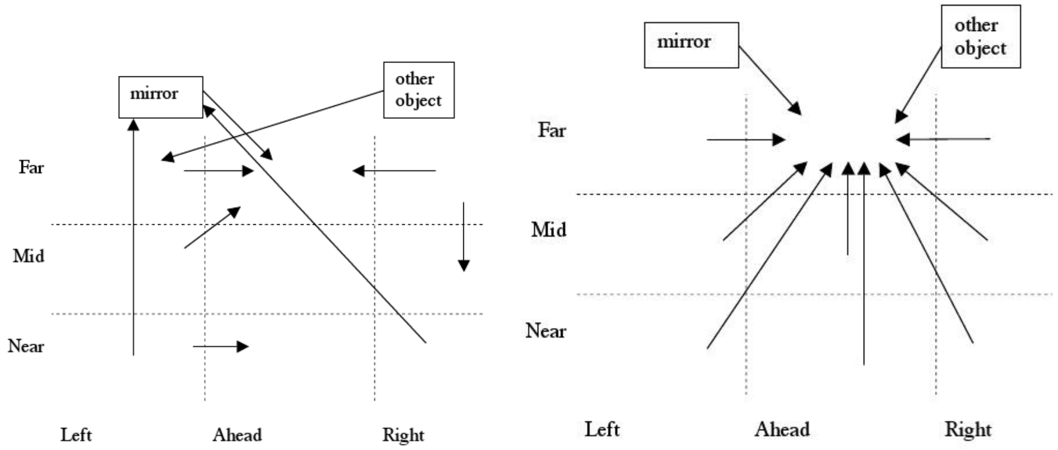
The prioritization of information that drivers do is resembled in the fact that for the increasing difficulty of the driving task, the fixation durations are decreasing especially regarding the irrelevant traffic objects and scanning fixations. [Schweigert03] found that when having to perform additional tasks, the following tasks were omitted: checking irrelevant traffic objects (in 83% of cases in comparison to 11% in baseline), checking instrument panel, traffic sings and mirrors (omitted in 93%), checking participants not having right of way (72% against 41% in baseline), checking participants which have the right of way (omitted in even 32% against 7% in baseline). Regarding the intersection task, he found that 68% of drivers retract from scanning for pedestrians when they have to perform an additional task. It is concluded that when performing an additional task, attention is relocated to the objects, relevant for rudimentary tasks like longitudinal and lateral movement, to the control of vehicles, and to the participants in right of way.

For good orientation at intersections, reading and perception of traffic signs is fundamental. [Diem04] found that during the day only approximately 20 to 25% of drivers focus their attention on the traffic signs and during the night only up to 10% of drivers. The mean duration of the fixations is $0,34$ s on average. [Diem04] also found that regulatory and navigation signs are focused two times more than the mandatory signs. Mean fixation distance is around 120 m with straight rural roads, and in curves it is up to 26 m. The process of paying attention to the traffic signs is divided in the following steps:

- perception of traffic signs $d = 150 - 300$ m,
- recognition of the structure $d = 75$ m, and
- reading of what is written $d < 50$ m.

Regarding the fixation of traffic signs, when negotiating an intersection, no detailed information could be found.

Not only the fixation durations but also the sequences of the eye movements give relevant information about the applied searching strategies. [Diem04] found that sequence of fixations in urban areas depends on the type of street and is strongly influenced by other traffic participants. [Harsenhorst88] found that there is a regularity in the visual orientation regarding the maneuver and type of intersections, but that the applied strategies are independent of drivers' level of expertise. Yet, more detailed analyses than the descriptive statements are rare to find. The works from [Liu98] and [Underwood03] indicate that each driver has his own searching strategy which corresponds to the retrieved inner mental model. [Liu99] showed that by applying *Hidden Markov Models (HMM)*, it is possible to deduce driver's cognitive state from the sequence of eye movements. He observed four different maneuvers and found that each maneuver can be described by a unique Markov matrix. Maneuvers at intersection were however not included in these experiments.



(a) (b)

Figure 4.5: *Transition variability between (a) experienced and (b) novices [Underwood03]*

Another investigation of the eye movements sequence in longitudinal traffic has been carried out by [Underwood03]. He found a *preview pattern* between alternate fixations of close and far areas, so called lateral scanning pattern. It was shown that this pattern differs for novices and experienced drivers. [Underwood03] reported that it was possible to observe *individual patterns* as well. He found that the novices in general fixate longer and perform unnecessary eye movements. He also proved that experienced and non-experienced drivers have different variability of transitions. The transitions of glances in the horizontal plain happen always in the same manner for novices, where experienced drivers adopt their searching strategy to the driving situation. Different transitions variability between experienced drivers and novices on the rural road is illustrated in Figure 4.5.

One of the rare experiments analyzing the sequence of eye movements at intersections has been conducted by [Langham06]. He also observed differences between experienced and novices: he found that experienced drivers fixate fewer spots but wider areas than novices. The difference in the fixation sequence is also present. This is depicted in Figure 4.6, where the red boxes present the search pattern of experienced and blue boxes of novice drivers. The numbers in each of the boxes represent the order in which fixations were made.

The speed of scanning affects the safety as well. In [Plavsic10a] is shown that the best scanning speed is the moderate speed: too many saccades can lead to the suppression of visual perception, but too few saccades reflect inefficient searching strategies. The experiment dealt with the driver's erroneous behavior at intersections and it determined two different groups of drivers that caused an accident: subjects scanning the scene relatively slow and the ones that scanned the scene ineffectively fast.

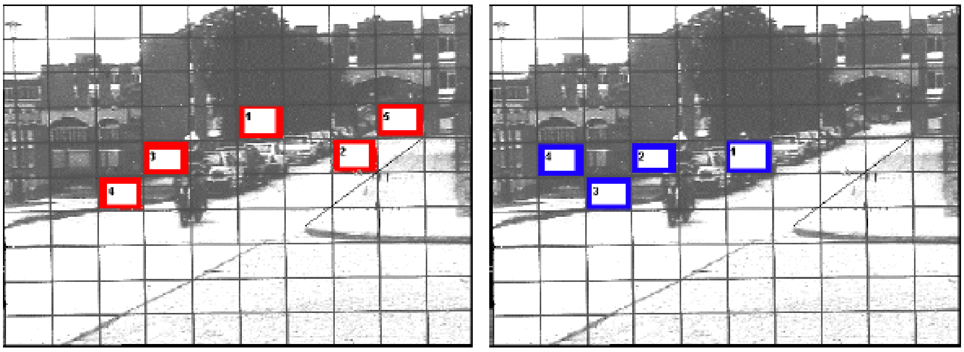


Figure 4.6: *Search pattern for experienced drivers (red boxes) and novices (blue boxes); the numbers in each of the boxes represent the order in which fixations were made [Langham06]*

4.3 Conclusion

In spite of deficiency of methods and techniques for recording the eye movements, the analysis of driver's glance performance present the best way to analyze and compare underlying cognitive strategies. It also enables the detection of erroneous behavior, which can lead to accidents. As the eye tracking technology improves, results of eye-tracking driving studies are changing. The majority of recently published studies are examining the effects of infotainment devices on the driving performance or finding out the best layout and location of on-board devices. Fewer studies are dealing with discovering general driving strategies and visual allocations. Among them, analysis of visual continuous tasks is fairly represented in the literature, but there is a general lack of studies dealing extensively with situation required gaze behavior, especially at intersections.

The presented literary overview shows that there are no systematic studies that analyze driver visual strategies at intersections. The most relevant issues for the research are: the prioritization of information, the influence of intersection characteristics on the applied visual strategies, the existence of individual searching patterns, and their variance. The answers on these question will contribute to the prediction of the driver errors and will enable more precise requirements on an ergonomic Intersection Assistance. The experiment reported in the next chapter has as an objective to concentrate more on these issues.

Chapter 5

Theoretical and Experimental Analysis of Driving Task at Intersections

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The demand for a systematic analysis of drivers' behavior at intersections has been argued in the previous chapters. This chapter reports on the theoretical and experimental study, which investigated the performance of 24 drivers in 10 different intersection scenarios in a fixed-base driving simulator. As previously discussed, the focus of the experiment is the observation of the applied visual strategies and the analysis of glance distributions. The driving tasks at intersections are first analyzed theoretically and then the difference between the theoretically ideal and naturalistic behavior is explored. The difference is determined by observing the omitted tasks and errors committed as well as by analyzing the distribution of attention. The investigated parameters are factors, which are determined in Chapter 3 to have the highest influence on the driver behavior: right of way, maneuver, the presence of the leading vehicle, and time pressure. The results revealed systematic deficiencies in drivers' behavior, which in rare circumstances may lead to accidents, and which require assistance support. By comparing the drivers' visual behavior in the baseline trial and under time pressure, the patterns of the individual performances were observed. Additionally, a comprehension of drivers' prioritization strategies at intersections is gained. The findings enable the determination of application scenarios and ergonomic requirements on an Intersection Assistance system.

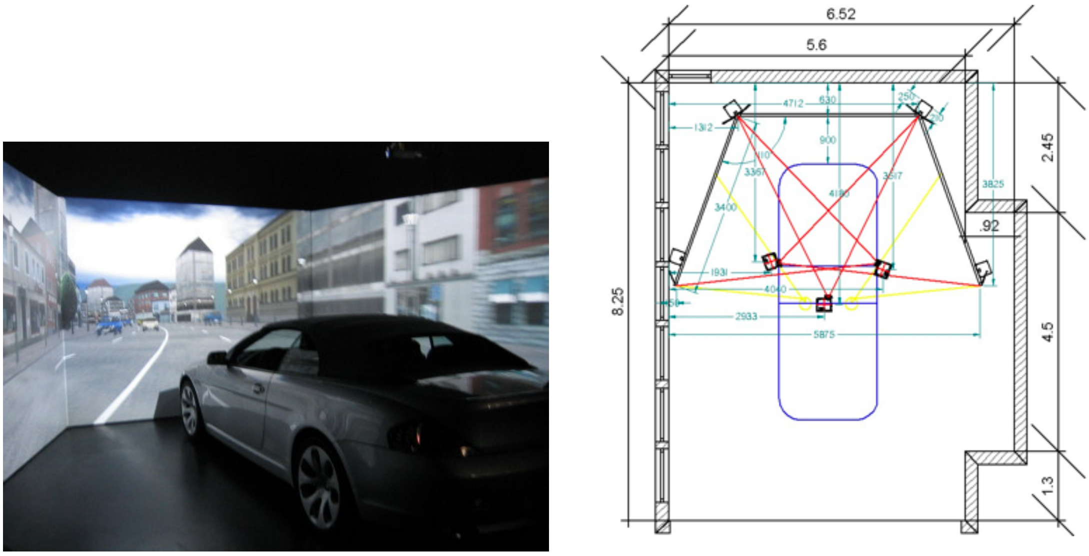
First, the apparatus and selected scenarios are presented, followed by the theoretic analysis of the driving task. This is done based on the classification of traffic scenarios and the driver cognitive model developed in Chapter 3. Subsequently, the study procedure and the most relevant experimental results are presented in the form of omitted tasks and committed errors. Conclusively, the suggestions for an Intersection Assistance system are given.

5.1 Apparatus

This section gives an overview on the hardware setup and software used for conducting the presented experimental study. First, a fixed-base driving simulator located at the Chair of Ergonomics, Technische Universität München is described. Afterwards, the eye-tracking system used to record and analyze the drivers' visual behavior is presented.

5.1.1 Driving simulator

The driving simulator is a mockup of a real vehicle, the E64 BMW 6th series convertible. The simulator and the surrounding projection walls are presented in Figure 5.1(a). To simulate the world around the car, three projection walls with three projectors displaying the surrounding scenery were used. Each projector has a dedicated computer with a high quality graphic card. The projection walls provide the driver with approximately 180° field of view. Figure 5.1(b) presents the projection walls and geometry of the mockup vehicle. To account for a contact-analog Head-Up Display (HUD), a fourth appropriately calibrated video projector is used.



(a) (b)

Figure 5.1: *The physical setup of the driving simulator at the Chair of Ergonomics (a) Mockup vehicle and projection walls, (b) Geometrical set-up*

The gas and brake pedals, steering wheel and infotainment devices are all elements taken from the real vehicle. They are connected and managed by the driving simulator software [SILAB]. This software also enables the implementation of arbitrarily, user-defined driver assistance systems. Some of them are implemented as a part of hardware like *Active Gas Pedal* or *Active Steering Wheel*, but are controlled directly by SILAB. The simulator also contains a built-in serial-production programmable $18x9$ cm HUD, which enables testing of different user interfaces for driver assistances.

Driving Simulator Software: SILAB

[SILAB] is software produced by Würzburg Institute for Traffic Sciences (WIVW). SILAB is PC-based and uses commercial, off-the-shelf hardware. It is written in C++ and it provides a flexible framework for implementation of different scenarios. SILAB also enables the arbitrary exchange of the look and feel of the environment. The architecture of SILAB allows for the flexible integration of external hardware and software components via CAN, UDP, and TCP protocols. SILAB is distinguished from other software by a very realistic impression of driving: it can simulate not only highways and rural scenarios but has also a very realistic simulation of urban scenarios and enables control over all traffic participants including pedestrians.

SILAB is extendable by customized components - so called *Data Processing Units (DPUs)*. It can also be extended by models developed within MATLAB/SIMULINK. Several *Application Programming Interfaces (APIs)* offer detailed access to the components of the simulation like database, the traffic simulation, and image generation, both during the simulation and offline. Apart from being observed, all the data and parameters can be also modified on the fly. In addition, all parameters can be automatically changed during the simulation depending on the driver's position on the road network. This is possible because of the modular way the scenery is loaded, which is a specific feature of SILAB. Hence, it is possible to adapt the sequence of the road to the behavior of the driver. This is applied, for example, for performance adaptive training.

Implementation of Scenarios in SILAB. SILAB allows users to define traffic scenarios by themselves. Scenarios can be implemented either by using a graphical editor or with a scripting language. Rural sections (called *Course sections*) are written using a scripting language where length, environment and traffic are defined directly in the script. Figure 5.2 shows an exemplary look of the rural and urban segment.

(a) (b)

Figure 5.2: *Exemplary scenery modeled with SILAB (a) rural road, (b) urban area*

Urban environments (called *Area2 sections*) are created by graphical editor. Intersection scenarios are designed in several steps. First, main infrastructure of the scene is layed out and the roads are attached to it. The profiles of the roads as well as the appearance of the surrounding (e.g., concrete, pavement, grass) can be chosen freely. The next step is to set objects around the scene like trees, rows of houses or passive cars. After that, the traffic can be inserted. At the end, trigger logic for controlling the traffic is implemented and tested. This presents the most demanding part of the implementation and is implemented by two mechanisms: *flowpoints* and *hedgehogs*. They allow the direct control over other vehicles like stopping, setting speed or accelerating and decelerating. Both mechanisms present invisible markers on the lane, which are activated when the subject vehicle drives over them. In this way, a self-defined variable is sent to be processed outside the simulation. A screenshot of an intersection traffic scenario designed in SILAB graphic editor is shown in Figure 5.3.

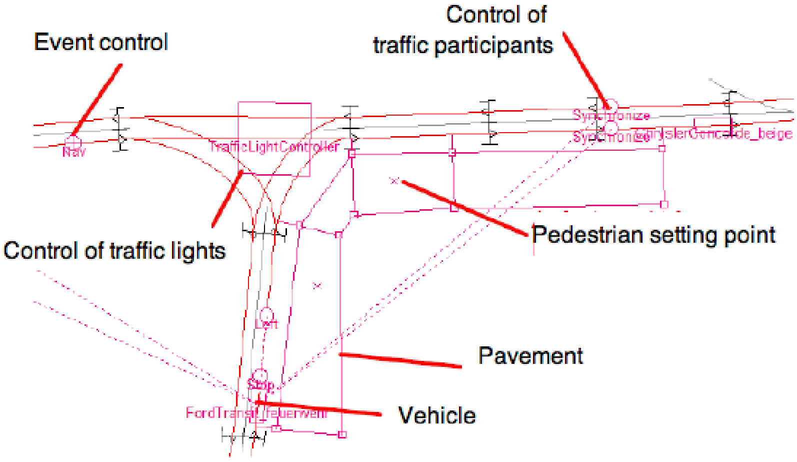


Figure 5.3: *Implementation of traffic scenario in SILAB graphic editor*

SILAB also allows the implementation of self-made objects, a feature, rare for the commercial driving simulator software. A lot of objects such as traffic signs, houses or people are already provided and can be arbitrarily placed in the scenery. The self-made object can be both 2D and 3D and can be imported in SILAB by using predefined DPU named *DPUSIGObject*. The objects can be inserted either as an overlay or as a transparent model. The main characteristic of imported objects is the definition of vertices and the definition of how these vertices are connected. Additionally, the texture and the color of the objects have also to be defined.

5.1.2 Eye Tracking System

The eye tracking system applied in the presented study is *Dikablis (Digitales Kabelloses Blickerfassungssystem)*. This is a head-mounted eye tracking system, developed as well at the Chair of Ergonomics at Technische Universität München [Lange06]. It consists of three elements: head unit, receiver and recorder. The head unit is shown in Figure 5.4 and it is equipped with two cameras that capture the images of the right eye, operator's field of view and the ambient sound. The receiving unit sends all three signals to the recording unit and writes them directly to the hard disk.

The software delivered with Dikablis enables the analysis of gaze data. It provides a graphic overlay

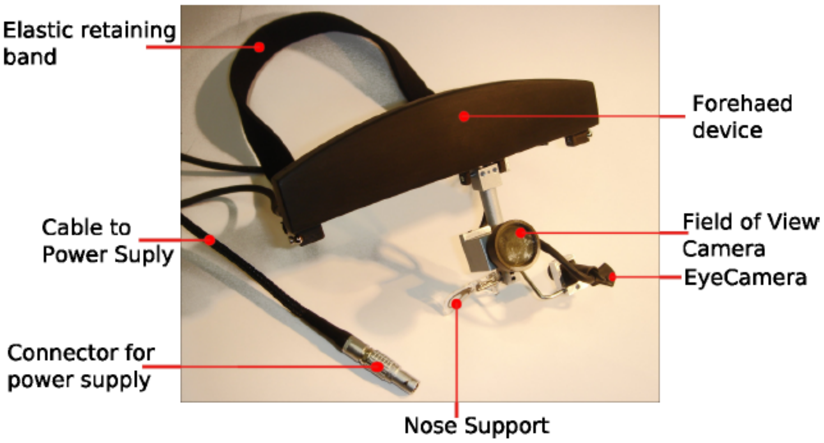


Figure 5.4: *Head unit of Dikablis eye tracking system [Ergoneers09]*

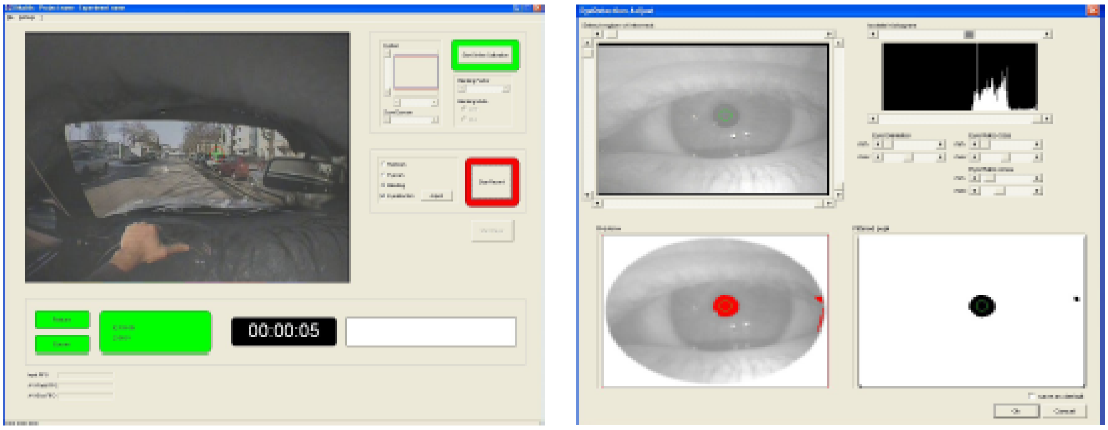
of the simultaneously recorded video streams of the eye and field-cameras. The screenshot of the *Graphical User Interface (GUI)* of the used software (Version 1.7) is presented in Figure 5.5(a). Figure 5.5(b)) shows a graphical user interface for the calibration of the gaze data. The software enables online and offline calibration for better pupil recognition.

The recorded data is saved in a *Journal file* that can be opened with a text editor or spreadsheet program. The glance data is written in the journal file with a frequency of 40 Hz, where each row represents one glance. This means that every 25 ms the glances data are recorded in the file. The journal file can be used for the offline analysis of glances by defining so called *Triggers*. Triggers are used to count the occurrences of certain events or to count the time between two of such events. The event can be a glance at a traffic sign or at any other *Area Of Interest (AOI)*. To each trigger a keyboard key can be dedicated. For example, the fixation on the traffic sign is presented by a key T. When the subject fixates on the traffic sign this key is once pressed. The second press of the key T should be done when the gaze move away from the traffic sign. In this way, a new column is added to the journal file and the title of the column is the key letter or the number, which activates the trigger. Between the two presses of T key, each row of the column is filled with 1, otherwise it has a value of 0. In this way a semi-automated analysis of video data is possible.

A disadvantage of Dikablis is the huge amount of time needed for the evaluation of video data. The version of Dikablis software (Version 1.7) used for this experiment is an older version and time needed for analysis of one video is around five to six time longer than the duration of the recorded sequence. This is improved by the newer version of the software, which enables more automated analysis.

5.2 The Objective and Selected Scenarios

The objective of the presented study is to analyze the drivers' visual behavior in selected intersection scenarios. The investigated influences are: right of way, maneuver, the presence of a leading vehicle, and time pressure. The choice of parameters is done based on the analysis in *section 3.3.4*. They are



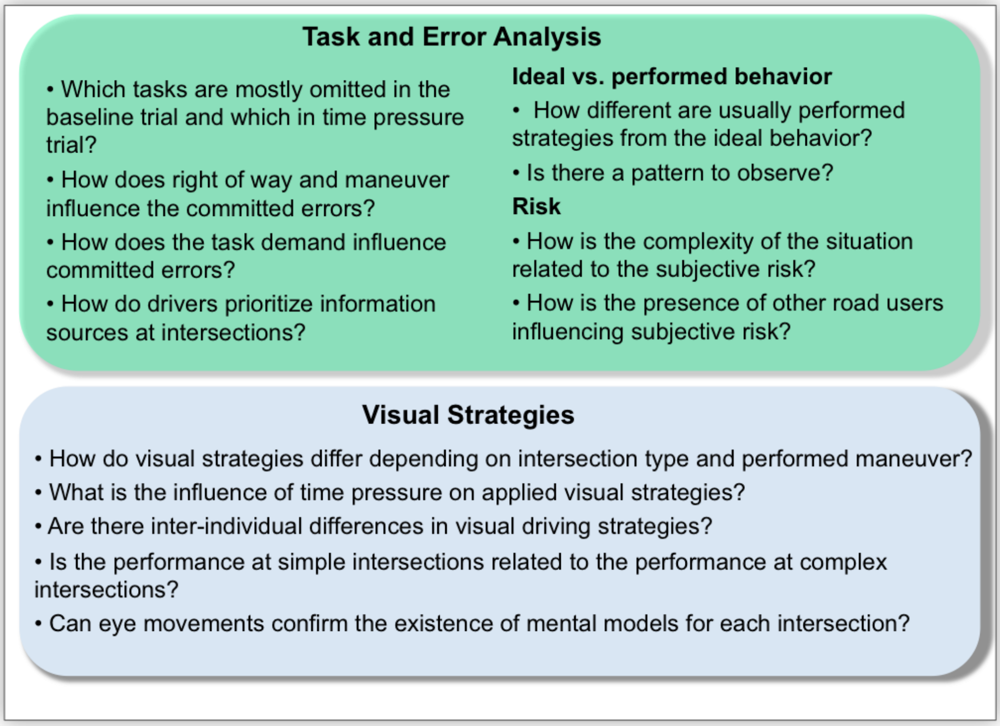
(a) (b)

Figure 5.5: *Dikablis GUI for the analysis of gaze-tracking data (Version 1.7) (a) Overlay of field and eye camera, (b) GUI for the calibration of pupil recognition*

chosen as the most influential factors on the driver's behavior, which have not been experimentally analyzed in a systematic manner yet. The study investigates the influence of these factors on the applied visual strategies and the difference between naturalistic and the ideal driver behavior. The study of [Bengler96] showed that drivers show the same qualitative behavior of the viewing strategies in the driving simulator and the field when negotiating curves. The observed difference is most probably the consequence of the lack of lateral acceleration in the simulator the and thereupon different stabilization strategies. Hence it can be assumed that the visual behavior in the driving simulator and field shows even higher similarity for intersections. The quality analysis of the difference between the visual behavior in the baseline trial and under time pressure gives information whether the same drivers apply the same strategies in same situations. Of interest are the individual behavioral differences and specific visual behavior, as exactly the individually specific behavior can reveal relevant information about causes of accidents. Also, special attention is paid to the individual performance of the drivers and whether the visual behavior at simple intersections relates to visual behavior at complex intersections.

Figure 5.6 summarizes the most relevant questions for this study. The questions occupy the general task analysis of the resulting behavior and the visual behavior specific questions. The given questions in Figure 5.6 present general and basic inquiries regarding the performance of intersection task. Their objective is to detect the most relevant influences and to drive the direction of the future research. The answers on these issues are of essential importance for determining the adequate functionality of the Intersection Assistance system.

To test selected influencing factors, appropriate intersection scenarios have to be applied. The experience from the pilot experiment has shown that the number of urban intersections within the applied driving simulator should not exceed twenty per test run. A higher number of intersections results in a higher probability for the occurrence of simulator sickness. Pilot experiments conducted within the work of [Duschl08] have shown that subjects experience sickness more in urban than in rural



Task and Error Analysis

- Which tasks are mostly omitted in the baseline trial and which in time pressure trial?
- How does right of way and maneuver influence the committed errors?
- How does the task demand influence committed errors?
- How do drivers prioritize information sources at intersections?

Ideal vs. performed behavior

- How different are usually performed strategies from the ideal behavior?
- Is there a pattern to observe?

Risk

- How is the complexity of the situation related to the subjective risk?
- How is the presence of other road users influencing subjective risk?

Visual Strategies

- How do visual strategies differ depending on intersection type and performed maneuver?
- What is the influence of time pressure on applied visual strategies?
- Are there inter-individual differences in visual driving strategies?
- Is the performance at simple intersections related to the performance at complex intersections?
- Can eye movements confirm the existence of mental models for each intersection?

Figure 5.6: *Relevant aspects and questions of interested for the conducted study*

environments probably because of the high immersion of the virtual world. For testing the influence of time pressure, a drive through each intersection has to be accomplished twice. For this reason, ten representative intersection scenarios have been selected by the deduction principle concerning analyzed aspects: right of way, maneuver, and the presence of the leading vehicle.

For the comparison of the behavior when in right of way and when having minor priority, two exemplary regulations are selected: the regulation by traffic sign *Right of way* and by traffic sign *Yield (Give way)*. The intersections regulated by traffic lights are not considered. This is done for three reasons: first, as shown in *section 3.3.4*, the driver behavior regarding the traffic lights has been extensively researched. The second reason is that the duration of the yellow phase, as the most influential parameter concerning traffic lights, would need to be taken into account as a separate variable and this fact would displace the focus of the work. Also, the situation in which traffic lights are in the green phase does not differ too much from the situation regulated by *Right of way* traffic sign. The red phase of traffic lights corresponds to the simpler version of the *Stop sign* regulation. The third reason for omitting the traffic lights from the analysis is that by comparing the right of way between intersections, which are all regulated in the same manner, here by traffic signs, involves less variability.

Therefore for both types of traffic signs: *Right of way* and *Yield (Give way)*, a scenario is designed in SILABEdit program as described in *section 5.1.1*. This is done for all three maneuvers: crossing, right turn and left turn. Three criteria are followed when designing the scenarios: first, they should have the highest demand on the driver, second, they should be designed so that the comparison

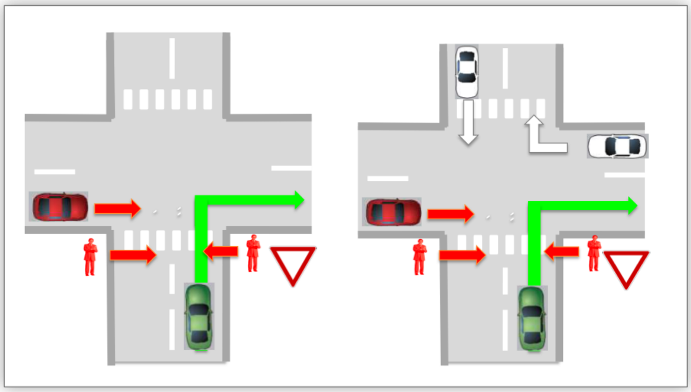
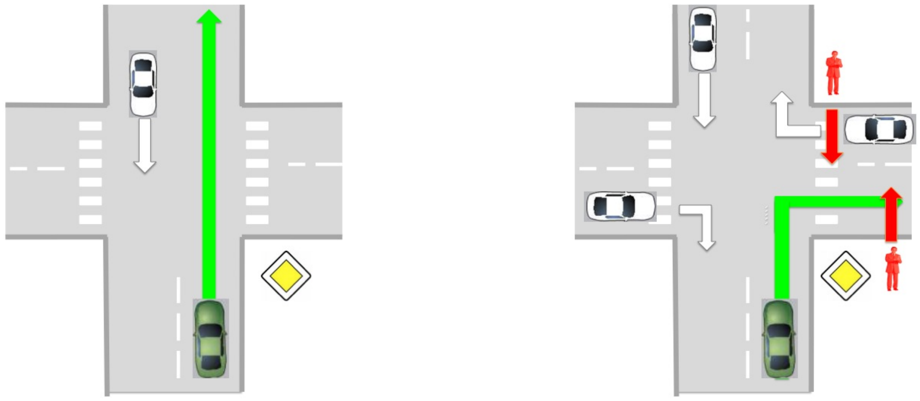
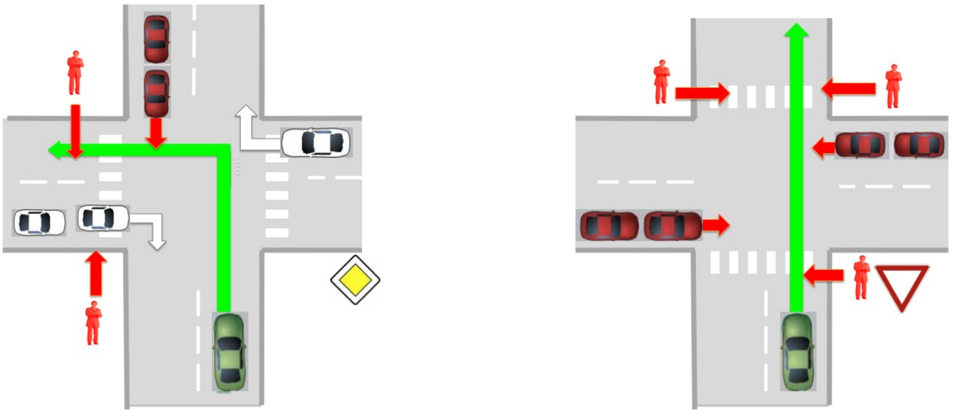


Figure 5.7: *An example of scenario design approach. The subject vehicle is depicted by green car and has the task to turn right. In the design process first traffic participants in right of way are integrated (picture left) and then traffic participants who are not on the collision trajectory with the subject vehicle (picture right)*

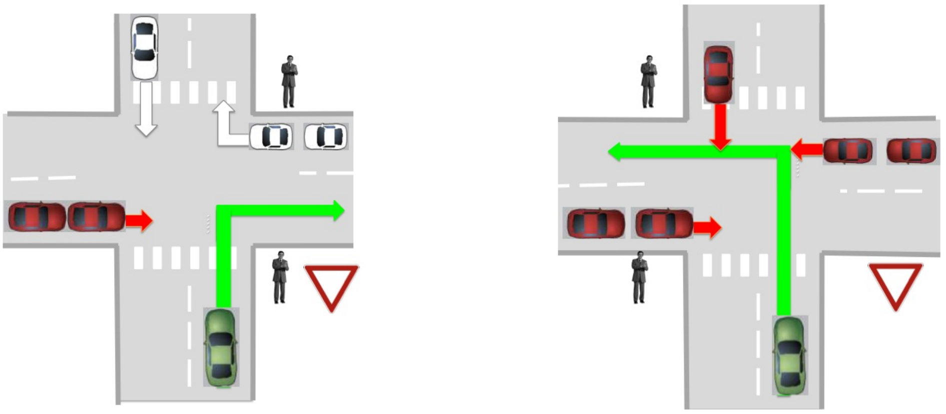
among them have as few variables as possible and third, they should be as realistic as possible. To fulfill the criteria, all traffic participants who are in right of way are present in the scene, except when they have to be omitted for comparison reasons. Additionally, several ”neutral” traffic participants are included in the scenario, which are not on the collision course with the subject vehicle. They are named ”neutral” traffic participants because objectively they do not increase the task demand. For the reason of simplicity, the participants not having right of way are excluded. An example of the scenario design approach is given in Figure 5.7. The subject vehicle is depicted by the green car and it executes the right turn from the minor street. First, road users having right of way (painted in the red color) are integrated into the scene and then participants who are not on the collision trajectory with the subject vehicle are added (white vehicles). Here it is important to understand that all road users behave according to the traffic rules.



(a) Scenario 1 - C4-K3-F0 (b) Scenario 2 - C4-K3-F1



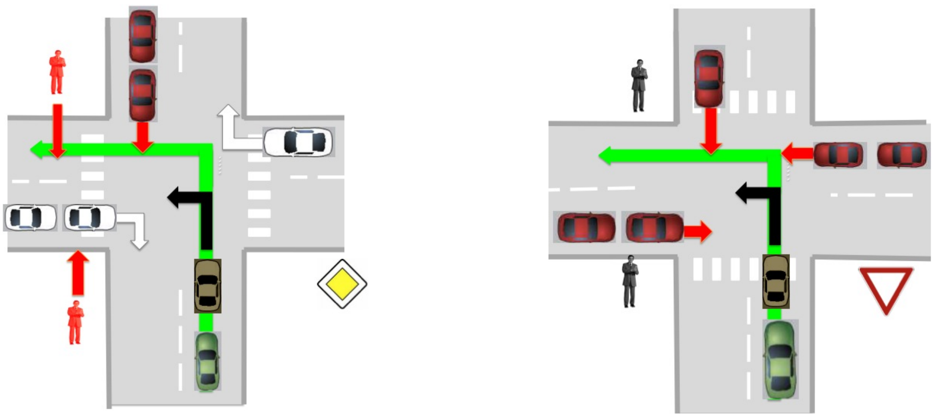
(c) Scenario 3 - C4-K3-F2 (d) Scenario 4 - C4-K4-F0



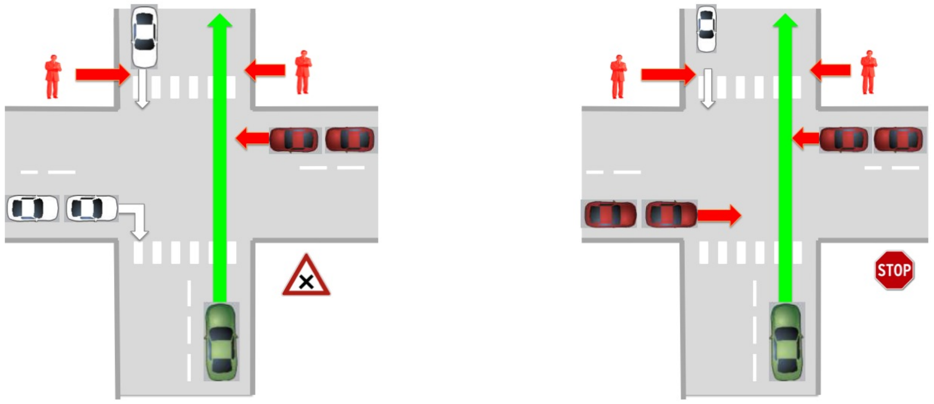
(e) Scenario 5 - C4-K4-F1 (f) Scenario 6 - C4-K4-F2

Figure 5.8: *Chosen scenarios: three maneuvers when in right of way and three maneuvers performed from minor street (taxonomy from Table 3.2)*

To six resulting scenarios (*2 right of way x 3 maneuver*), four additional scenarios are added. Two scenarios include the leading vehicle and they both present the left-turn maneuver. The other two



(a) Scenario 7 - C4-K3-F2 (b) Scenario 8 - C4-K4-F2



(c) Scenario 9 - C4-K2-F0 (d) Scenario 10 - C4-K5-F0

Figure 5.8: *Chosen scenarios: two scenarios with the leading vehicle, one unordered intersection and one intersection scenario regulated by Stop sign (taxonomy from Table 3.2)*

scenarios are intersections regulated as unordered intersection and intersection regulated by *Stop sign*. They are included in order to compare two more ways in which the intersection is regulated. The *Stop sign* should simplify the driving task in comparison to the *Yield* traffic sign as it relieves the driver of the decision whether to stop or not. All ten selected scenarios are presented in Figure 5.8. The detailed description and unfolding of scenarios are provided together with the presentation of results.

All scenarios are implemented with the same geometrical properties: they are one-carriageway intersections with the lane width of $3,50$ m and a crossing angle of $90°$. More complex scenarios would not provide more significant information beyond what is already available in the analyzed configuration regarding the stated objective. In the work of [Wiltschko04], it is shown that the distribution of accidents between different intersecting roads (C1 to C4) is similar. Also, parameters like visibility, occlusion or curvature are not considered in order to reduce variability. It is already known that they systematically increase the task demand and of interest to this study are the factors, which are not clear whether they increase or decrease the demands of the tasks.

Scenarios are grouped for comparison, based on their characteristics: (1) right of way, (2) maneuver, (3) the presence of the leading vehicle, and (4) the presence of ”neutral” road users. Additionally, all scenarios are compared with each other regarding the subjectively experienced risk and task demand. The grouping of scenarios is given in Appendix A.

5.3 Theoretical Analysis

To compare the scenarios as accurately as possible, each intersection is divided into segments. The current section first explains the way this is done. For comparison of the resulting behavior to the ideal one, the normative visual behavior is subsequently defined, and finally it is reported on the conducted theoretical visual and error analysis as well as on theoretical evaluation of task demand.

5.3.1 Theoretical Task Analysis

The task analysis is a methodical procedure, which aims to describe the specific, goal-driven human-machine interaction. It consists of a systematic analysis and breakdown of an activity into a series of less complex task by defining the goal of each task [Kirwan92]. In this way, given the task, the actions that should be performed to achieve the particular outcome state can be determined. Accordingly, the structure and the sequence of subtasks required to achieve a particular goal can be analyzed, together with the manner of how these tasks are to be accomplished. The key benefit of using the task analysis approach is that it provides specific information about driver’s activities at various points in time. This is not achievable by using other approaches like accident analysis. The task analysis is also helpful for the development of the computer simulation of the driver’s behavior. By breaking down tasks into simple rules that are to be followed, these rules can be directly used to simulate the normative behavior of the driver. The analysis can then identify the deviation of the performed behavior to these rules.

The driving task at intersections consists of multiple subtasks. Each of these subtasks has to be accomplished in a particular span of time and space. It is of interest to analyze how precise should these spans be defined and on what do they depend upon. When negotiating an intersection, there are many tasks that the driver has to perform and they cannot be strictly divided into sub-tasks. Some of them have and should be executed in parallel and some of them exclude each other. Therefore a level of detail should be chosen that could be analyzed efficiently. It is decided to divide crossing and left turn maneuvers into five segments, and the right turns into four. This is done based on the driver cognitive model for intersection task presented in *Chapter 3*. By chosen division, each of the segments is characterized by subtasks that are all leading to one goal, and in each segment one conscious decision has to be made. Also, the five segments can be considered as a compromise between too many segments, which complicate the analysis and too few segments, which can falsify results. An example of the division in segments for all three maneuvers is shown in Figure 5.9. The first scenario is divided into following segments:

- *Approach*,

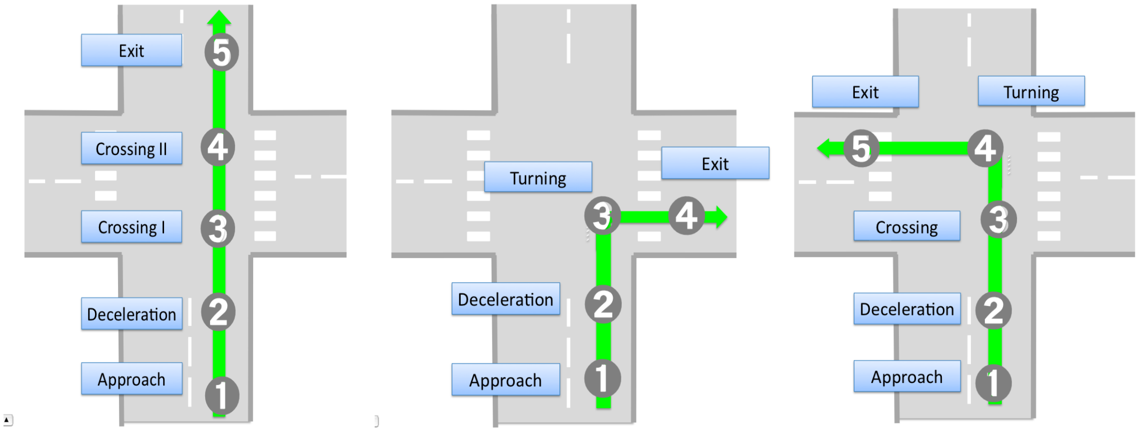


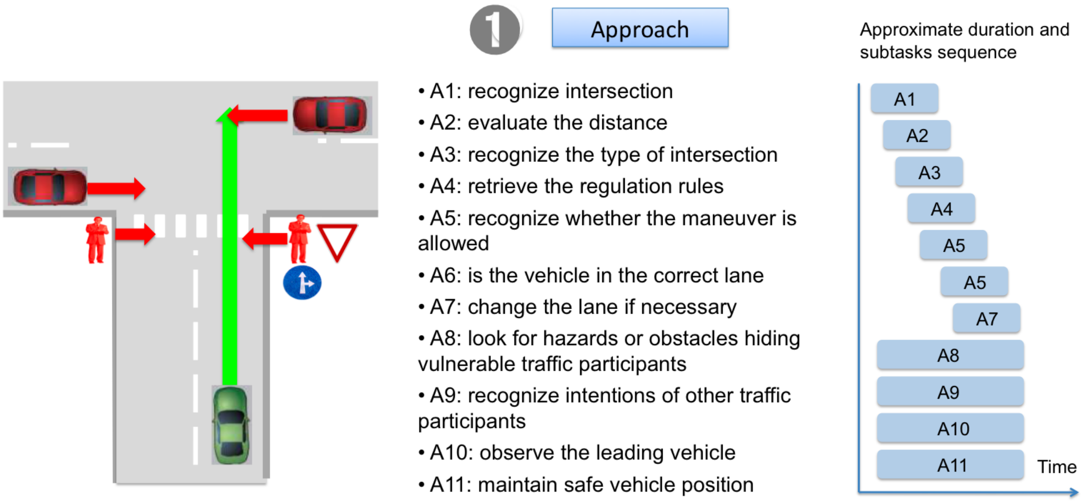
Figure 5.9: *An example of the intersection segmentation for task analysis: Approach, Deceleration, Crossing, Turning and Exit. Each segment is characterized by subtasks that are all leading to one goal and in each segment one conscious decision has to be made.*

- *Deceleration*,
- *Crossing I*,
- *Crossing II*, and
- *Exit*.

The *Approach* segment is defined from the moment the crossing is visible up to 3 s before the junction. By choosing a fix value for the start of *Deceleration* segment, the same duration for all the segments is assured and the more correct comparison can be made. The value of 3 s is chosen as time when drivers on average start pressing the brake pedal when approaching intersection [VanderHorst07], [Harsenhorst88]. The other segments are geometrically separated from each other, as in these segments the geometry dictates the tasks and decision to be made. *Crossing I* starts with the crossing roads and ends at the middle of intersection, before the second crossing lane. *Crossing II* has the length of the second crossing lane and *Exit* segment starts at the end of the junction area and ends 2 s after.

The objective of each phase and the corresponding decision to be made is described in the following. For each segment further subtasks that are to be committed are defined. There are tasks that are common for all segments like keeping the lane and there are tasks that are segment specific and depend on the executed maneuver. Here the assumption is not that all the tasks will be committed, but the task analysis is taken as an indicator to what should be done. The tasks to be realized in each segment are analyzed in more detail on the example of *Scenario 4* from Figure 5.8.

Approach phase. For safe performance at intersections, it is necessary to recognize an intersection, its type, and regulation already in the approach phase. The early recognition is directly connected to the choice of correct strategy. As mentioned in *Chapter 3*, [Williams08] found that the difference between experienced drivers and novices is present already in the approaching phase. The experienced drivers choose significantly lower speeds than the novices.



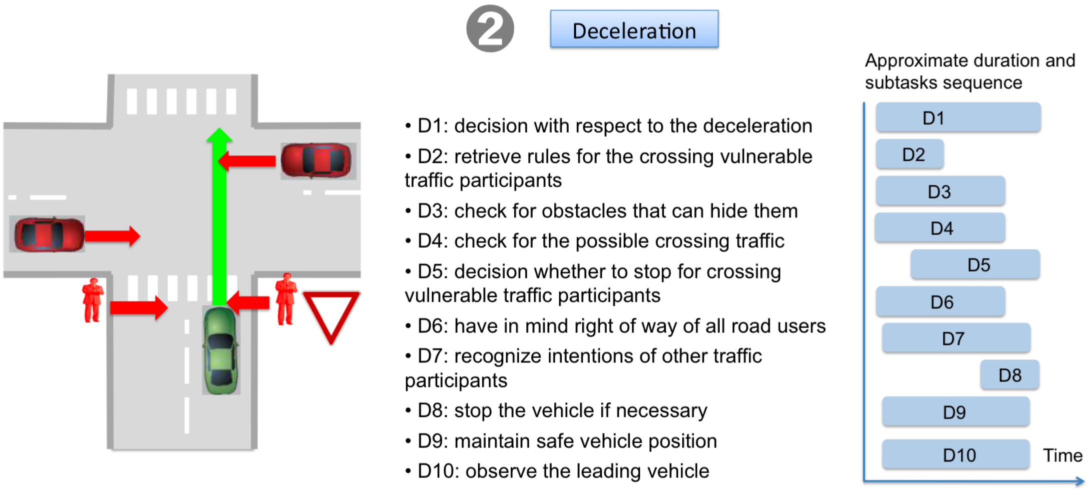
- A1: recognize intersection
- A2: evaluate the distance
- A3: recognize the type of intersection
- A4: retrieve the regulation rules
- A5: recognize whether the maneuver is allowed
- A6: is the vehicle in the correct lane
- A7: change the lane if necessary
- A8: look for hazards or obstacles hiding vulnerable traffic participants
- A9: recognize intentions of other traffic participants
- A10: observe the leading vehicle
- A11: maintain safe vehicle position

Figure 5.10: *The exemplary Approach phase, subtasks that are to perform, their approximate duration and sequence*

The subtasks within the approach phase have as the common objective to identify the intersection and its regulation as well as its surrounding. The subtasks of the guidance level that should be realized within this phase, their approximate sequence and duration are presented in Figure 5.48. The driver has first to recognize that an intersection is coming up. At the same time the distance to intersection is to be evaluated. Meanwhile, the driver should look for the intersection type and decide whether the intersection belongs to the familiar places or not. By recognizing the type of intersection, the driver assures whether the desired maneuver is allowed and whether he has a priority. It is considered here that the driver is relieved from the navigation task, by for example a navigation system. In case of not driving in the correct lane, the driver has additionally to change to the appropriate lane. In the implemented scenarios this is not the case as there are no dedicated lanes for maneuvers. Simultaneously, the driver has to look for hazards, to monitor and recognize the intentions of the other traffic participants, and to adapt the behavior accordingly.

The temporal measure that describes the approaching phase is *Time To Intersection (TTI)*. TTI represents the time that is left before the intersection is reached. Expressed in meters, this results in *Distance to Intersection (DTI)*. [vanderHorst90] suggested three additional, widely accepted parameters: TTI_{br}, TTI_{min} and TTI_{1st}. TTI_{br} presents the time of beginning of the braking and is characterized by moving away the foot from the gas pedal. TTI_{1st} is the time when the driver makes the first head movement and TTI_{min} is the minimum point of the TTI curve. The typical approaching speed at intersection is between 25 and 40 km/h. A detailed analysis of approaching speeds can be found in [Scheuchenpflug04], based on field experiments. Further temporal values concerning the normative behavior can be found in detail in [Reichart00]. He calculated the necessary distances and visibility requirements regarding the comfortable deceleration values.

Of interest for this study are however not the dynamic values, but inter- and intra-individual differences in visual driver behavior regarding defined tasks.



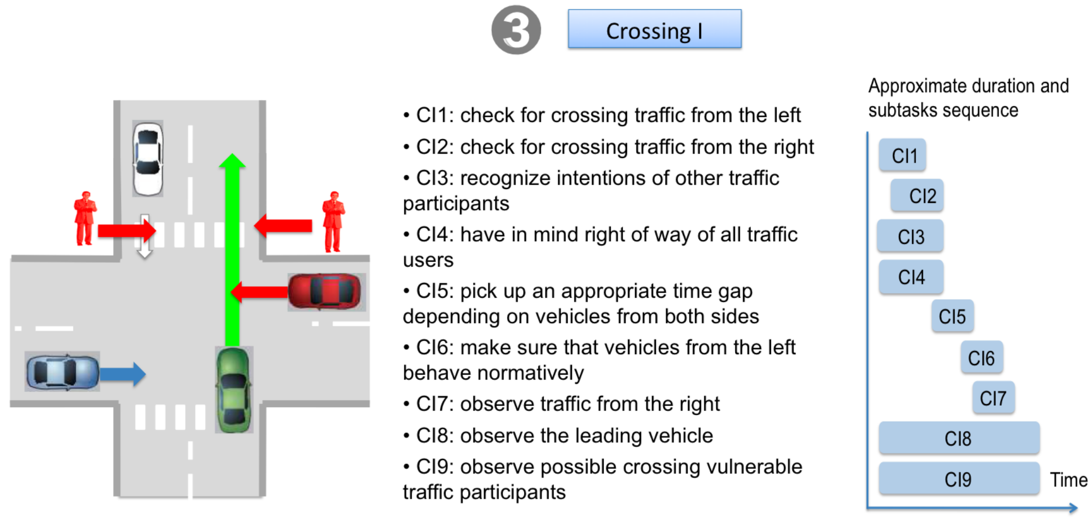
- D1: decision with respect to the deceleration
- D2: retrieve rules for the crossing vulnerable traffic participants
- D3: check for obstacles that can hide them
- D4: check for the possible crossing traffic
- D5: decision whether to stop for crossing vulnerable traffic participants
- D6: have in mind right of way of all road users
- D7: recognize intentions of other traffic participants
- D8: stop the vehicle if necessary
- D9: maintain safe vehicle position
- D10: observe the leading vehicle

Figure 5.11: *The exemplary Deceleration phase, subtasks that are to conduct, their approximate duration and sequence*

Deceleration phase. The deceleration phase starts theoretically the moment the driver moves the foot off the gas pedal and ends at the beginning of the junction area. To have a fixed duration of deceleration phases, for comparison among scenarios, the *Deceleration phase* in this work is defined to start at TTI = 3 s. The objectives of this phase are the decisions whether to stop until intersection entry and/or how hard to decelerate. During this phase the driver has to observe the present traffic and to look for the specific features characterizing the intersection. Based on perceived features and objects, the driver forms expectations about behavior of the other road users and retrieves the strategy for the maneuver. In parallel, the driver should look for obstacles that can hide vulnerable traffic participants, monitor them, and recognize their intensions. Based on that, the driver should decide whether to stop to give way to the crossing vulnerable participants on the pedestrian crossing and whether the crossing traffic require an additional halt a few meters after. The Figure 5.11 presents tasks that should be completed in this phase and their approximate time sequence.

Even though dated, the studies from [Harsenhorst88] and [vanderHorst90] give one of the most detailed available analyses regarding the braking strategies when approaching intersection, based on the field experiments. Unfortunately, not too many newer works deal with such analyses and even the recently conducted studies still refer to values from [Harsenhorst88] and [vanderHorst90]. Some newer but not that detailed findings can be found in [Sato07] or in publications of [Perez04] and [Doerzaph04], which present the condensed results from the 100-car naturalistic driving study [Dingus06].

The findings from [Harsenhorst88] and [vanderHorst90] comply with each other. They both found that braking starts at about the same point independent of the type of maneuver. The braking profile consists of three phases: (1) applying a pressure to the brake until the maximum position is reached, (2) keeping the brake at the maximum position, and (3) releasing the brake. There are two braking maxima while approaching the intersection and the brake pressure between them is constant. The intersection entry speed is achieved by timing the braking actions and not by varying the pressure



- CI1: check for crossing traffic from the left
- CI2: check for crossing traffic from the right
- CI3: recognize intentions of other traffic participants
- CI4: have in mind right of way of all traffic users
- CI5: pick up an appropriate time gap depending on vehicles from both sides
- CI6: make sure that vehicles from the left behave normatively
- CI7: observe traffic from the right
- CI8: observe the leading vehicle
- CI9: observe possible crossing vulnerable traffic participants

Figure 5.12: *The exemplary Crossing I phase, subtasks that are to conduct, their approximate duration and sequence*

on the brake. [Harsenhorst88] also found that there is a nearly constant deceleration for minor (-1.0 m/s^2), medium and major ($-.70$ m/s^2) intersections. The deceleration is not completely constant since there is an instance where the acceleration pedal is released but the brake pedal is not yet pressed and it takes a while for the brake pressure to reach its maximum.

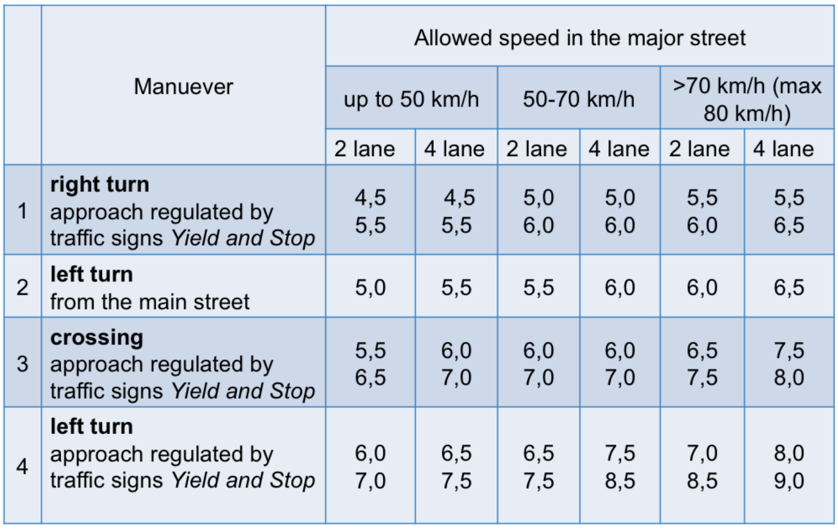
Distance to Intersection (DTI) is used as a cue for the moment the driver starts to apply pressure on the brake. [Harsenhorst88] found that the first braking moment is not affected by the type of intersection or maneuver when using DTI as a cue. The same experiments have shown that drivers usually start breaking at DTI of 10 m to 20 m. It seems that when approaching a major intersection drivers have a fixed desired speed, reducing the number of decisions that need to be made. [Harsenhorst88] also found that at major and intermediate intersections deceleration occurs 7 to 9 s or 75 m before reaching the intersection. At minor intersections deceleration occurs just before crossing the intersection with pretty constant TTI of 3 s. This is also confirmed by findings of [vanderHorst90]. With the reaction time being 1 s, the decision to brake is around 4 s of TTI.

Thus, it is concluded that there is a stable speed-control pattern, depending on the type of intersection. Of the interest here is to find out whether such a pattern also exists for visual behavior.

Crossing I phase. The *Crossing I* phase corresponds to driving over the first crossing lane. Depending on the right of way and regulation, it either starts after the driver has stopped or exactly at the junction area of intersection. The decision to be made in this phase is a choice upon appropriate time gap between the crossing traffic. The time gap is defined as the time between the passing of the rear of the leading vehicle and the front of the following vehicle over the same point on the roadway lane.

Figure 5.12 gives the tasks that should be accomplished for safe crossing and their time sequence in this phase. Independently of whether the driver stopped in the previous phase, in this phase he has

Table 5.1: *Safe time gaps for intersections depending on the speed and maneuver [Sammer08]*



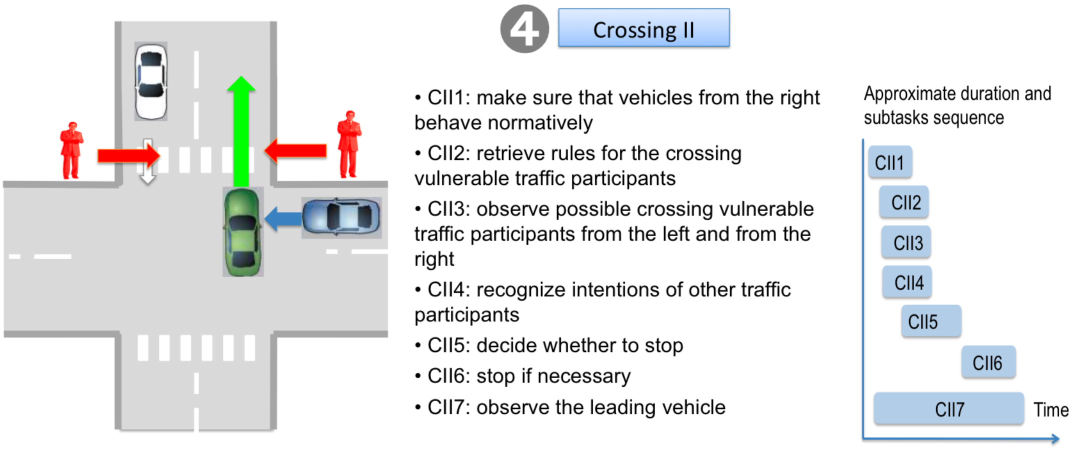
	Manuever	Allowed speed in the major street					
		up to 50 km/h		50-70 km/h		>70 km/h (max 80 km/h)	
		2 lane	4 lane	2 lane	4 lane	2 lane	4 lane
1	**right turn** approach regulated by traffic signs *Yield and Stop*	4,5 5,5	4,5 5,5	5,0 6,0	5,0 6,0	5,5 6,0	5,5 6,5
2	**left turn** from the main street	5,0	5,5	5,5	6,0	6,0	6,5
3	**crossing** approach regulated by traffic signs *Yield and Stop*	5,5 6,5	6,0 7,0	6,0 7,0	6,0 7,0	6,5 7,5	7,5 8,0
4	**left turn** approach regulated by traffic signs *Yield and Stop*	6,0 7,0	6,5 7,5	6,5 7,5	7,5 8,5	7,0 8,5	8,0 9,0

to monitor the traffic from the left and right and to pick up the appropriate time gap from both sides. In the moment the driver has picked up a gap, he should assure that the vehicles from the left have noticed him and that they behave normatively. On an example in Figure 5.12, the vehicle from the left side has the blue color because in the moment the subject vehicle starts crossing the main street, the blue vehicle should yield to the subject vehicle. Simultaneously, the driver should anticipate the behavior of the vehicles from the right lane and of the crossing vulnerable traffic participants.

[Harsenhorst88] found that the entrance speed at major intersections is not determined by the type of maneuver and that it is about 17 km/h. Details about the normative values of acceleration in the entry phase of intersection can be found in [Reichart00] as well. [Schweigert03] quotes [Pfleger94] who found that the speed evaluation as well as time gaps are worse on the left than on the right side. He explains this phenomenon with the fact that for the right side driving, an angle from the left side to the crossing traffic is sharper, so that the object coming from the left is detected by its change in size, which is easier to detect than a change in position.

The choice of time gaps has been thoroughly researched in field experiments in [Williams08] and [Vollrath04]. In general, the longer the waiting time is, the shorter the accepted time gaps are. They are also shorter with the busier traffic. Also the lower the allowed speed was, the shorter the accepted time gaps were. [Williams08] found that for a gap length interval of 4 to 4.5 s, conservative drivers refused all gaps, while the sporty ones accepted 40% of them. The percentage of accepted gaps for the gap length intervals between 4.5 and 6 s was higher. [Sammer08] analyzed the safe time gaps for all the type of maneuvers and intersections. He found that they lay in the range from 4 to 9 s. The results of the analysis are shown in Table 5.1. As shown, the safe time gaps do not depend on the number of lanes for the right turn. For the crossing and the left-turn the time gaps are increased with the width of intersection.

The existence of the detailed data about drivers' dynamic behavior enable the focus of this study to



- CII1: make sure that vehicles from the right behave normatively
- CII2: retrieve rules for the crossing vulnerable traffic participants
- CII3: observe possible crossing vulnerable traffic participants from the left and from the right
- CII4: recognize intentions of other traffic participants
- CII5: decide whether to stop
- CII6: stop if necessary
- CII7: observe the leading vehicle

Figure 5.13: *The exemplary Crossing II phase, subtasks that are to conduct, their approximate duration and sequence*

be on the information perception and processing in this phase, rather than on the faulty decisions of the driver when choosing the time gaps. Therefore it is analyzed for this phase whether the drivers check simultaneously for the vehicles on both sides, how many glances is given to each direction, when are these glances omitted and how this behavior depends on the intersection characteristics.

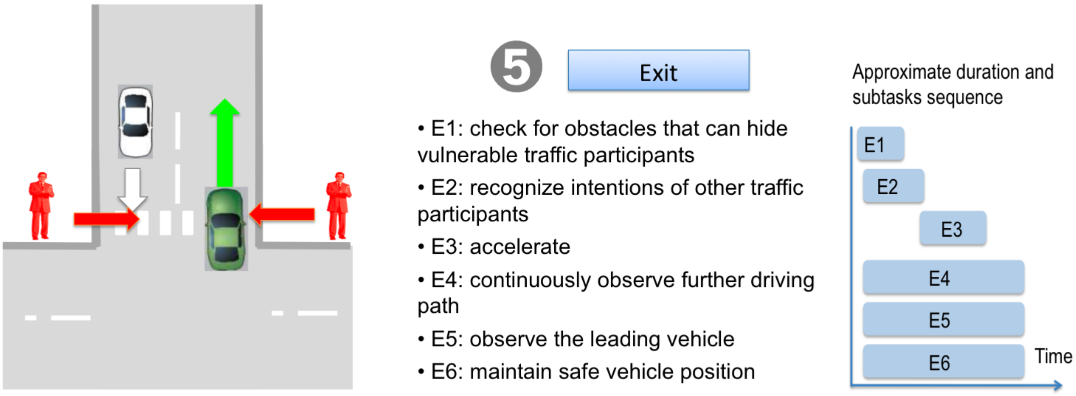
Crossing II phase. The *Crossing II* phase corresponds to the second part of crossing the junction. It starts at the middle of intersection and ends either when driver stops to yield the crossing pedestrians or when he leaves the junction area. The majority of drivers decide whether to cross intersection already in the *Crossing I* phase. Just in case of incorrect evaluation it is sometimes necessary to stop at the middle of intersection and to give way the traffic from the right. In any case, the driver should observe whether the accepted time gap is enough for the traffic from the right lane as well. At the same time the driver should anticipate the behavior of the crossing vulnerable participants and decide whether it is necessary to stop at pedestrian or bicycle crossing. The possible time sequence and duration of these tasks is depicted in Figure 5.13.

The questions that are analyzed for this phase are the same as for *Crossing I* phase.

Exit phase. In this phase the subject vehicle has an objective to leave the intersection area and to accelerate to full speed. Still, this should be done carefully as there can be participants crossing close but not exactly on the pedestrian street crossing. The acceleration should not be too fast and the driver should continue observing for possible hazards. The tasks that should be realized in this phase and their time sequence is presented in Figure 5.14.

5.3.2 Analysis of Visual Behavior

For a meaningful analysis of the visual behavior it is not sufficient to only measure the various visual parameters. It is more worthwhile to analyze whether the resulting visual behavior belong to critical or normative driver behavior types and whether these parameters are of critical or non-critical values.



- E1: check for obstacles that can hide vulnerable traffic participants
- E2: recognize intentions of other traffic participants
- E3: accelerate
- E4: continuously observe further driving path
- E5: observe the leading vehicle
- E6: maintain safe vehicle position

Figure 5.14: *The exemplary Exit phase, subtasks that are to conduct, their approximate duration and sequence*

In the study of [Bengler96], the visual behavior in the simulator and field when negotiating curves was compared to each other and it was found that they are in the quality the same, except for the differences in the viewing angles and the fixations of the opposite lanes tangent point in the simulator, which can be explained as the compensations for the missing lateral acceleration. As for the intersections, it is expected that the similarity between the simulation and real world viewing strategies is even higher as the lateral acceleration plays less role. The majority of studies that analyze drivers' visual behavior restrict on giving absolute values of visual performance, but they rarely define what is critical and what non-critical behavior. The precondition for judging critical behavior is a definition of the normative visual behavior. More fundamentally, it should be cleared whether a normative visual behavior for intersections can be determined with sufficient precision.

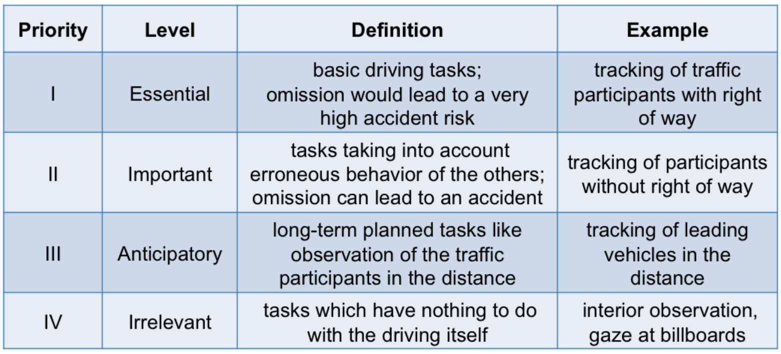
[Schweigert03] explored this question in a more detail. He applied the categorization of driving situations from [Reichart00] presented in *section 3.1*. This categorization distinguishes between tasks that are to be fulfilled always *(following lane* and *choice of the speed)* and tasks to be fulfilled only in particular situations *(reaction on obstacles* and *behavior at intersections)*. Based on this, [Schweigert03] divided visual tasks into three categories:

- continuous control of movement of the subject vehicle (mostly done by peripheral view),
- continuous anticipation of behavior of other traffic participants (explorative scanning behavior, possible only with foveal vision), and
- situation required eye movements (visual behavior at intersections or reactions on obstacles).

For continuous control and anticipation, there are multiple adequate visual strategies. But with growing relevance of a foveal vision, increasing time pressure, and the complexity of the situation, the time span in which fixations, gazes and saccades are to happen is getting narrower and the variance of correct visual behavior is decreasing. According to [Cohen90], an analysis of gaze behavior for the detection of cognitive processes makes sense only when the requirements on the driver are high and the driver has to use full cognitive capacity.

Another relevant aspect for defining what is the normative visual strategy is the importance of visual tasks. [Schweigert03] distinguishes between four categories: *essential*, *important*, *anticipatory* and *irrelevant* visual tasks. They are presented in Table 5.2. The first category occupies the essential driving tasks whose omission would lead to a very high accident risk. The second category occupies the tasks that take into account the erroneous behavior of the others like tracking of road users without right of way. The third category occupies the anticipatory tasks that include observation of the happenings in the distance and to the fourth category belong the tasks that are not relevant for the basic task of driving.

Table 5.2: *The four prioritization categories of visual driving tasks according to [Schweigert03]*



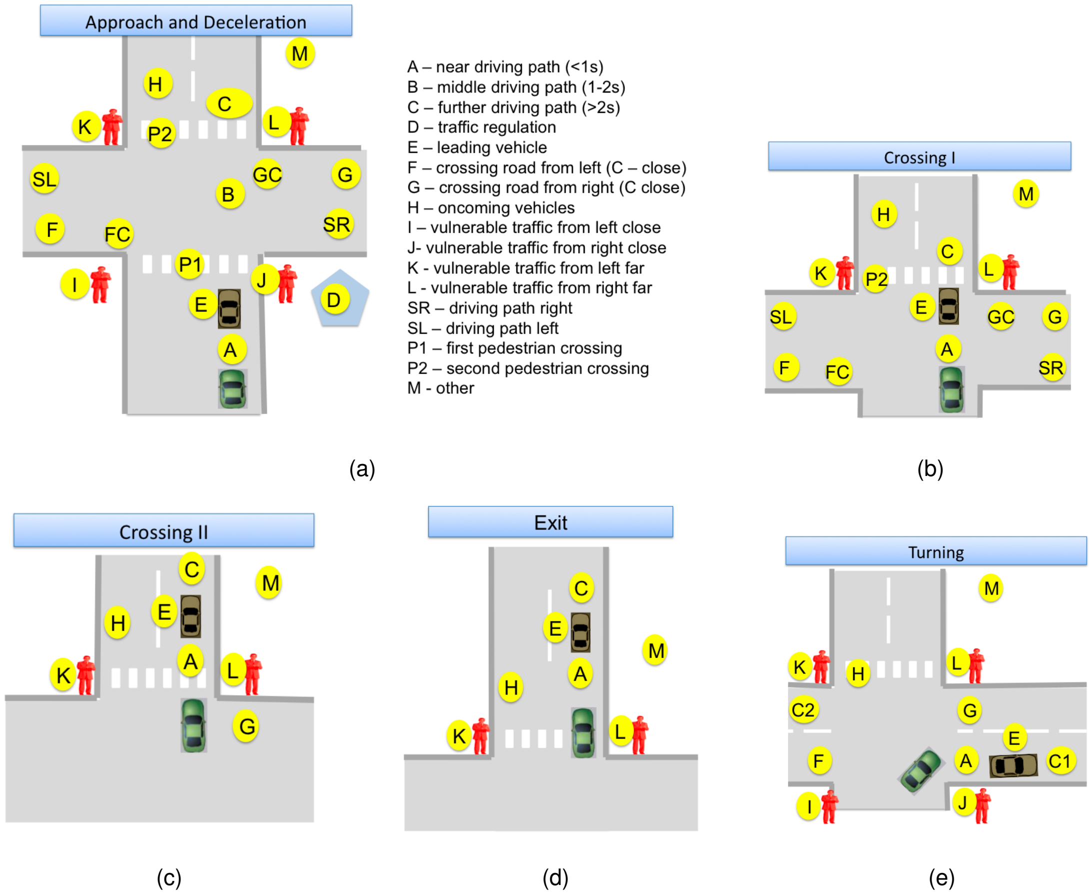
Priority	Level	Definition	Example
I	Essential	basic driving tasks; omission would lead to a very high accident risk	tracking of traffic participants with right of way
II	Important	tasks taking into account erroneous behavior of the others; omission can lead to an accident	tracking of participants without right of way
III	Anticipatory	long-term planned tasks like observation of the traffic participants in the distance	tracking of leading vehicles in the distance
IV	Irrelevant	tasks which have nothing to do with the driving itself	interior observation, gaze at billboards

Having this in mind, the normative visual behavior at intersections is defined based on the segment analysis described in the previous section. The visual tasks that have to be committed within each of the intersection segments are determined based on the corresponding segment objectives. One of the four categories is attached to each task. Also the sequence in which they are to be accomplished is determined for each segment. The normative behavior is defined on the level of the driving situation. This means that the normative visual behavior depends on the type of intersection and maneuver but it does not depend on the presence of the other traffic participants. By that, for example, *Scenario 4* and *Scenario 10* presented in Figure 5.8 have almost identical visual normative behavior. Based on this analysis, the lists of visual tasks that are to be realized at each intersection are made. An exemplary task list applied for the analysis is presented in Appendix A. The driver's behavior is then analyzed for performance and omission of these tasks by using Dikablis software.

Additionally, the most relevant parameters of visual behavior are also determined. They are chosen based on [ISO-15007-1:2002], [ISO-15007-2:2002], and [Rötting01] and they are:

- *glance durations* (mean, standard deviation, and total per intersection and segment),
- *frequency of glances* (mean, standard deviation, and total per intersection and segment),
- *percentage time* (mean, standard deviation, and total per intersection and segment), and
- *maximal glance duration*.

For calculating these parameters, the objects were triggered within the eye tracking system software as described in *section 5.1.2* and illustrated in Figure 5.15. This Figure presents the visualization of the trigger list for the intersection scene. It shows the keyboard keys dedicated to each of the objects. The triggering is done consequently for each segment of intersection and for every intersection. For each of triggers in Figure 5.15, the parameters of visual behavior are determined in each segment.



(a) (b)

(c) (d) (e)

Figure 5.15: *Visualization of the trigger list for all objects and segments for the analysis of visual behavior with Dikablis software (a) Approach and Deceleration, (b) Crossing I, (c) Crossing II, (d) Exit, and (e) Turning*

5.3.3 Task Demand

Arguments were given within *Chapter 3* to focus on the comparison of objective task demand and perceived task difficulty of scenarios, rather than on objective and subjectively perceived risk. For comparison of intersections regarding the task demand and perceived difficulty, the objective task demand should be quantified in an appropriate way. To do so, a heuristic for the evaluation of the task difficulty for intersections is suggested here. The heuristic is based on the determination of the number of possible conflict points and different weight factors for the road users in right of way and those not having right of way. This can be considered as a form of dividing the traffic scene into *Chunks* of information. It is reasoned that each group of objects, standing at the same place and/or moving dependent of each other, and requiring the same driver's reaction, can be considered as one chunk of information. Each chunk requires a different level of driver's reaction. In the most general sense this reaction is dichotomous: the driver has either only to observe the chunk or has to react on it. With respect to the analysis of information processing conducted in *Chapter 3*, the more chunks one intersection possesses, the more it is complex for the driver.

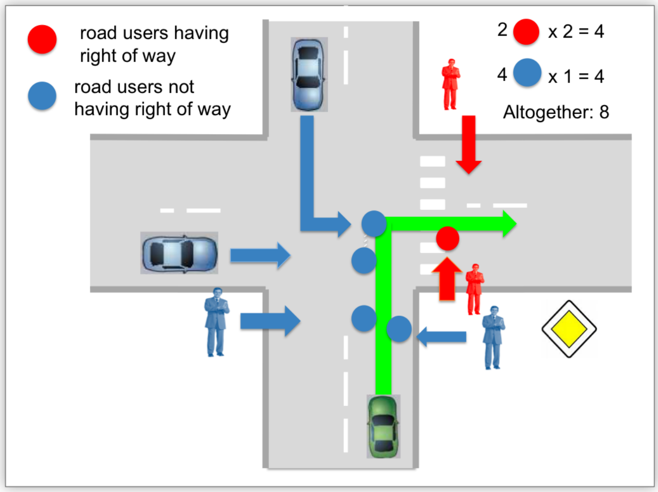


Figure 5.16: *Example of the suggested heuristic for the quantification of objective task demand at intersections*

The suggested heuristic is explained on the example given in Figure 5.16. The subject vehicle executes the right turn coming from the major road. For this maneuver, there are two directions from which road users have right of way: these are the crossing vulnerable traffic participants (pedestrians or bicycles), parallel to the driven vehicle. They are marked with red circles and are given the weight of 2 because the driver has to react on these objects. Additionally, there are 4 more directions with possible road users that the driver has only to observe but not to react on them. They are marked by blue circles and are given the weight of 1. The sum of weighted circles presents the evaluated difficulty of the intersection task. The task difficulty for the presented example is evaluated to be 8.

Each scenario is quantified by applying the explained heuristic (see Appendix A) and the ranking of chosen scenarios is presented in Figure 5.17. The objectively least demanding scenario is the scenario in which the driver has right of way and is going straight, followed by the right turn maneuvers. On the fourth place is the left turn maneuver when in right of way, followed by left turn maneuver when having to give way. The objectively most demanding is the task of crossing the intersection when having to yield.

Here no distinction is made based on whether the road users are present in the scene or not. The driver has anyway to scan all the directions in both cases when the traffic participants are present and when they are not. However, in case of their presence, the driver has additionally to monitor and follow them, to form expectations and to anticipate their further movement. Thus a more precise heuristic can be done for each scenario when taking into account whether the particular road user is present in the scene or not.

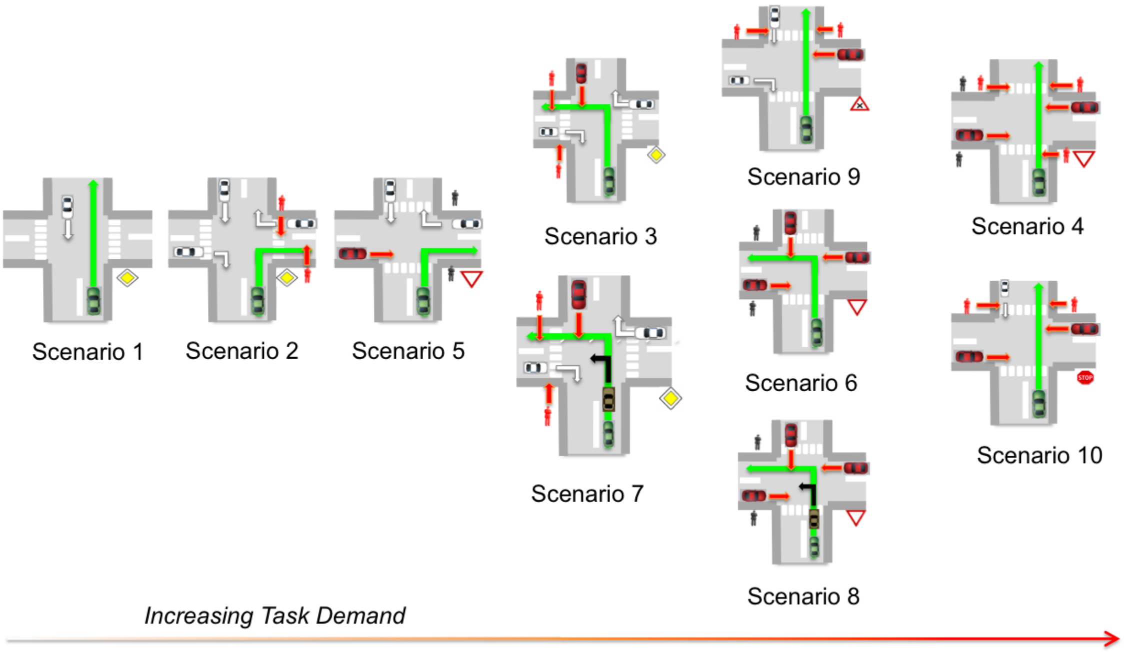


Figure 5.17: *Scenarios ranked by objective task demand evaluated with Chunks heuristics. The evaluated value for each scenario is given in Appendix A*

5.4 Experimental Analysis

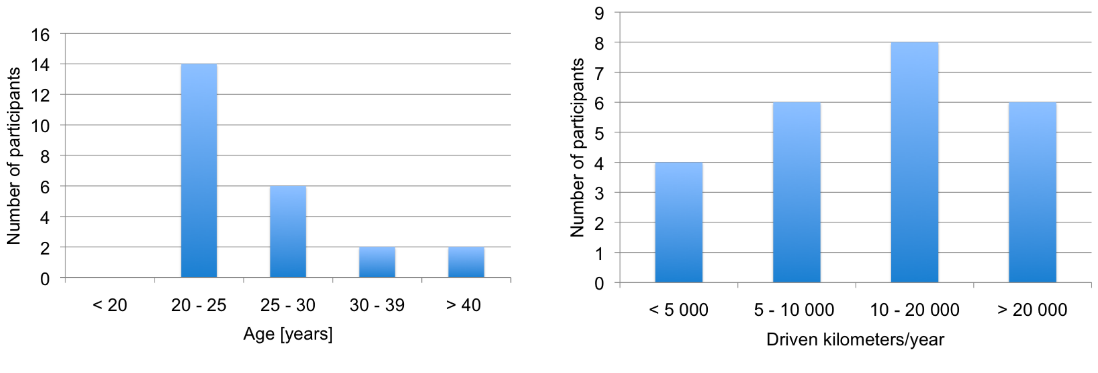
In this section, the test sample and the experimental procedure are presented, followed by the most relevant subjective and objective results for each scenario.

5.4.1 Test Sample and Experimental Procedure

The analyzable test sample consists of 24 subjects. The analyzable video recordings vary from scenario to scenario and will be presented together with objective results. Altogether, 28 subjects took part in the experiment but 4 did not finish the test because of occurring simulator sickness. The ratio of successful drives is high and confirms that twenty intersection scenarios present a good choice. The participants were mainly the students from the Faculty of Mechanical Engineering, Technische Universität München, which is the reason for the gender distribution of 3 females and 21 males. The drivers' age ranges from 21 to 63 years and the mean age is 27 years ($SD = 8.71$). The age distribution is shown in Figure 5.18(a).

All the drivers held the valid driver's license of European B category. Four participants were driving less than 5000 km annually, six between 5 and 10000 km, eight between 10 and 20000 km, and 6 of them were driving more than 20000 km per year. The histogram of drivers' experience is depicted in Figure 5.18(b). The histogram of the possession of the driver's license is given in Figure 5.19(a).

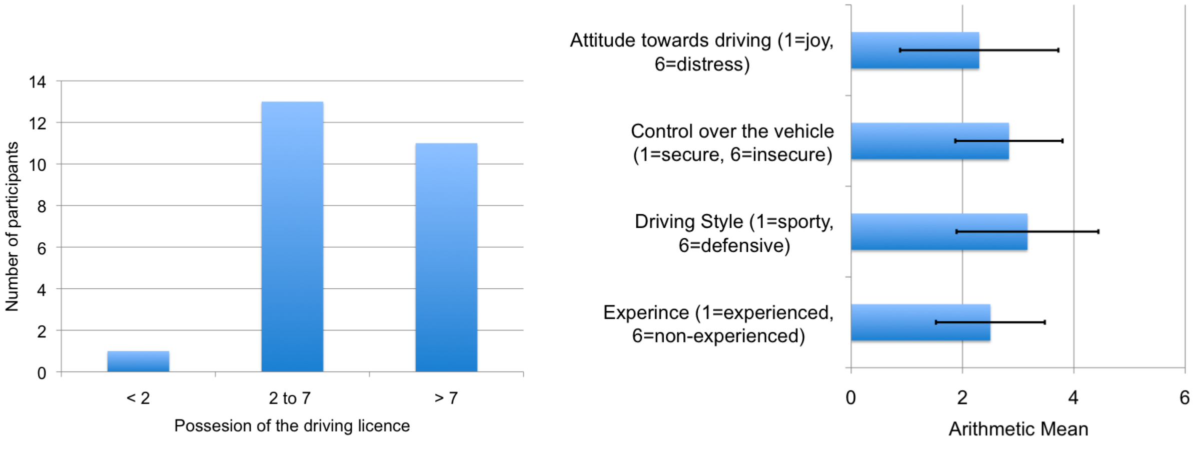
Additional questions in the demographic questionnaire occupied subjective ratings of the different



(a) (b)

Figure 5.18: *Demographical distribution of subjects (a) age distribution, (b) driven kilometers per year*

parameters like driving experience, driving style, behavior in the conditions of high traffic density, and the control over the vehicle. The applied ranking was 6-leveled, where 1 stands for: ”very experienced”, ”sporty/dynamic”, ”offensive”, and ”I have control in any situation”, respectively. The 6 stands for ”inexperienced”, ”calm/balanced”, ”rather defensive”, and ”in some situation I experience difficulties”. The results of the self-evaluation are presented in Figure 5.19(b). The participants evaluated themselves as rather experienced, balanced drivers who are having good control over the vehicle.



(a) (b)

Figure 5.19: *Demographical distribution of participants (a) the years in possession of driver’s license, (b) Self-evaluation towards the driving*

Experimental Procedure. After filling out the demographical questionnaire, participants got a brief introduction to the study and drove a practice course to get familiarized with the simulation environment. Participants were instructed to drive as they would normally drive and to obey traffic regulations. They were told to keep the speed in the city under 50 km/h and to drive with as uniform speed as possible. Subsequently, the participants drove the experimental trial, equipped with the eye tracking system Dikablis. Navigation instructions were received via on-board sound system and the whole drive was recorded. The first drive lasted from fifteen to twenty minutes.

After the first trial, each situation was replayed to the subjects and they were asked to fill-out the situation-specific questionnaires and the questionnaire for measuring the subjectively experienced workload during the baseline drive. The situation-specific questionnaires have the objective to collect subjective opinions about each scenario regarding the difficulty of orientation, task difficulty, risk of the incorrect evaluation of situation, and risk of collision. Additionally, drivers had to mark the most dangerous objects in the scene and to mark the three, for them, the most important data sets. Answering on questions in this part lasted 20 minutes on average.

The next part of experiment was the drive of the same course under the induced time pressure conditions. As previously explained, time pressure was chosen as one of the most influential Performance Shaping Factors, which evokes errors commitment under realistic conditions. By that, time pressure trial can reveal the deficiencies in applied driving strategies and expose the way the drivers prioritize information. With ten different scenarios, it is hard to remember all of them but still the environment around each intersection has been alternated in the second trial. This proved to be sufficient measure for the participants to not recognize the situation, even with less scenarios [Plavsic09a].

The participants were motivated to drive under time pressure by an announced competition. They were told to drive as fast as possible and if they are the fastest and do not cause any accident, they will be rewarded. After the time-pressure trial, participants filled out one more questionnaire for measuring the perceived workload in this trial and they answered the questions about the difference in their behavior in the comparison with the baseline.

5.4.2 Presentation and Discussion of Results

In the following the most relevant subjective and objective results are presented and discussed.

Subjective data

The analyzed and presented subjective data include:

- experienced workload in the baseline trial and the trial under time pressure,
- ratings of the subjective evaluation of the orientation difficulty, task difficulty, risk of faulty evaluation, and risk of collision for each scenario,
- ratings of the subjectively most important information sources for each scenario,
- determination of especially dangerous objects in the field of view, and
- subjective opinions about possible assistance systems in particular situations.

Workload. The subjectively experienced workload is collected with NASA TLX method [NASA88]. NASA TLX presents a standardized assessment tool for a subjective workload. It is a multi-dimensional rating procedure that derives an *Overall Workload Index (OWI)* based on a weighted average of ratings on six subscales. The six subscales include *Mental Demands*, *Physical Demands*, *Temporal Demands*, *Own Performance*, *Effort*, and *Frustration*. The workloads in the baseline trial and under time pressure conditions are compared and presented in Figure 5.20.

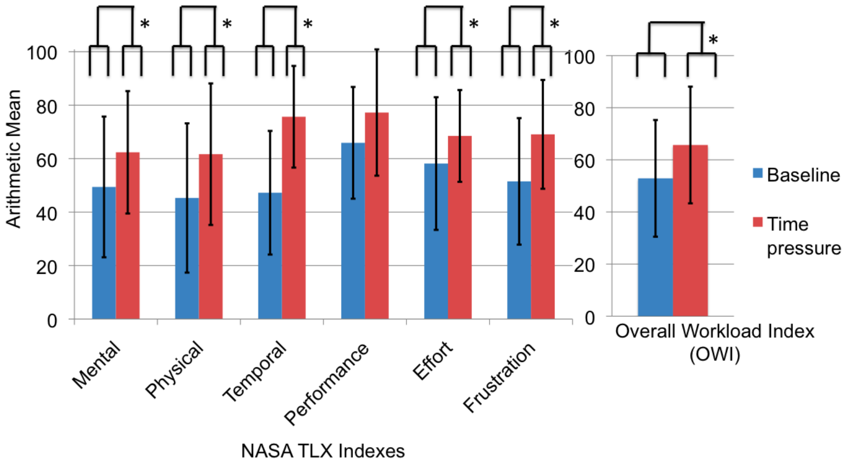
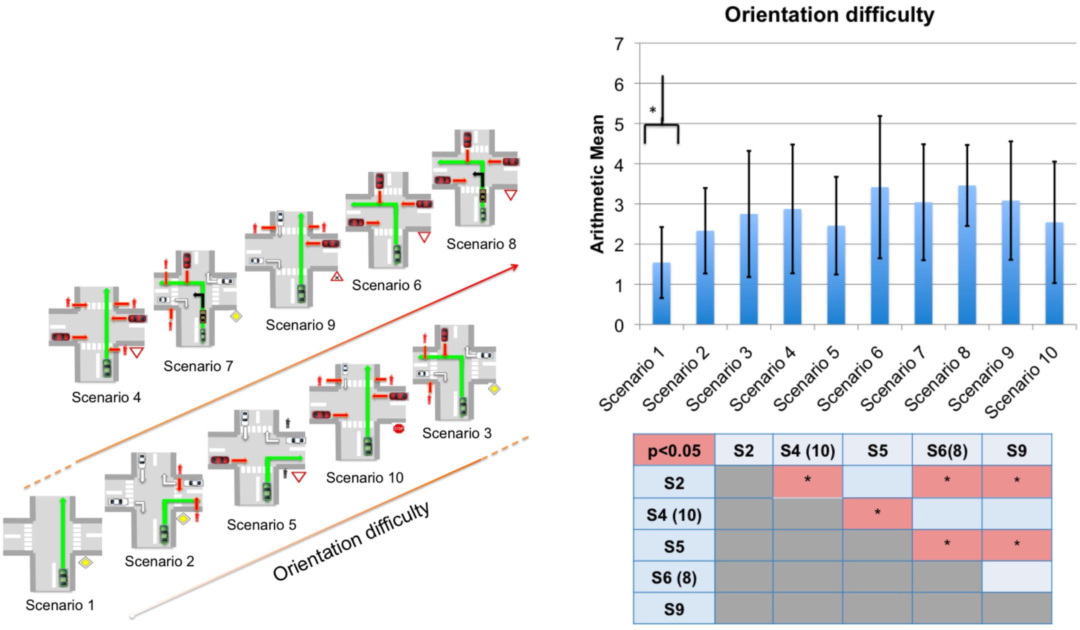


Figure 5.20: *Measured workload in the baseline trial and the trial with time pressure: individual dimensions of NASA TLX workload scale, and Overall Workload Index (OWI)*

The statistical analysis showed significant difference between the two trials $(F(1,23) = 4.48, p = 0.045)$. There are significant differences for each of the dimensions except for the *Performance*. This is shown in Figure 5.20 by the caps with the star above the respective column bar. The star denotes the significant difference for $p < 0.05$. All six subscales induce comparably equal workload on the drivers, except the *Performance*, which is rated as slightly higher in the baseline trial. Figure 5.20 also shows that drivers consider themselves as capable enough that the dimension of *Performance* is not influenced by the time-pressure. In the baseline trial, each of subscales caused the average workload around 50%. This shows that the driving through intersections presents, even subjectively, a very demanding task. For time pressure trial the dimensions of the average workload were often higher than 80%. Several individual ratings were even 100%, showing that test persons were overwhelmed with executing the maneuvers. Hereby, it should be also noticed that these scenarios were not designed to be critical and were very realistic. The reason for high workload may also be the simulation environment, which require some acclimatization.

Orientation difficulty. The results of the subjective ratings of the orientation difficulty are presented in Figure 5.21. The applied scale was a six-level scale and each criterion was rated by numbers between 1 and 7, where 1 stands for ”very easy” and 7 for ” very difficult”. For a better understanding, the comparative ranking is illustrated in Figure 5.21(a).

The analysis showed a significant difference between scenarios $(F(9,207) = 312.584, p = 0.001)$. *Scenario 1* was evaluated as significantly the easiest for the orientation. This is marked in Figure 5.21(b) by the cap with the star above the bar depicting the arithmetic mean for this scenario. For



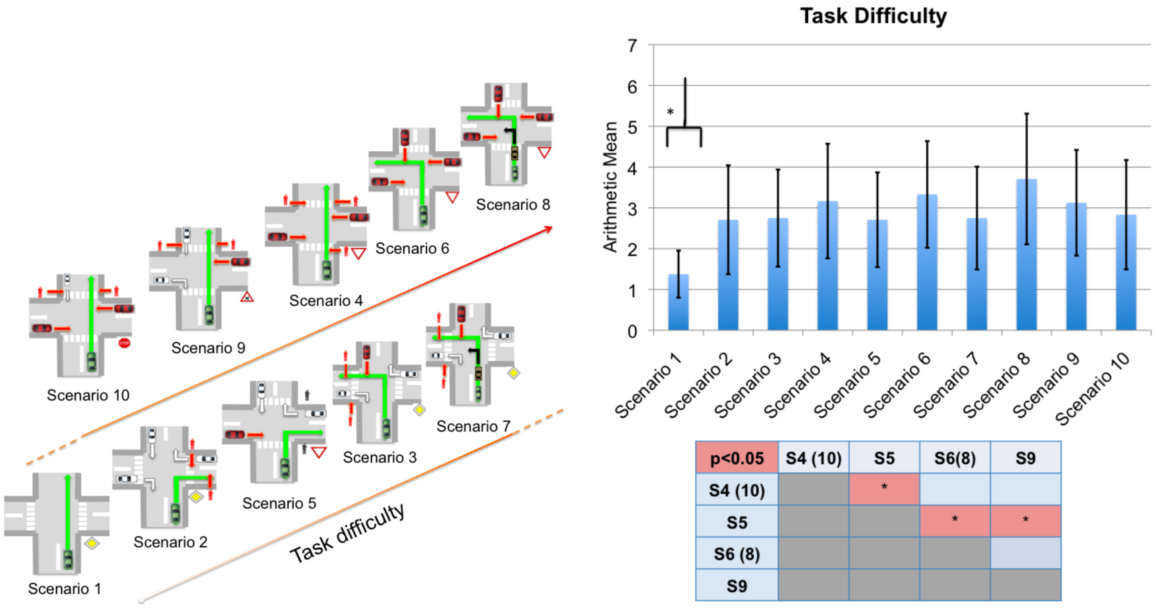
p<0.05	S2	S4 (10)	S5	S6(8)	S9
S2		*		*	*
S4 (10)			*		
S5				*	*
S6 (8)					
S9					

(a) (b)

Figure 5.21: *Subjective ranking of intersection scenarios regarding the experienced orientation difficulty (a) comparative ranking (d) means, standard deviations and significant differences*

the clarity of the diagram, the other significant differences are shown in the table beneath the figure. *Scenario 6 and 8* are evaluated as the most difficult for the orientation, followed by *Scenario 9*, *Scenario 7* and *Scenario 4*. *Scenario 6* is the left turn scenario when the subject vehicle has to yield. Therefore it is necessary to pay attention to five different directions, which are all having right of way. As discussed in *Chapter 3*, it is very hard to have all these directions in the working memory at the same time, especially when the driver has to perform additional tasks such as monitoring, steering or braking. *Scenario 8* is the same as *Scenario 6* except that there is a leading vehicle present. *Scenario 9* is an unordered intersection, which is expected to be difficult for orientation as the drivers have also to decide which participants are on the right side of the others and this task requires significant amount of the visuo-spatial working memory. Figure 5.21(a) also shows that turning right presents less orientating difficulty than going straight. When the driver has to drive straight, there are more conflict points than for turning right, which increases the orientation difficulty. *Scenario 7* is a left-turn scenario with the leading vehicle and is rated among more demanding scenarios, but there are no significant differences to other scenarios for $p < 0.05$. *Scenario 4* and *Scenario 10* are identical scenarios and have the same number and type of road users having right of way, with the difference that *Scenario 4* is regulated by *Yield sign* and *Scenario 10* by *Stop sign*. *Scenario 4* is evaluated as slightly easier to orientate than *Scenario 10* but there is no significant difference for $p < 0.05$. From the comparison of *Scenario 3* to *Scenario 7* and *Scenario 6* to *Scenario 8* it is concluded that the leading vehicle does not affect the orientation difficulty as well.

Task difficulty. Figure 5.22 presents the results of the subjective ratings of experienced task difficulty. This is also shown to be significant with $F(9, 207) = 319, 232, p = 0001$. The relative and absolute ratings of the orientation difficulty and the task difficulty are almost identical. This correlation may mean that the orientation at intersection influences the experienced task difficulty or that the drivers do not distinguish between these two dimensions. Therefore, everything discussed in terms of the orientation difficulty can be mapped and is valid for the task difficulty.



p<0.05	S4 (10)	S5	S6(8)	S9
S4 (10)		*		
S5			*	*
S6 (8)				
S9				

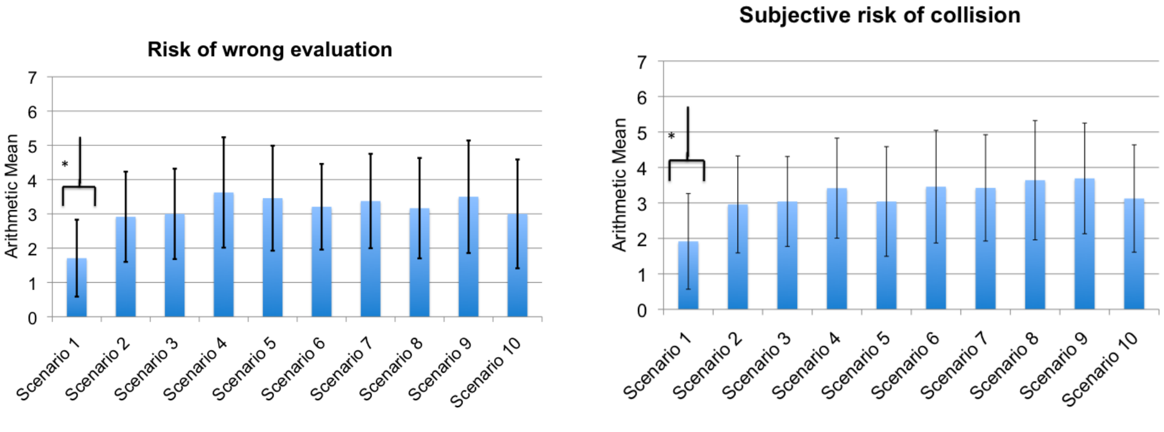
(a) (b)

Figure 5.22: *Subjective ranking of intersection scenarios regarding the experienced task difficulty (a) comparative ranking (d) means, standard deviations and significant differences*

The evaluation of subjective task difficulty almost fully comply with the heuristic estimation of the objective task difficulty presented in Figure 5.16. The only exceptions are *Scenario 10* and *Scenario 4*, which are subjectively not evaluated as difficult as objectively estimated. This is probably connected with the common impression of drivers that not changing direction at intersection is not that difficult as executing the turn.

Risk of faulty evaluation. Figure 5.23(a) shows the subjective ratings of the risk of wrong evaluation. There are no significant differences for this dimension for $p < 0.05$ except for the *Scenario 1*, for which is the risk of faulty evaluation significantly lower than for the other scenarios. Therefore no illustrative ranking is necessary to be given. This result indicate that drivers are insecure about their performance independently of the traffic scenario. Even though they can fulfill the task successfully, they are aware of the possibility of the faulty evaluation, which causes insecurity and a high subjectively experienced risk. When compared to the difficulty of orientation and the task difficulty, the main difference to the risk of the faulty evaluation is that the right turn scenarios are evaluated as high as the others. The rest of discussion about the orientation difficulty can also refer to this dimension.

Also, it is important to mention that for *Scenario 4* and *Scenario 9* the average risks of wrong evaluation are higher than 50%, indicating that in these scenarios assistance would be highly beneficial for decreasing the subjectively experienced risk and for increasing comfort.



(a) (b)

Figure 5.23: *Subjective rankings of (a) the risk of faulty evaluation, and (b) the subjective risk of collision*

Risk of collision. Figure 5.23(b) presents the results of the evaluation of the subjective risk of collision. The evaluation of the subjective risk of collision is almost identical to the subjective risk of faulty evaluation and does differ from the evaluation of the task difficulty. This supports the hypothesis from *Chapter 3* that the experienced task difficulty does not have to correlate with the subjective evaluation of the risk of collision. The only significant difference here is with *Scenario 1* and the remaining scenarios are evaluated similarly high. For *Scenario 8 and 9* the average ratings are higher than 50% of the maximal level.

Information prioritization. Another aspect that drivers were asked to evaluate is the prioritization of information in each scenario. The participants were asked to mark the three most important data sets in the screenshot of each intersection. The analysis showed that the traffic signs present the most important source in almost all scenarios. Another important information presents the crossing vulnerable traffic participants, but only in scenarios in which they are in the *Exit phase* of intersection. They were not considered as that relevant when they were present in the *Deceleration* segment. The evaluations of the hazard level of particular objects correspond to these results. Crossing participants in the *Exit phase* were often labeled as the most dangerous ones. When having the task to cross intersection, the crossing traffic was often labeled as the most dangerous and this more from the left than from the right side.

Concluding Summary. The results of the subjective ratings lead to conclusion that negotiating an intersection presents a very demanding task, which causes a high workload on the driver even in non-critical scenarios. The subjective evaluation of the orientation difficulty and task difficulty were almost identical. It is also concluded that the heuristic with the conflict points, suggested in the previous section, could be used as a good approximation for the subjectively experienced task difficulty and the difficulty of the orientation. Also it has been shown that the subjective risk of collision and the risk of the faulty evaluation do not differ. They are both evaluated as high and they do not seem to depend on the scenario. This means that an ergonomic assistance system would increase the comfort of driving in any intersection scenario. The drivers also expressed the desire for an assistance system, which will help them for intersection tasks. However, except that they expressed a resistance towards warning systems, there was no clear concept about how the system should work. The crossing traffic participants in the *Exit phase* and crossing traffic from the left side when going straight were labeled as the most hazardous objects by the majority of participants.

Objective Data

The objective results consist of task analysis, committed errors, and visual parameters. The resulted visual behavior is compared to the normative behavior within explained task analysis procedure and specific parameters of visual behavior are calculated with respect to the different Areas Of Interest. This has been done for each particular segment in all ten scenarios in both baseline and time pressure trial. Presenting the data on the level of scenario and not on the level of the particular segment in each scenario would result in the loosing of relevant data. For example, the distribution of attention on the level of the whole scenario is giving information, which is hard to interpret because it is not connected to the *driving situation* but to the *traffic situation*. Also, such a result occupies in one value the different spatial constellation of the road users. For example, the average glance duration value on the vehicle from the left lane in *Scenario 4* is not relevant enough because it is not known whether this vehicle was focused in the appropriate moment. The available literature considering visual behavior at intersections is unfortunately mostly offering only ”condensed” data about visual behavior.

Therefore, the analyzed data are here presented for each segment in each scenario for the baseline trial and the trial with time pressure. Altogether, this sums up to 100 segments. Presenting detailed data for each of the segments would take up too much space. Therefore only the most relevant data are presented. The focus is on the erroneous behavior and the most critically omitted tasks. The remaining analysis and data are given only when relevant. Also, the attention is paid to the individual specific behavior and it is analyzed whether the same subjects committed the same errors and applied similar driving strategies throughout the trial. The consideration of individual behavior presents a distinguished aspect of the analysis because it enables more specific insight into the drivers' behavior and causes of accidents.

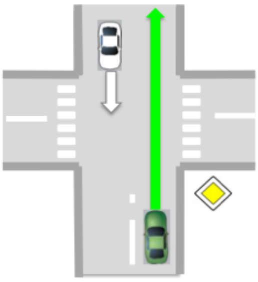
The gaze distribution is presented in detail for *Scenario 1*. The gaze distributions in other scenarios are respectively similar. As they do not reveal much beyond what is already presented in the analysis of omitted tasks, the gaze distributions for the rest of scenarios are not presented. Instead, the visual strategies are presented in more descriptive manner. The particular values of visual behavior parameters for each scenario and each segment can be found in *Appendix B*. The presentation starts with the most relevant results for *Scenario 1*. When analyzing the tasks, which are common for all scenarios such as for example the behavior regarding the traffic signs, the comparison with the rest of scenarios is given at the same place, within analysis of *Scenario 1*. These elements of analysis are than omitted within the presentations of the other scenarios and only scenario specific data are presented.

The analysis of *Scenario 1* includes the detailed investigation of the influence of time pressure on the drivers' behavior. Because of the specific triggering logic of SILAB, it is not possible to design the scenarios in the way that the unfolding of the traffic situations happens always in the exactly same manner. The triggering logic of SILAB is such that the behavior of the other road users depends on the driven speed. Because of the different speeds of the subject vehicle in the baseline and time pressure trial, the behavior of the other traffic participants was not always identical in both trials. For example, in some scenarios within the baseline, the drivers had to stop to yield the crossing pedestrians, but in the time pressure trial there was not enough time for pedestrians to reach the crossing before the subject vehicle. The main problem here is the fixed acceleration of the pedestrians in SILAB software. The future functionality of SILAB should eliminate these problems. For this reason, the influence of time pressure is presented in detail for *Scenario 1*, as in this scenario there are no other traffic participants and the driver situation was the same in both trials. For the rest of the scenarios, the main differences between baseline and time pressure are summarized together and the most critical omitted tasks are presented in the corresponding section.

In the following, the results for each scenario are presented in the form discussed above.

Scenario 1

Scenario 1 is presented once more in Figure 5.24. Not all 24 videos are available for each scenario, either because of the bad video quality or because the eye-tracking glasses slipped away during the recording and the video could not be properly calibrated. There are 21 analyzable videos for the *Scenario 1*.



Scenario 1
(C1-K3-F0)

		Baseline	Time pressure
Missing data	*Test Persons*	*5, 8, 9*	*8, 16, 24*
	Analyzable sample	21	21

Figure 5.24: *Scenario 1 and analyzable test sample*

In this scenario, the subject vehicle has the right of way and there are no crossing vehicles or pedestrians. All test persons rated *Scenario 1* as the easiest scenario in all the aspects. As the most important information in this scenario, all subjects pointed out the traffic sign. No accidents were committed in any of runs except that in the trial with time pressure TP 22 lost control of the vehicle and drove over the pedestrian pavement in *Approach* segment.

Duration of scenarios. As discussed previously, time pressure presents one of the most influential Performance Shaping Factors. The direct influence of time pressure in the driving is the increased driving speed. At intersections, the increased speed is mirrored in the decreased time span for the perception and processing of relevant information. The average speed during the performance at intersections did not change too much because the main change was in leaving out and shortening of the stopping phases. Therefore instead of the average speed, the average duration of the performance for each scenario in the baseline and the trial with time pressure is given in Figure 5.25. Compared to the baseline, during time pressure trial, drivers had up to half the time for the perception of the same load of information. This high difference appeared because in some scenarios drivers did not stop to let the pedestrians cross or were observing the surrounding during the halt as much as they did in the baseline. For the same reasons it should not be compared between the durations of scenarios among themselves but rather between the duration of each scenario in the baseline and with time pressure. The presented figure testifies that usual driver behavior at intersections has high safety reserve: the time that drivers take for the maneuver can be as twice as long as they are able to accomplish under time pressure.

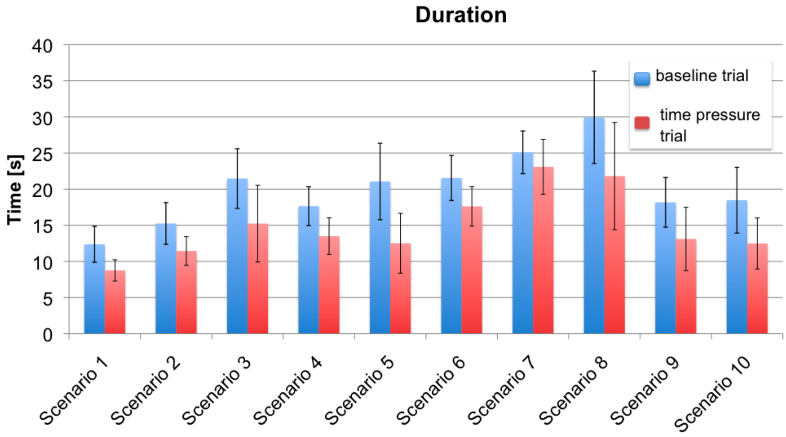


Figure 5.25: *The comparison of average durations of performing the maneuvers at intersections for the baseline trial and the trial under time pressure. The difference is mainly in leaving out or shortening of stopping phases*

In the following, the gaze distribution in each segment is compared for the baseline and time pressure.

Approach phase. The left diagram in Figure 5.26 presents the percentage of subjects focusing particular *AOI* in the *Approach* phase. The data are presented as percentages and not as absolute values because of the varying number of analyzable videos through scenarios. The letters in brackets designate the specific area, already denoted in Figure 5.15. The diagram shows that under time pressure almost all objects have less probability to be focused. In the baseline, the middle $(1-2$ s) and the far driven lane $(>2$ s) have the highest probability to be focused. In time pressure trial, drivers mainly focused on the far driven lane. This is in compliant to the visual strategies of straight driving discussed in *Chapter 4*. Data in *Appendix B* show that similar strategies were applied in all scenarios.

Depending on the maneuver to be performed, the distribution of subjects focusing near, middle or far driving path differs. When the drivers had the task to turn, the close lane was focused more than the middle and the far driven lane. The presence of the other road users also influenced the applied strategies. For example, the pedestrian on the crossing behind the intersection in *Scenario 4* can be seen already in *Approach* segment of the baseline trial. In the trial with time pressure this is not the case and the percentage of test persons focusing the far driven lane is less than for the baseline.

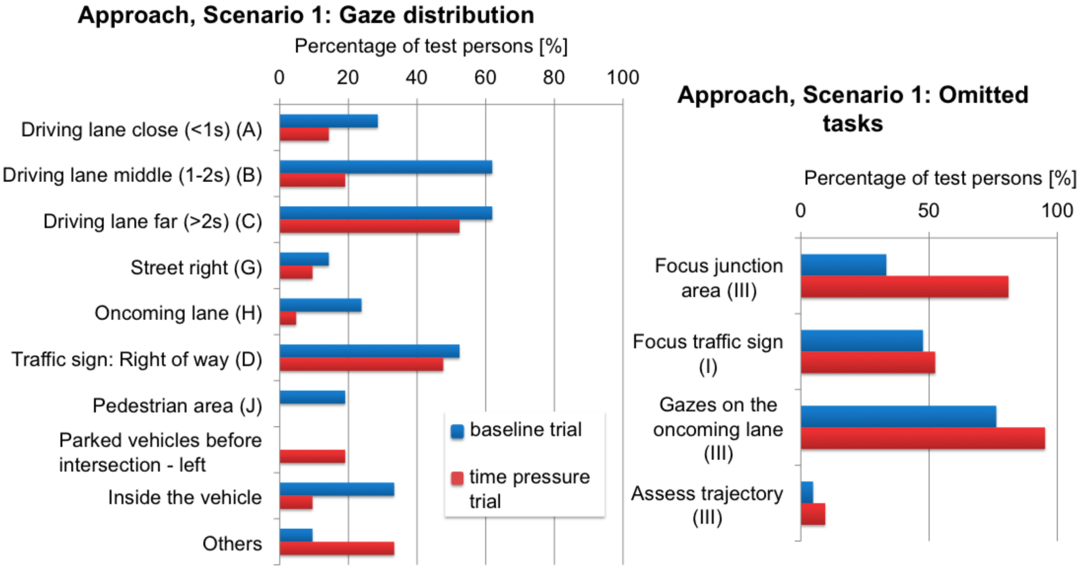


Figure 5.26: *The percentage of subjects focusing particular Area Of Interest in Approach segment of Scenario 1 (left) and the percentage of test subjects omitting the particular tasks (right)*

The number of glances per AOI, including close, middle and the far driven lane is in this segment between one and three. Also, the maximal duration per AOI does not increase 1 s. The detailed values can be found in *Appendix B*. The drivers had on average around four to eight gazes in this segment among all scenarios in the baseline, and three to five in the time pressure trial. To illustrate this, the comparison of glance sequences for *Approach* segment for TP 2 and TP 6 is given in Figure 5.27. These two persons had two extreme glance behaviors. TP 2 did almost no scanning while TP 6 changed the direction of glance even seven times in the baseline trial. In the rest of scenarios the behavior was similar: TP 6 had more glances on average per segment than TP 2.

The crossing streets in *Scenario 1* are subordinate and the left street is not focused in the *Approach* segment neither in baseline nor in time-pressure trial. The right crossing street is focused on by only 15% of participants in the baseline and 10% of participants in the time pressure trial. These glances belonged mainly to the junction area and were not directed deeply into the right crossing street. Therefore they may also be categorized by the glances, which belong to own driving path.

The high decrement of irrelevant gazes under time pressure (Inside the vehicle) signals the higher demand of the task under the time pressure. There are only two areas, which were focused more in the time pressure than in the baseline trial. Interestingly they belong to the categories *Others*

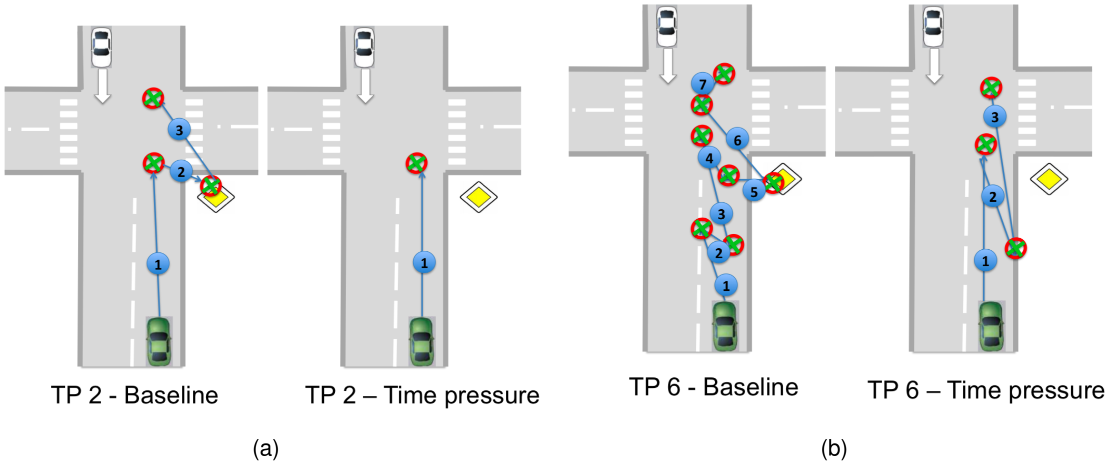


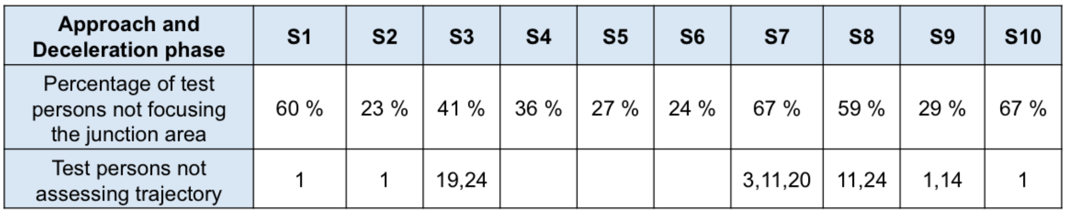
Figure 5.27: *Illustration of the glance sequences in Approach segment of Scenario 1 for two extreme visual behaviors (a) TP 2, who has only few glances, and (b) TP 6, who has many glances*

and *Parked vehicles on the left lane*. In the baseline drive, the parked vehicles on the left side were completely neglected and the area behind the intersection was not focused during *Approach* but later in *Deceleration* segment. In the time pressure trial drivers were focusing much more forward than in the baseline, resulting in focuses of these two categories. The gaze in the time pressure trial was predominantly directed towards the horizon. In the first phase of *Approach* segment the forward area included the vehicles on the both side of the street and in the second phase of *Approach* segment this was the area behind the intersection and the surrounding buildings. It can be argued that the area of surrounding buildings presents the *Focus of Expansion* point and its focusing serves to the better vehicle stabilization. The stabilization of the vehicle in the driving simulator is a particularly demanding task when driving at higher speeds. The obstacle is the resolution of the applied eye tracking system as, in this case, it does not allow the determination of the exact position of the gaze. These gazes are therefore categorized as the *Others*.

Stabilization glances. The right diagram in Figure 5.26 sums up the most critical visually omitted tasks in the *Approach* phase of *Scenario 1*. The omitted tasks are assigned to the four priority categories, as discussed in *section 5.3*. The first category involves the essential tasks, like checking for the road users in right of way. The second category occupies important tasks, which take into account the erroneous behavior of the others and the third category occupies anticipatory tasks. Except for focusing of the traffic signs, which is discussed later, there are no other essential tasks in this scenario because the subject vehicle has the right of way.

One omitted task, depicted in Figure 5.26, is *Focus of the junction area*. The observation of the performance of this task reveals the strategy with which drivers evaluate the distance to the approaching intersection. This task is also essential for the stabilization of the vehicle. Not focusing this area means that drivers also have techniques to evaluate the distance to the intersection by the peripheral vision, probably directly from the optical flow. This was the case for 30% of participants in the baseline and more than 81% in time pressure trial. This means that when needed drivers may evaluate the distance to intersection without focusing the junction area directly. The Table 5.3 gives the percentage of test persons not focusing on the junction area for all the scenarios. The table shows that depending on the maneuver and whether there exist the pedestrian crossing or not, the applied visual strategies change.

Table 5.3: *Percentage of test persons not focusing the junction area and persons not assessing the trajectory in the first two segments of all scenarios (S = Scenario)*



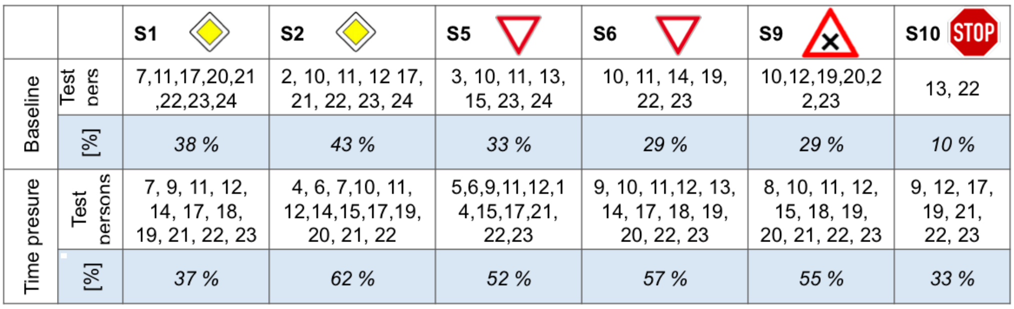
Approach and Deceleration phase	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Percentage of test persons not focusing the junction area	60 %	23 %	41 %	36 %	27 %	24 %	67 %	59 %	29 %	67 %
Test persons not assessing trajectory	1	1	19,24				3,11,20	11,24	1,14	1

Another anticipatory task that is expected to be conducted when moving towards an intersection is *Assess trajectory*. This task describes focusing along the farther driving path. Theoretically it is necessary to focus along one's own driving path in order to know where to drive further. However, there were some test persons who did not orientate themselves based on focusing on their own path but were focusing on the areas around the intersection, behind it, or were focusing only on the edges of the roads. These persons were keeping the vehicle in the lane fully relying on the peripheral vision. The second row of Table 5.3 gives the test subjects who did not assess the trajectory in the first two segments in all scenarios. The table shows that only few test persons have the strategy to assess the trajectory by the peripheral view. Hereby it should be mentioned that TP 1 is an experienced driver, familiar with the driving simulator environment.

Visual focusing on traffic signs. The analysis revealed a troubling fact regarding the visual behavior concerning the traffic signs. Traffic signs were not foveally focused by approximately 50% of the participants. In *Scenario 1* the traffic sign is not focused by 10 participants in the baseline and even by 11 participants in the time pressure trial. One from these participants focused the traffic sign in the next, *Deceleration* segment in the baseline drive and two participants focused the sign additionally in *Deceleration* segment in the time pressure trial. Also in all the other scenarios participants either focused the traffic sign in the *Approach* segment or they did not focus it at all. When focused, the average number of glances to the traffic sign was around 1 in all scenarios. The mean duration was between $0,2$ s to $0,6$ s and did not differ in the baseline and time pressure trial. The Table 5.4 presents traffic participants who did not focus the traffic sign in any of phases in all scenarios. The indexes of test persons are also given to show that mainly the same test persons do not foveally focus on the traffic signs.

As the videos were properly calibrated and the rest of the gazes were fitting, the conclusion arrived at is that the majority of test persons perceived the traffic signs peripherally. Anyhow, from the behavior of some test persons, it is concluded that around 5% of them did not perceive the traffic sign at all. Sometimes they were stopping at the junction when they had right of way and were hesitating to drive further. They were than extensively checking all the directions independent of the right of way. In scenarios in which drivers are aware that they have right of way, they mainly do not check for the

Table 5.4: *Indexes and percentage of test persons not focusing the traffic sign foveally in all scenarios. The same test persons did not foveally focus traffic signs. Stop sign was focused by most of subjects.*



		S1	S2	S5	S6	S9	S10 STOP
Baseline	Test pers	7,11,17,20,21,22,23,24	2, 10, 11, 12 17, 21, 22, 23, 24	3, 10, 11, 13, 15, 23, 24	10, 11, 14, 19, 22, 23	10,12,19,20,22,23	13, 22
	[%]	*38 %*	*43 %*	*33 %*	*29 %*	*29 %*	*10 %*
Time presure	Test persons	7, 9, 11, 12, 14, 17, 18, 19, 21, 22, 23	4, 6, 7,10, 11, 12,14,15,17,19, 20, 21, 22	5,6,9,11,12,14,15,17,21, 22,23	9, 10, 11,12, 13, 14, 17, 18, 19, 20, 22, 23	8, 10, 11, 12, 15, 18, 19, 20, 21, 22, 23	9, 12, 17, 19, 21, 22, 23
	[%]	*37 %*	*62 %*	*52 %*	*57 %*	*55 %*	*33 %*

possible erroneous behavior of the others. From this it is concluded that, frequently, drivers either do not perceive traffic signs or they do not have it available in the short-term memory anymore.

The *Stop sign* was foveally focused by almost all subjects. The *Stop sign* differs from the other signs because it has the highest priority as the driver has to react on it and to bring the vehicle to a halt. Also, the *Stop sign* has letters on it which have to be focused foveally to be read. These can be the reasons why the *Stop sign* has been focused by almost all participants. For the other regulation signs, drivers most probably developed by experience the peripheral recognition, based on the shape and color. Also, it can be that drivers, based on the width of the street and other cues, assume the regulation type of intersection and when peripherally recognizing the traffic sign, they do not foveally focus on it anymore. However, this comparison of the assumption and the peripheral image of traffic sign can happen on the rule-based level. Therefore, it may be that drivers on the conscious level loose the information about the traffic sign few seconds afterwards. The percentage of drivers not focusing on traffic signs may be even higher in real life because of the higher and better resolution and recognition of the traffic signs. This is in accordance with the findings from [Diem04] who found that only 25% of traffic signs are foveally perceived and in case of the bad visibility even less.

Deceleration phase. The gaze distribution in the next, *Deceleration* segment of Scenario 1 is given in the left diagram of Figure 5.28. Figure shows that in time pressure trial, the category of *Other* gazes is substituted with the gazes in front of the vehicle, meaning that drivers were not focusing anymore far behind the intersection but moved the focus to the front of the vehicle. By this, the drivers compensated for their strategy of looking far forward in the *Approach* segment and were checking intensively for the hazards just before entry into the intersection. In that way they also scanned the areas from where the vulnerable traffic participants can come from in higher extent than in the baseline trial. The drivers were most probably not expecting anymore to see the vulnerable traffic participants peripherally because they were driving so fast that they would not have enough time to react on them. Therefore they searched the area actively. In the baseline trial, the reliance on the peripheral vision was much higher. The average number of glances is also between one to two glances per AOI and the mean duration of the glance in this segment was between $0,2$ and $0,4$ s.

The right diagram in Figure 5.28 sums up the most relevant omitted tasks in this phase. In this segment, these are mostly the tasks of the second category: not checking for the crossing traffic

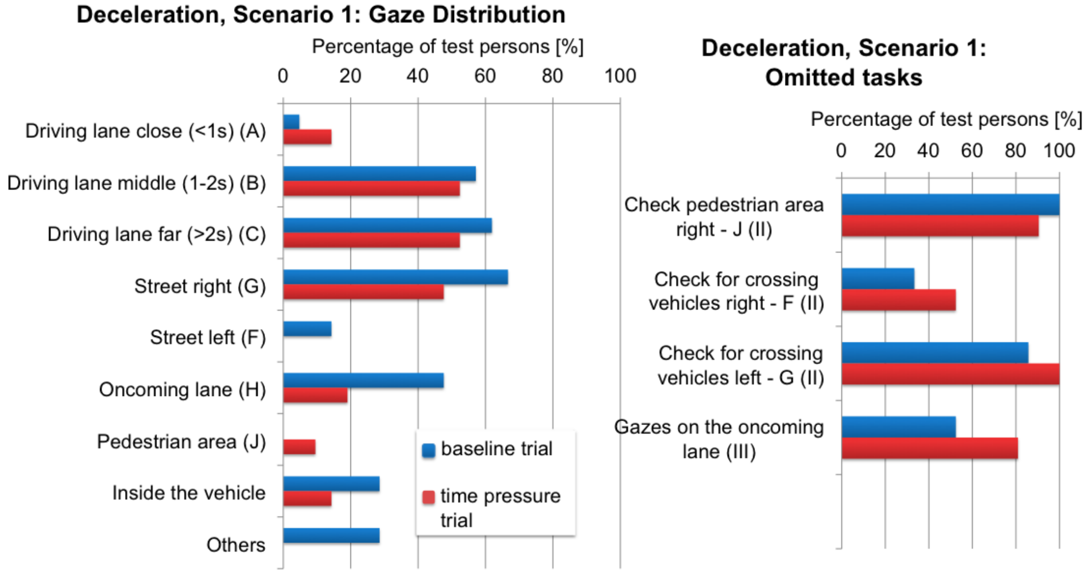


Figure 5.28: *The percentage of subjects focusing particular objects in Deceleration segment of Scenario 1 (left) and the percentage of test subjects omitting the particular tasks (right)*

and crossing vulnerable road users. These tasks have not been done by almost any of the drivers. Pedestrian pavements are not focused at all and the street from right is focused slightly more than the street from left. In general, the right side of the road in all intersections received more gazes than the left. Also, when checking for the crossing traffic, drivers almost never looked deep into the crossing streets but limited the gaze on the very junction area. With such strategies, a high speed crossing vehicle appearing from any of the crossing street would always result in a collision.

Crossing I phase. The next phase of performing the task in *Scenario 1* is the *Crossing I* segment. The distribution of the glance behavior and omitted tasks are presented in Figure 5.29. The right diagram in Figure 5.29 presents the most common omitted tasks in this segment. Again, these are the tasks of the second category. A very high reliance on the rule-compliant behavior of the others is visible in both trials. In this phase the drivers started again to focus the areas farther away, especially in the time pressure trial. Interestingly, more tasks were omitted in the baseline trial than in the time pressure trial. One explanation can be that in the time pressure trial drivers performed the tasks, which they did not have time to perform in the *Deceleration* segment. For example, in the time pressure trial, drivers reassured themselves that the vehicle from left did not take right of way - this is the task that should have been fulfilled in the previous phase. Such behavior is an indication that drivers' mental models are the same for the baseline and time pressure and that corresponding actions are committed in the same sequence if possible. If there is a lack of time, the tasks are delayed, as it is the case in this scenario.

Crossing II phase. The similar strategies are also shown in *Crossing II* segment. The visual behavior of participants is presented in Figure 5.30. Figure shows that the active search for the hazards is more emphasized in the time pressure than in the baseline trial. Also, the fact that the pedestrian

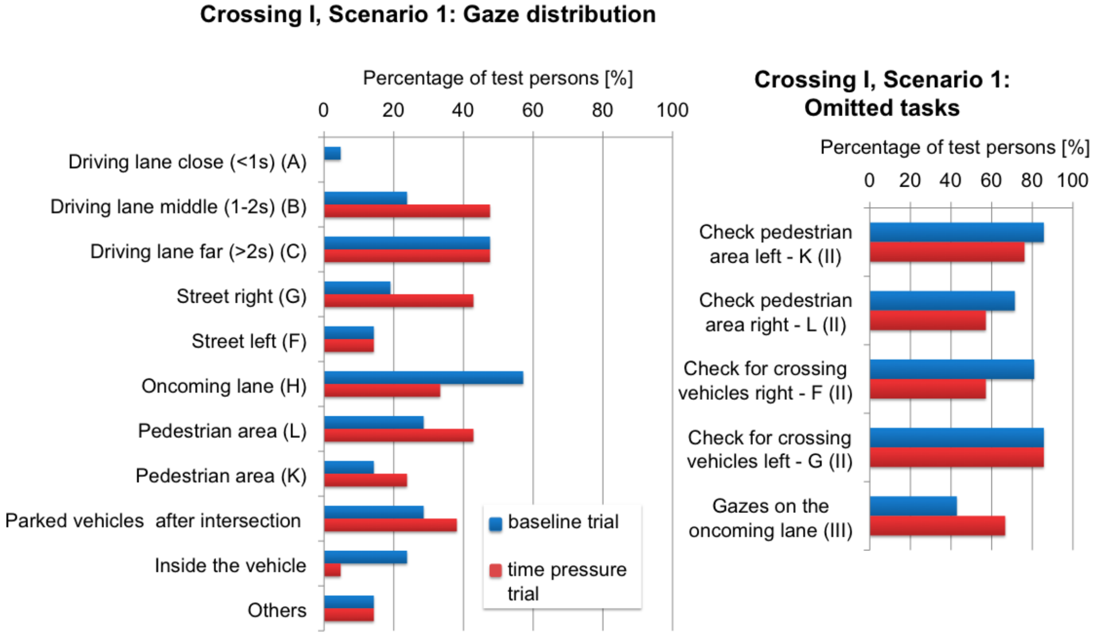


Figure 5.29: *The percentage of subjects focusing particular objects in Crossing I segment of Scenario 1 (left) and the percentage of test subjects omitting the particular tasks (right)*

area from the right street side (area L) was focused more during the trial with time pressure than in the baseline can be the part of drivers' techniques to focus far forward and does not have to mean that they specifically focused the pedestrian crossing.

Exit phase. In the last, *Exit* phase, the drivers' behavior was similar to the behavior in *Approach* segment. In both trials the main focus was on the far driven lane, and the gaze was stable and did not move too much. The detailed values are given in Appendix B.

Conclusive Summary. Within the presentation of results for *Scenario 1*, several remarks referred to all scenarios: the typical influence of time pressure on drivers' behavior, the visual strategies on the stabilization level of the driving task in both *Approach* and *Deceleration* phases, and the focusing of traffic signs. When performing the driving task at intersections, drivers usually have high safety reserve, as they are able to perform the maneuver twice as fast. The gazes of the *Approach* segment belonged largely to the own driving path. The focused distance depended on the maneuver and the presence of the other road users. For keeping the vehicle in the lane, the majority of drivers assessed the trajectory by focusing along own driving path. Only few subjects, who were experienced with the driving simulator environment, were able to drive without focusing along the driving path and were scanning the surrounding instead. The traffic signs were focused either in *Approach* phase or not at all and surprisingly few participants did this. Most probably, the recognition of the traffic sign is based on the peripheral recognition of the color and shape. The exception was the *Stop sign* which was focused by the majority of participants.

The driving under time pressure presents a typical speed-accuracy trade off. To compensate for the

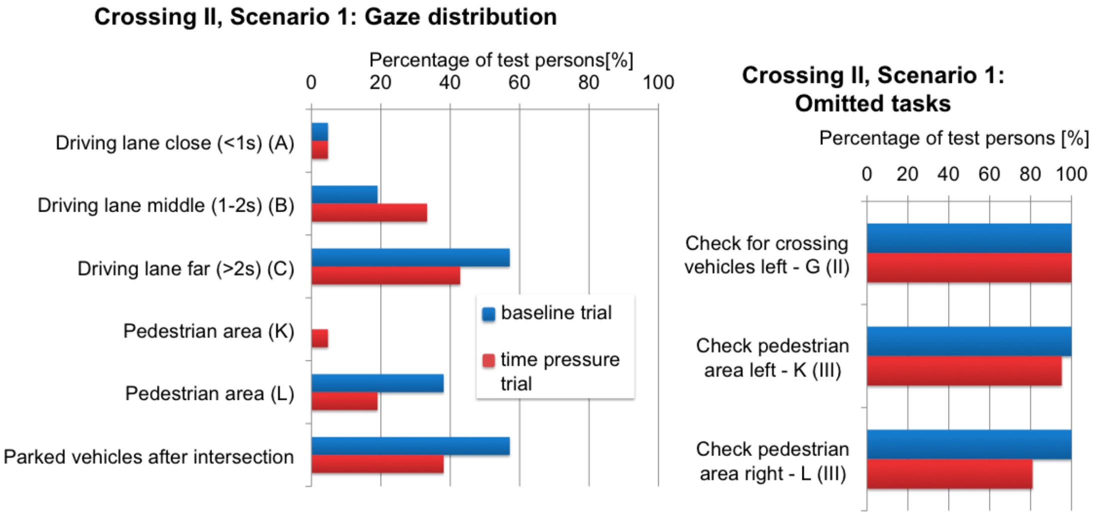


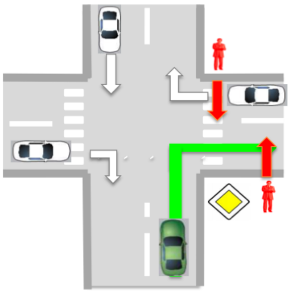
Figure 5.30: *The percentage of subjects focusing particular objects in Crossing II segment of Scenario 1 (left) and the percentage of test subjects omitting the particular tasks (right)*

high speed, the drivers apply such ”far-forward” strategy and are by that able to anticipate more in advance. In the baseline trial drivers probably expected to peripherally see the hazards because they had high time reserve to react on them. When driving at higher speeds the drivers were actively searching for hazards, as in case of their appearance they would not have enough time to appropriately react. However, such strategy is inappropriate for the detection of fast changes just in front of the vehicle. In general, the gaze in this phase changed only along the vertical axis and almost no horizontal movements were made; even oncoming lane was not focused by 76% of participants in the baseline and even 95% of them in the time pressure trial.

Scenario 2

Scenario 2 and analyzable test sample for this scenario are presented in Figure 5.31. The missing data are the same as for *Scenario 1*, except that the drive of TP 8 was successfully recorded. In the trial with time pressure TP 3 did not turn but continued to drive straight and this drive is therefore excluded from the analysis.

Unfolding of the scenario. *Scenario 2* presents the right turn scenario in which the subject vehicle approaches the intersection from the main street. The first part of the *Approach* segment is slightly curvy. In the second part of the *Approach* phase the intersection is fully visible. The visibility to the left and to the right is the same and it is about one width of the vehicle. From both left and right crossing street there is a vehicle, which is not on the collision path with the subject vehicle (white vehicles in Figure 5.31). There is also an oncoming vehicle, which is crossing the intersection. All of them are visible from the *Deceleration* segment on and they approximately reach the level of the subject vehicle in the phase of *Turning*. The vehicle from the right crossing street was usually executing the turn already during the *Deceleration* segment. During the *Turning* phase, the driver should yield to



Scenario 2
(C1-K3-F0)

		Baseline	Time pressure
Missing data	*Test Persons*	*5, 8, 9*	*3, 16, 24*
	Analyzable sample	21	21

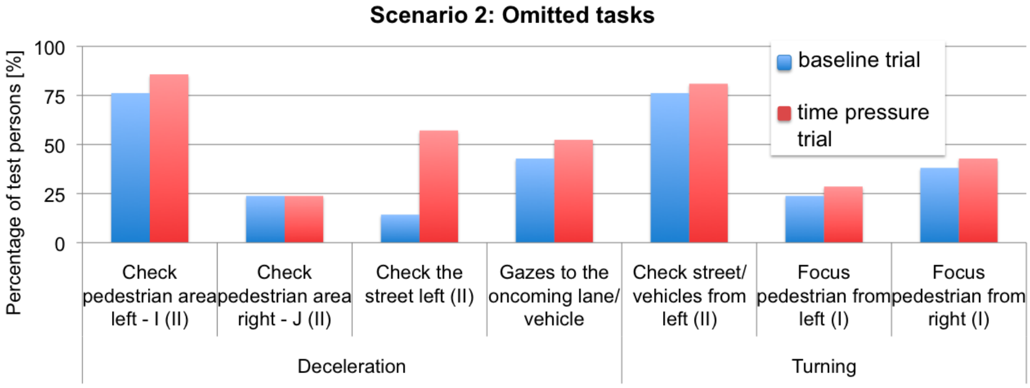
Figure 5.31: *Scenario 2 and analyzable test sample*

crossing pedestrians. In *Scenario 2* the unfolding of the situation in the trial with time pressure was in most cases very similar to the unfolding of the situation in the baseline. The pedestrians were triggered in each of the runs, but their position on the crossing depended on the speed of the subject vehicle.

As already discussed, the presentation of the results is focused on the most critical omitted tasks for each segment. This information is presented as it is considered to be of higher importance than the particular values of the glance durations. The knowledge about omitted tasks presents one of essential information for the modeling of driver cognition for the purpose of developing an assistance system. As it is shown in the following chapters, the model of the driver that is used for the development of assistance systems should focus on the erroneous behavior of the drivers. By knowing the percentage of persons performing such a behavior, a probability model of the driver behavior can be made not necessitating the modeling of all details of the deterministic mechanisms of the complete behavior. Another reason why particular values of the visual parameters are put in the second plan is because they can be considered only as the relative and not absolute parameters. The resolution of the applied eye tracking system and the evaluation procedure is such that no claims for absolute values can be made, and these values should be understood rather as the orientation values. Still, for the completeness, the particular values of glance parameters are presented in *Appendix B*.

Task Analysis. The comparison of the most critical omitted tasks for the baseline trial and time pressure trial for *Scenario 2* is given in Figure 5.32. Here only the omitted errors of the first and second category are presented. The visual strategies of keeping the vehicle in the lane and behavior towards the traffic signs have been presented within the analysis of *Scenario 1*. What is additionally of interest here regarding the stabilization strategies is that during the *Turning* phase, the drivers mainly focused one point at intersection, which probably served as a visual cue for keeping the control over the vehicle. This point was around the middle of the turning lane in the very crossing area of the intersection. When focusing such an *Anchor point*, the performance of the turn is easier to make, especially for novices. During this time, the scanning of the environment for the crossing pedestrians is drastically decreased. The number of glances during the turning phase is approximately around 4 and the glances are alternately drifting between the anchor point and the pedestrians on the crossing.

During the *Deceleration* phase, the drivers have to observe the junction area and to check for possible crossing pedestrians who can cross even though not having the right of way. There is no pedestrian



Test persons committing an accident / conscious violation		
	Baseline	Time pressure
Collision with the parked vehicle left in the *Approach* segment	none	21
Collision with the parked vehicle left in the *Deceleration* segment	none	23, 20
Collision with vehicle from the left in the *Crossing I* phase	none	21

Figure 5.32: *The most critical omitted tasks in Scenario 2 and test persons causing an accident*

crossing on the road ahead and the visual task of checking for pedestrians belongs to the second category - taking into account the possible erroneous behavior of the others. Figure 5.32 indicates that pedestrian areas are expected to be captured peripherally and the gazes to pedestrian areas I and J (see Figure 5.15) belong most probably to the general scanning of the whole scene rather than to the dedicated search. This explains why the right pedestrian area I, which is in the direction of the further driving path receives more gazes than the left pedestrian area J.

Figure 5.32 also shows that the left street was focused by the majority of subjects during the *Deceleration* segment, even though it does not belong to the own driving path. The reason is the vehicle appearing from the left, which shortly attracts the attention of the subjects. This vehicle is on average focused only once and that very shortly: for $0,37$ s in the baseline and $0,23$ s in the time pressure trial on average. As such, this gaze can be considered as a fully data-driven gaze. Just one test person (TP 9) did not focus the vehicle from left in this phase in the baseline. In the trial with time pressure even eight test persons did not focus the left area of intersection (in both *Deceleration* and *Turning* phase). Also, the oncoming direction was checked mainly during the *Deceleration* phase, but even though there was the vehicle present, 43% of participants in the baseline and 52% in the second trial, did not look in the direction of oncoming lane/vehicle.

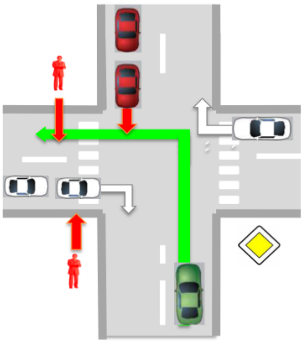
After the subjects started to turn, only few of them checked the street left of them to assure that the crossing traffic is behaving normatively. If the vehicle from the left was turning at that moment than the majority of the participants gazed at it. If there was no vehicle present than only around 62% of participants had the look to the left. The most frequent gaze sequence in this phase was a short look to the left and than look to the right. In around 40% of the cases, between the look to the left and right, there was the look in the oncoming direction. In the time pressure trial, these glances were left out by the majority of subjects. While *Turning*, the tasks of the first category, to focus and look for the crossing pedestrians were left out by some subjects. During the baseline, two test persons did not focus the crossing pedestrian, neither from left nor from right (TP 22 and TP 23). They only drove between the pedestrians endangering them. TP 15 and 14 also drove between them, even though they focused both of the pedestrians. The majority of test persons did not focus on both pedestrians but only on the pedestrian from the left side of street, following him by the gaze as long as he crossed the street. Meanwhile, the pedestrian from the right side crossed the street as well. The number of gazes on the pedestrian was on average more than one and these gazes lasted longer: approximately $0,4$ s and $0,66$ s for the baseline and time pressure trial, respectively. The similar behavior was shown during the trial with time pressure.

The influence of time pressure was reflected mostly in the behavior during *Deceleration* segment. Figure 5.32 shows that the major exception in the time pressure trial are omitted gazes to the left street in the *Deceleration* segment, which presents the task of the second category. As there were no tasks of the first category in this segment, these were the most critical omitted tasks.

Committed accidents. No accidents were committed in the baseline and four accidents were caused in the trial with time pressure (see Table in Figure 5.32). All these accidents happened because the drivers lost the control over the vehicle in *Approach* (TP 20, 21 and 23) or *Turning* phase of intersection (TP 21). As already mentioned, with the higher speeds this is particularly demanding task in the driving simulator and thus requires some practice.

Scenario 3

Scenario 3 and analyzable test subjects are given in Figure 5.33. For this scenario, there are 21 analyzable videos for the baseline and 22 for the time pressure trial.



Scenario 3
(C1-K3-F0)

		Baseline	Time pressure
Missing data	*Test Persons*	*5, 8, 9*	*16, 24*
	Analyzable sample	21	22

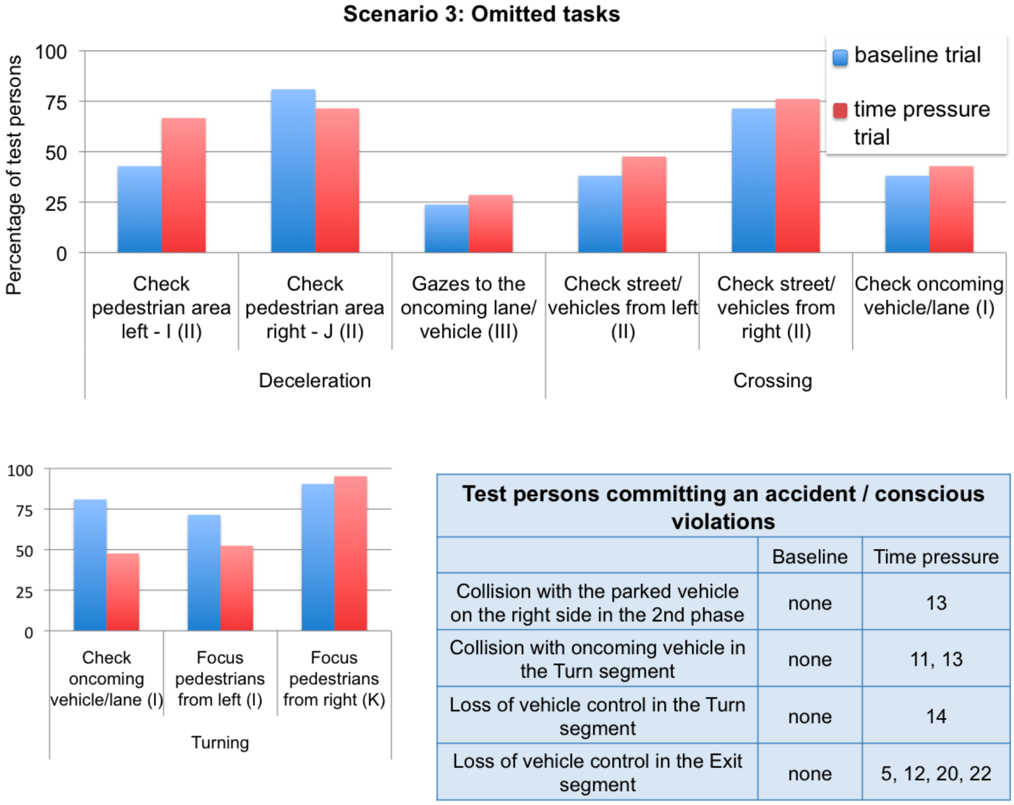
Figure 5.33: *Scenario 3 and analyzable test sample*

Unfolding of the scenario. In this scenario the subject vehicle drives along the main road and has the task to turn left. There are three chunks of objects that are in right of way regarding the subject vehicle: two oncoming vehicles and the crossing pedestrians in *Exit* segment (colored in red in Figure 5.33). The approach to the intersection is a straight road, without curvature and the crossing pedestrians are visible already in the *Approach* phase. The oncoming vehicle can be seen at the beginning of *Deceleration* segment. Apart from the road users having right of way, this scenario also include the crossing traffic from the left and right, which does not have right of way and is not on the collision course with the subject vehicle. The crossing vehicles are appearing in group of two: two vehicles from the left and two from the right. They are synchronized and they drive just behind each other, presenting by that one chunk of information. The crossing vehicles are approximately on the level of the subject vehicle at the beginning of the *Crossing I* segment. Oncoming vehicles usually passed the subject vehicle during the *Deceleration* phase. Only in few cases did drivers have to stop in the middle of intersection to give way to the oncoming traffic.

Task analysis. The most critical omitted tasks of the first and second category in *Deceleration*, *Crossing*, and *Turning* segment are presented in Figure 5.34. Theoretically, in the *Deceleration* segment, the drivers had to perform the very same tasks as in *Scenario 2*. However, the omitted tasks differ slightly: the pedestrian area from the left (I) was focused more and the pedestrian area from the right (J) less than in the previous scenario. In the time pressure trial, the pedestrian area right (J) was not focused at all. As in the previous scenario, these gazes most probably did not belong to the active search of these areas, but to the farther driving path and the scanning of the whole scene. The left area belongs to the direction of the farther driving path and is therefore scanned more, than the right area. Also, there is a pedestrian standing in this area, which is additionally attracting the attention. The gazes in the direction of oncoming lane in the *Deceleration* segment were similar as in the previous scenario. The oncoming lane was checked slightly more, but it was not clear whether this was the case because the participants were aware that oncoming traffic had the right of way or because the oncoming traffic was in the direction of the further driving path.

During the *Crossing I* segment, the majority of gazes belonged to the left street and oncoming lane. The majority of subjects did not focus on the right street even though there was a vehicle from the right executing a turn in this phase. The vehicles from the left were focused slightly more but still around 38% and 48% of participants omitted this task in both trials, respectively. Depending on the speed, some drivers had to stop in the middle of the intersection to yield both oncoming vehicles. In the baseline trial this was the case for five subjects and in the trial with time pressure for even 11 subjects. In the baseline trial all test persons checked the oncoming vehicle at least once except for the TP 23. In the trial with time pressure, two test persons did not focus on the oncoming vehicles having right of way (TP 9 and 12). They were driving very fast and turned before the oncoming vehicles, without looking whether there are other vehicles coming. The most frequent sequence of gazes in this phase was a short look to the oncoming direction (or long look if there was something to be seen) and than long look to the left. The look to the right between these two looks happened in only 25% of cases.

While executing the turn, the drivers had to either observe the oncoming vehicle and wait for him to pass or to check for the crossing pedestrians. Here only the pedestrian from the left area (area I) is relevant. Because of the limited acceleration of pedestrians in SILAB software, it was not possible to activate both pedestrians so that they can appear on the crossing exactly before the subject vehicle. Therefore the pedestrian from area I was activated earlier, so that he can show up on the pedestrian crossing just before the leading vehicle. The pedestrian K is still on the pavement in that moment.



Test persons committing an accident / conscious violations		
	Baseline	Time pressure
Collision with the parked vehicle on the right side in the 2nd phase	none	13
Collision with oncoming vehicle in the Turn segment	none	11, 13
Loss of vehicle control in the Turn segment	none	14
Loss of vehicle control in the Exit segment	none	5, 12, 20, 22

Figure 5.34: *The most critical omitted tasks in Scenario 3 and test persons causing an accident*

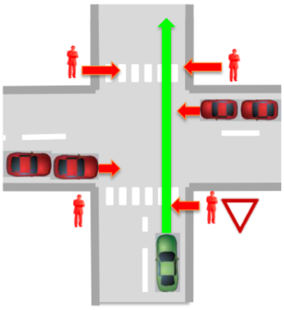
In the baseline trial 4 test subjects (TP 2, 3, 14, 22) drove before the pedestrian and in the time pressure even 13 of subjects. The pedestrian was focused only if he was directly on the own driving path. If the pedestrian was still in the left lane, 83% of participants did not focus him. The same as in the previous scenario, while executing the turn, the drivers mainly focused the junction area in the middle of the lane, improving by that the stabilization of the vehicle. The drivers had only few glances in this segment and again these were either *Anchor point* or the crossing pedestrians.

Similarly as in the previous scenario, the influence of the time pressure is mainly visible in the *Deceleration* segment. The subjects paid less attention to the possible crossing pedestrians, than in the baseline trial.

Committed accidents. In this scenario no accidents were committed in the baseline drive. In the trial with time pressure even six test persons lost the control over the vehicle, mainly while performing the turn. Two test persons (TP 11 and 13) committed an accident with the oncoming vehicle. Even though they focused it, they were driving two fast and collided with the rear part of the oncoming vehicle while executing the turn.

Scenario 4

The scenario and the analyzable test sample is presented in Figure 5.35. Up to the presented scenarios, *Scenario 4* presents the first one in which the subject vehicle approaches the junction from the subordinate street.



Scenario 4
(C1-K3-F0)

		Baseline	Time pressure
Missing data	*Test Persons*	*5, 8, 9*	*16, 24*
	Analyzable sample	21	22

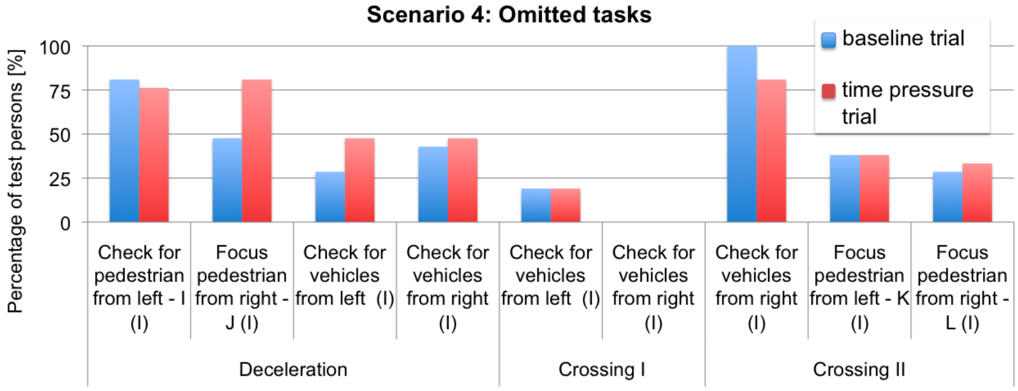
Figure 5.35: *Scenario 4 and analyzable test sample*

Unfolding of the scenario. There are six groups of road users, which have right of way regarding the subject vehicle in such scenarios: the crossing traffic from the left, the crossing traffic from the right, and the crossing pedestrians from both sides before and behind the junction. All of them are implemented and triggered in the testing scenario except for the pedestrian in area I. The pedestrian in area I was not activated and was standing still. By this, it can be analyzed how the bare presence influences the gazes in comparison to the pedestrians movement. The whole intersection, including the pedestrians, is visible in the *Approach* segment.

The crossing pedestrians were appropriately triggered and the drivers had to stop to yield to them in both trials. In the baseline trial, the drivers mainly had to stop to give way to the pedestrian on the first pedestrian crossing. Meanwhile, in the majority of tests, the pedestrians on the second crossing passed already. In the time pressure trial, the majority of drivers did not have to stop for the pedestrians on the first crossing but had to stop to yield to the pedestrians on the second pedestrian crossing. Because of the mentioned issue of the triggering logic in SILAB, it was not possible to arrange scenarios in a way that the subject vehicle has to yield to the pedestrians on both crossings.

The crossing vehicles from the left and right street were visible during the *Deceleration* segment. In the majority of test runs they crossed the junction area while subject vehicle was waiting for the pedestrian from the area J to cross. In some test runs, in the second trial, drivers arrived at the junction before the pedestrian did and therefore they had to stop to yield to the crossing traffic.

Task analysis. The most critical omitted tasks are presented in Figure 5.36. During the *Approach* and *Deceleration* segment, drivers mainly focused the far driven lane. The pedestrians standing on the pavement near the second pedestrian crossing provoked these gazes. Focusing on the possible crossing pedestrians from areas I and J presents the task of the first category. Yet, this task was rarely done. The left pedestrian area (I) is not checked by around 80% of participants in both trials. Still, compared to *Scenario 1*, which presents the same situation, this area is gazed slightly more. It can however not be clearly distinguished whether this is the case because the pedestrians were present in this scenario and were attracting drivers' gazes on the data-driven level or because drivers were aware that the pedestrians in this scenario had right of way. Also, the reason for more focuses may not be the pedestrians, but the fact that drivers should check the left street for the crossing vehicles. The difference between these two gazes is hard to distinguish. The same as in all other scenarios, the pedestrian area from the right was focused slightly more than the pedestrian area from the left. Anyhow, the difference between visual behavior towards possible crossing pedestrians in *Scenario 1* and *Scenario 4* can be considered as fully negligible.



Test persons committing an accident / conscious violations		
	Baseline	Time pressure
Changed to oncoming lane to avoid the pedestrian in the Exit segment	22	20
Drive over the pavement to avoid the vehicle from the right in the 3rd phase		12, 15

Figure 5.36: *The most critical omitted tasks in Scenario 4 and test persons causing an accident*

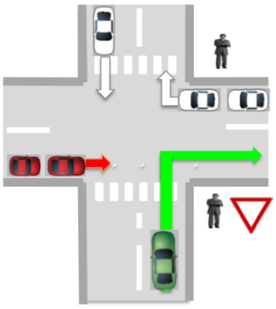
The possible crossing traffic, even though it would have the right of way, was not checked by some participants. In the trial with time pressure, even three subjects did not look to the left (TP 6, 22, 23) and two did not look to the right (TP 18, 23). Also several subjects checked only the junction area very shortly in both directions without viewing deeply into the street. The crossing traffic from right was focused on by all participants in both trials in *Crossing I* segment. Mostly, these gazes belonged to the area close to the junction and were not directed deeply into the street. The vehicles from the left were focused partly during the *Deceleration* and partly during the *Crossing I* segment. The gazes during the *Crossing I* segment were deep into the street. These drivers reassured once more that there were no vehicles from left. Drivers were frequently not focusing the vehicles directly but the fixations were between, in front, or behind them. In the *Crossing II* phase, drivers did not check anymore for the crossing traffic from the right, but focused more on the further driving path. The crossing pedestrians were fully visible in this segment and there was no violating behavior against them.

The influence of time pressure on the driver behavior in the *Deceleration* segment is in this scenario visible even more than in the previously presented scenarios. Figure 5.36 shows that focusing the pedestrian area from the right and checking for vehicles from the left were missing in higher extent than in the baseline. Both tasks are the tasks of the first category.

Committed accidents. In this scenario no accidents were committed. The table in Figure 5.36 lists the consciously committed violations of the normative behavior. In the baseline trial, TP 22 violated the traffic rules by driving in the opposite lane to avoid the pedestrian from the left. In the trial with time pressure, three other test persons showed the same behavior.

Scenario 5

Scenario 5 is presented in Figure 5.37. The analyzable test sample is the same as for the rest of scenarios except for TP 17 who missed to turn right in the trial with time pressure.



Scenario 5
(C1-K3-F1)

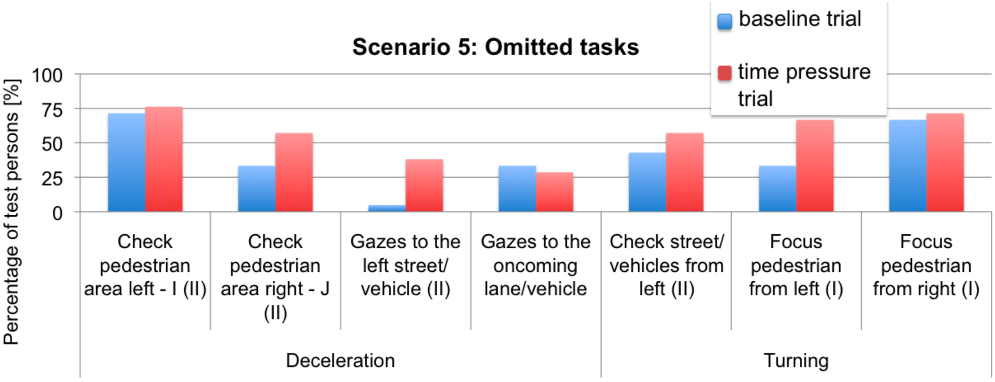
		Baseline	Time pressure
Missing data	*Test Persons*	*5, 8, 9*	*16, 17, 24*
	Analyzable sample	21	21

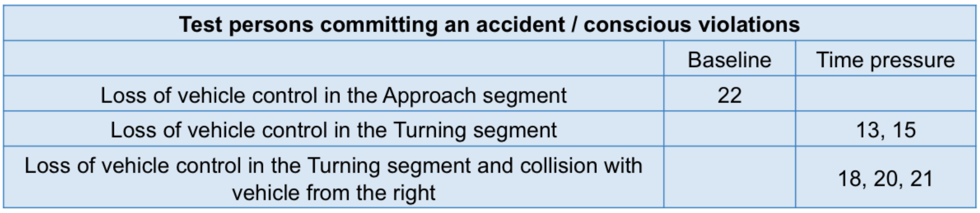
Figure 5.37: *Scenario 5 and analyzable test sample*

Unfolding of the scenario. In this scenario the subject vehicle also approaches the intersection from the subordinate road and has the task of turning right. There are three groups of objects having the right of way in this scenario. These are the crossing traffic participants in the *Deceleration* phase from two directions and the crossing traffic from left in the *Turning* phase. When the crossing pedestrians are present, the drivers have to stop to let them pass. Meanwhile, the crossing traffic with right of way would pass. It is very hard to trigger the scenario in a way that the subject vehicle has to stop to yield both the crossing pedestrians and crossing traffic. To eliminate this influence and to directly observe the drivers' behavior towards the crossing traffic, the crossing pedestrians in the *Deceleration* segment are left out. Also, in this way, the direct comparison with *Scenario 3* is possible. From the reason of comparison with *Scenario 3*, two another crossing pedestrians are placed in *Turning* phase in the respective pedestrian areas J and L. In this way the influence of the right of way on the driving behavior in the *Turning* phase can be examined without additional variance.

During the *Approach* segment both pedestrians could be seen. The oncoming vehicle and the crossing traffic from the right could be seen in the second phase. The oncoming vehicle reached the height of the subject vehicle in *Deceleration* or *Turning* segment in most of the test runs. Before turning, the drivers had to yield to the crossing traffic from the left. The vehicles from the right executed the turn at approximately the same moment at which the subject vehicle turned.

Task analysis. The most critical omitted tasks are presented in Figure 5.38. Even thought the pedestrian crossing is visible on the road already from the *Approach phase* almost no subject checked the pedestrian area from the left (I). A bit more subjects checked the pedestrian area from the right (J). This behavior is very similar to the behavior in *Scenario 2*. That the crossing pedestrians in this scenario, opposite to *Scenario 2*, would have right of way, did not influence the drivers' gazes.





Test persons committing an accident / conscious violations		
	Baseline	Time pressure
Loss of vehicle control in the Approach segment	22	
Loss of vehicle control in the Turning segment		13, 15
Loss of vehicle control in the Turning segment and collision with vehicle from the right		18, 20, 21

Figure 5.38: *The most critical omitted tasks in Scenario 5 and test persons causing an accident*

Also, the left street in this scenario is focused only slightly more than in *Scenario 2*, even though in *Scenario 2* the crossing vehicles do not have right of way, and are not on the collision course. In contrary, in *Scenario 5* the drivers have to yield to them. One test person (TP 10) did not at all look to the left. In time pressure trial even eight test persons did not check at all for the vehicles from the left side. They were looking either straight or to the right. The most frequent pattern of gazes was the following sequence: short look to the left, to the oncoming direction, and then the look to the right. In the majority of trials these gazes were related to the appearance of vehicles from these directions. When there was no oncoming vehicle, the gaze to the oncoming direction existed in only around 50% of cases.

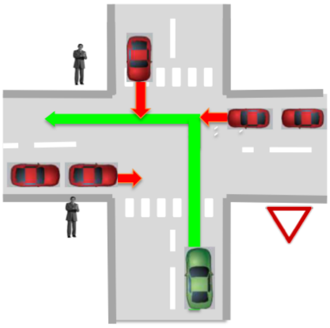
During the *Turning* segment, only few subjects reassured themselves again that there are no crossing vehicles from the left. Around 40% of subjects in the baseline and 60% in the time pressure trial, did not give way to the crossing pedestrians. In these cases pedestrians were mostly still not close to the vehicle but already on the street. Some test persons endangered pedestrians by driving without stopping in front of the crossing (TP 21 in the baseline and TP 19 in the time pressure trial). Both of them looked at pedestrians and focused them but still drove between them. When focused on, the pedestrians were focused on more than once and the duration was between $0,3$ to $0,6$ s.

When evaluating the influence of time pressure, the conclusion is arrived at, that the main portion of omitted tasks is again during the *Deceleration* phase. Interestingly, this is the same task, which was mostly omitted in *Scenario 2* in the time pressure trial: checking the left street. Additionally in *Turning* phase, the majority of participants omitted the gaze to the pedestrian from the left. This pedestrian was in most test runs still on the parallel lane during the turn execution.

Committed accident. Figure 5.38 shows that one accident was caused in the baseline trial by TP 22 because of the loss of control of the vehicle in the *Approach* segment. In the time pressure trial, three test persons collided with the vehicle from the right because of the loss of control and two additional test persons lost the control over the vehicle in the *Turning* segment.

Scenario 6

Figure 5.39 presents the *Scenario 6* and the analyzable test sample. For the baseline drive, five video recordings are missing and for the trial with time pressure, there are 22 analyzable recordings.



Scenario 6
(C1-K3-F2)

		Baseline	Time pressure
Missing data	*Test Persons*	*3,5,8,9,16*	*16, 24*
	Analyzable sample	19	22

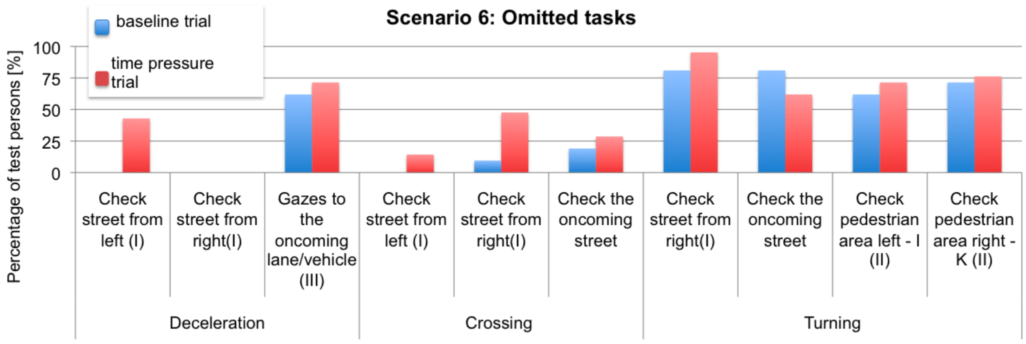
Figure 5.39: *Scenario 6 and analyzable test sample*

Unfolding of the scenario. In this scenario the subject vehicle approaches the junction from the subordinate street and has the task of turning left. There are altogether five groups of objects having right of way: crossing pedestrian in the *Deceleration* segment, crossing traffic from the both sides, and oncoming traffic. Therefore the task to be accomplished in this scenario is among the most complex tasks at intersections. The drivers have to actively follow five groups of independently moving objects, stabilize the vehicle, and all the time have in mind which directions should they give way to. The additional observation of the possible erroneous behavior of participants not having right of way exceeds the human cognitive limits. Only going straight when not having right of way presents the more complex maneuver.

All road users having right of way are implemented in the simulated scenario except for the crossing pedestrians on the first pedestrian crossing. They are excluded so that this scenario can be compared with *Scenario 3*, which is also the left turn scenario. Also, this scenario is analyzed in the variant with the leading vehicle *(Scenario 8)*. If the crossing pedestrians would be present, they would interfere and influence the behavior of the leading vehicle and no clear comparison could be made. Therefore no crossing pedestrians on the first crossing are included neither in this nor in *Scenario 8*.

To be as similar as possible with *Scenario 3*, two pedestrians are placed in areas I and K, and they are triggered to go over the crosswalk in the *Exit* segment of intersection. Already during *Approach* segment, these pedestrians are visible. The remaining traffic participants can be seen in the *Deceleration* segment. The triggering is the same as in *Scenario 3*. The oncoming vehicle passed the subject vehicle already during the *Deceleration* phase and only few drivers had to stop in the middle of intersection to yield to the oncoming vehicle.

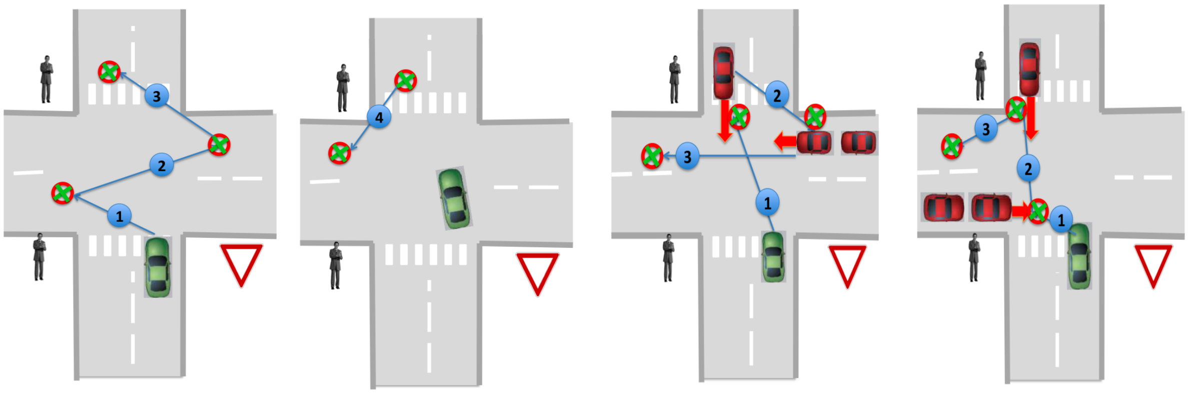
Task analysis. The most critical omitted tasks are presented in Figure 5.40. In the *Deceleration* segment pedestrian area from the left (I) was focused more than the pedestrian area from the right (J). This is very similar to *Scenario 3*. During the baseline, no drivers directly scanned the area J for pedestrians, however, the majority of them focused the junction area of the right crossing street. For such gazes the pedestrian area J is captured by the peripheral field of view and it is unnecessary for this area to be scanned directly. As the visual behavior towards crossing participants is fully comparable to *Scenario 3*, it is not presented in Figure 5.40.



Test persons committing an accident / conscious violations		
	Baseline	Time pressure
Drive into the left lane in the Exit segment	22	
Collision with the crossing vehicle from the left in the 3rd phase		18
Collision with the crossing vehicle from the right in the 4th phase		20, 22
Loss of vehicle control in the Turning segment		13

Figure 5.40: *The most critical omitted tasks in Scenario 6 and test persons causing an accident*

The crossing streets were focused by all test persons both during the *Deceleration* and *Crossing I* segment in the baseline trial. In the trial with time pressure, the crossing traffic was either focused on during *Deceleration* or during *Crossing I* segment. No test persons left out the gazes to the crossing street; still, few of them caused an accident with the crossing traffic. The reason is that the gazes were not given in an appropriate moment. The scanning sequence differed depending on the presence of other road users in the scene. If the junction area was free of the other traffic participants, the gaze sequence was usually as in Figure 5.41(a): first a look to the left, then look to the right, followed by the look in the oncoming direction, and then, in the *Crossing I* phase, a look to the left again. In the moment the drivers reached the middle of the intersection, they executed the left turn without checking any other direction.



(a) (b) (c)

Figure 5.41: *Typical gaze sequence in Scenario 6 for (a) Crossing I and Turning segment when no other road users were present in the junction area, (b) Crossing I segment in the presence of the right and oncoming traffic (behavior of TP 18), or (c) Crossing I segment in the presence of the left and oncoming vehicles (TP 20)*

When scenario unfolded so that other vehicles were present in these phases, the gazes were mostly data-driven. Typical gaze sequences in this case are presented in Figure 5.41(b) and in Figure 5.41(c). In the time pressure trial, both oncoming vehicles and both vehicles from the left were present in the segment of *Crossing I*. In such circumstances drivers did not look to the right at all. It seems that in the presence of more than 4 road users, the gazes become fully data-driven. This number of objects in the scene causes the drivers to replace the top-down driven strategies with completely data-driven mechanisms of eye movements. Such behavior can lead to critical situations because the appearance and movements of other road users almost fully control drivers' gazes and the most relevant directions may not be scanned at all.

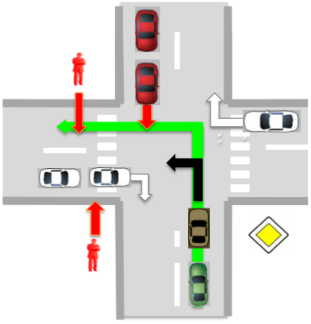
The main influence of the time pressure in this scenario is in *Deceleration* and *Crossing I* segments. In the baseline trial, the crossing streets were checked twice, once in each phase, where in time pressure trial, the crossing streets received only one gaze. In several cases, this gaze was not given in an optimal moment, which was the cause of the committed accident.

Committed accidents. The table in Figure 5.40 sums up all accidents and conscious violations committed in *Scenario 6*. In the baseline trial TP 22 committed conscious violation by moving to the opposite lane to avoid the pedestrian in the last segment of intersection. During the time pressure trial, TP 18 lost the control over the vehicle in *Turning* segment. Three other accidents happened with the crossing traffic: TP 18 collided with the vehicle from left, and TP 20 and 22 with the vehicle from right. TP 18 and 22 did not look to the left but only to the direction of own driving path. TP 20 focused on the vehicles from the right but did not look to the left. Figure 5.41(b) show the gaze behavior of TP 18 and Figure 5.41(c) the behavior of TP 20. These sequences present the discussed, critical, data-driven visual behavior.

Here it should be noticed that the accident did not actually happened in the simulator. The vehicles have the collision protection and are performing a full stop before the collision happens. In the experiments described in [Plavsic09a], it is observed that when the subjects experience the accident in the simulator, which is without consequences, they start to behave more unrealistically.

Scenario 7

Scenario 7 and analyzable test sample for this scenario are presented in Figure 5.42. Test person 1 missed the turn and videos of the other test persons are missing because of the loss of connection with the Dikablis eye tracking system.



Scenario 7
(C1-K3-F2)

		Baseline	Time pressure
Missing data	*Test Persons*	1,5,8,9,16	*16, 24*
	Analyzable sample	19	22

Figure 5.42: *Scenario 7 and analyzable test sample*

Unfolding of the scenario. This scenario is the same as in *Scenario 3* except that there is a leading vehicle present, during the first three segments. The leading vehicle is visible from the *Approach* segment and is also turning to the left before the subject vehicle in the *Turn* segment. The leading vehicle did not have to stop to yield the crossing pedestrians in *Exit* segment in contrast to the subject-vehicle. The triggering of the other road users is same as in *Scenario 3*.

Task analysis. The omitted tasks and the visual behavior in this scenario are comparable to the omitted tasks and visual behavior in *Scenario 3*. The only difference is that in *Scenario 7* the drivers focused on the leading vehicle instead of scanning the area around. The leading vehicle presents the AOI that received the highest number of glances on average among all AOIs in all presented scenarios. In the *Deceleration* segment the average number of glances on the leading vehicle is higher than 4 and in the trial with time pressure even higher than 5. Mean glance durations are around 1 s but there were participants focusing this vehicle for $1,8$ s in both trials. The visual behavior towards the leading vehicle in *Crossing I* segment is similar to the behavior in *Deceleration* segment. The average number of gazes in the time pressure trial is also 4 as in the baseline trial, and the mean and maximal durations are decreased from $0,52$ s and $1,23$ s in the baseline, to 1 s and $1,59$ s in the time pressure trial.

Depending on the speed, the unfolding of the scenario was different between the test persons. Therefore the clear comparison between the baseline and time pressure is hard to make as well as among subjects within the same trial. Conclusively, when the leading vehicle was present, drivers mainly orientated according to the leading vehicle and the gazes were data-driven. Also, the same as in the previous scenario, when there were no other vehicles present, the most frequent pattern of gazes while turning was following sequence: a look to the left, look to the oncoming direction, and than a look to the right (see Figure 5.41(a)). When the leading vehicle was present, the gazes usually drifted around the leading vehicle.

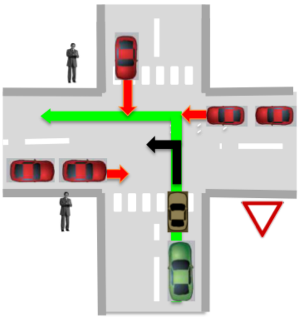
Table 5.5: *Test persons causing accidents in Scenario 7*

Test persons committing an accident / conscious violation		
	Baseline	Time pressure
Collision with the leading vehicle in the Deceleration segment	5, 20, 22	13, 22
Loss of vehicle control in the Turning segment	10	13, 14,20
Overtaking of the leading vehicle and loss of control in the 3rd phase		18

Committed accidents. The Table 5.5 lists the test persons committing an accident in *Scenario 7*. In the baseline trial, four test subjects lost the control over the vehicle. TP 5, 20 and 22 collided with the leading vehicle and TP 10 lost control over the vehicle in the *Turning* segment. In the time pressure trial two subjects caused a rear collision with the leading vehicle and three lost control while turning. One test person TP 18 overtook the leading vehicle in the third phase and also lost control.

Scenario 8

Scenario 8 is presented in Figure 5.43. The analyzable test sample is the same as in the first five scenarios, except that two test persons missed to turn in the baseline drive.



Scenario 8
(C1-K4-F2)

		Baseline	Time pressure
Missing data	*Test Persons*	*5,8,9, 14*	*16, 18, 24*
	Analyzable sample	21	22

Figure 5.43: *Scenario 8 and analyzable test sample*

Unfolding of the scenario. This scenario is a copy of *Scenario 6* with the addition of the leading vehicle. The leading vehicle is merging into the traffic just before the *Approach* phase and is present throughout the whole intersection. The leading vehicle was driving slower than in *Scenario 7*.

Task analysis. The gazing strategies were the combination of gazing strategies in *Scenario 6* and *Scenario 7*. The leading vehicle was influencing the driver behavior even more than in *Scenario 7* because it was driving slower. Otherwise the typical sequence of glances did not differ between these three scenarios. The maximal average duration of the gazes on the leading vehicle in the

Deceleration segment was higher than critical 2 s and it was $2,45$ s in the baseline trial and $2,27$ s in the time pressure trial. During the *Crossing I* segment the gazes to the leading vehicle were also critically long. One test person (TP 19) was focusing the leading vehicle almost exclusively throughout the whole scenario.

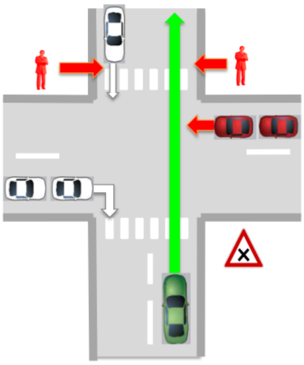
Table 5.6: *Test persons causing accidents in Scenario 8*

Test persons committing an accident/ Conscious violation		
	Baseline	Time pressure
Overtaking of the leading vehicle in the 1st phase	20, 21	18, 19, 22
Collision with the leading vehicle		3, 11, 14, 20
Collision with the vehicle from the right	16, 23	21
Collision with the vehicle from the left		19
Loss of vehicle control in the Turning phase		22

Committed accidents. No collisions with the leading vehicle were committed in the baseline but two test persons (TP 20 and 21) overtook the leading vehicle in the *Approach* segment causing by that the collision in the third segment (see Table 5.6). In this scenario the leading vehicle was driving slower than in *Scenario 7* and that is why several test persons overtook it. Two test persons (TP 16 and 23) collided with the vehicle from the right in the *Turning* segment. Both of them showed the same gazing behavior. They looked to the right, gave way to the first vehicle and did not look any more for the further vehicles from the right side. In the time pressure trial, four subjects collided with the leading vehicle and even three overtook it in the *Approach* phase. Consequently, one of them had a collision with the crossing vehicle from the left (TP 19) and another one with the vehicle from the right (TP 22).

Scenario 9

Scenario 9 and analyzable videos for this scenario are presented in Figure 5.44.



Scenario 9
(C1-K2-F0)

		Baseline	Time pressure
Missing data	*Test Persons*	*5,8,9,16*	*16, 24*
	Analyzable sample	20	22

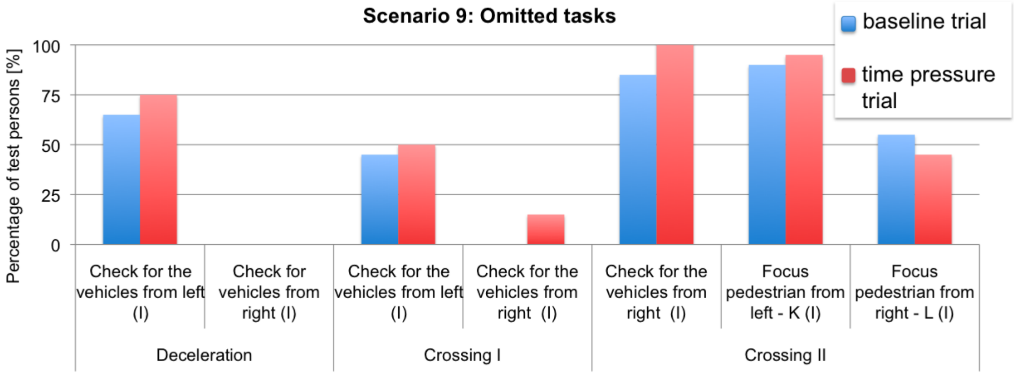
Figure 5.44: *Scenario 9 and analyzable test sample*

Unfolding of the scenario. This scenario presents the scenario in which the subject vehicle approaches an unordered intersection. At such intersections, the road users coming from the right have right of way. Two vehicles are coming from the right crossing street in this scenario and the driver should yield to them. There is also crossing traffic from the left, which does not have right of way and is not on the collision course with the subject vehicle. On the second pedestrian crossing there are two pedestrians on the crosswalk and the subject vehicle has to stop to let them cross.

The crossing vehicles from the right could be seen during the *Deceleration* segment. The vehicles from the left executed the turn at the end of *Deceleration* segment, being at about same height as the leading vehicle. The oncoming vehicle could be seen already in the *Approach* segment, but as it stops to yield to the crossing pedestrians, this vehicle can be seen almost throughout the whole intersection. This scenario presents the crossing maneuver when having to yield to the crossing traffic and even though only the vehicles from the right side have right of way, this scenario is comparable to *Scenario 4* and *Scenario 10*.

Task analysis. The most critical omitted tasks are presented in Figure 5.45. As in all other scenarios, the pedestrian areas left (I) and right (J) from the first pedestrian crossing were not actively scanned. The pedestrian area from the right street was focused more than the pedestrian area from the left street. During the *Deceleration segment*, the majority of gazes belonged to the right area of the further driving path. The crossing street from the left was not focused on by any of the participants, where the right crossing street was gazed on by all of them. However, as in all other scenarios these gazes belonged mainly to the junction area.

During *Crossing I* segment, both crossing vehicles from the left and right could be seen and therefore both directions attracted the attention of the participants. One test person (TP 18) did not look neither to left nor to the right and collided with the crossing traffic from the right street in the trial with time pressure. For three subject it was obvious that they were not aware that only the traffic from the right side has the right of way. They stopped at the crossing and were hesitating to drive further and were checking for the traffic from both crossing streets.



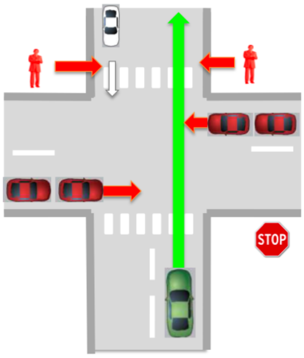
Test persons committing an accident		
	Baseline	Time pressure
Collision with the vehicle from the right		18

Figure 5.45: *The most critical omitted tasks in Scenario 9 and test persons causing an accident*

The influence of time pressure in this scenario was in particular reflected in leaving out the gazes to the right in the *Crossing I* segment. Instead, these gazes were performed during the *Deceleration* phase. The other aspects of resulting behavior in this scenario are similar as in *Scenario 4*, therefore, no further details are given here.

Scenario 10

Scenario 10 is presented in Figure 5.46. The analyzable test sample is the same as in the first five scenarios.



Scenario 10
(C1-K5-F0)

		Baseline	Time pressure
Missing data	*Test Persons*	*5,8,9*	*16, 24*
	Analyzable sample	21	22

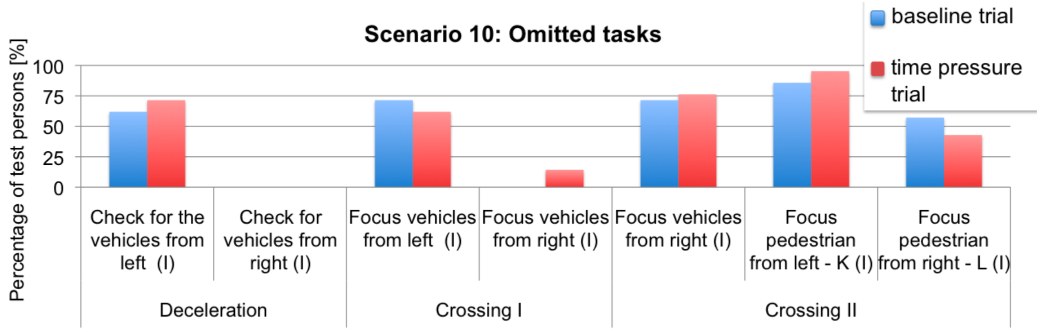
Figure 5.46: *Scenario 10 and analyzable test sample*

Unfolding of the scenario. In this scenario the subject vehicle approaches the junction from the subordinate street. The street along which the subject vehicle approaches is regulated by *Stop sign*. The participants were given the task to cross the intersection. Other than this regulation, this scenario is similar to *Scenario 4* and *Scenario 9*. The same as in *Scenario 4*, there are six chunks of road users to which the driver has to yield to. This presents the highest number of chunks to which it can be yielded to at one intersection and therefore this task presents the most complex task to conduct. However, executing the left turn from the subordinate street was evaluated as subjectively more difficult.

In the analyzed scenario, all road users having right of way are implemented except for the crossing pedestrians on the first crosswalk. They were left out for the same reason as in other scenarios. In case of their presence it would not be possible to analyze the behavior regarding the traffic sign and crossing traffic.

Task analysis. The most critical omitted tasks are presented in Figure 5.47. As discussed within the presentation of results for *Scenario 1*, in contrast to all the other scenarios, almost all subjects foveally focused on the traffic sign. Also, except for the TP 22 in the baseline and TP 11 in the trial with time pressure, all subjects performed a halt at *Stop sign*. These two subjects did not foveally focus *Stop sign*, they were only gazing in the direction of their own driving path. TP 22 also collided with the vehicles from the left, as he did not look to the left.

The average visual behavior of all participants in this scenario was very similar to the visual perfor-



Test persons committing an accident		
	Baseline	Time pressure
Not stopping at the Stop-sign	22	11
Collision with the vehicle from the left		22

Figure 5.47: *The most critical omitted tasks in Scenario 10 and test persons causing an accident*

mance in *Scenario 9*, even though in *Scenario 9* only the traffic from the right side has right of way. The behavior is similar regarding the omitted tasks (as it can be seen from the comparison of Figure 5.45 and Figure 5.47), but also regarding the typical glance sequences. Therefore the further details for this scenario are not given here.

5.5 Conclusion

Within this section, the drivers' visual behavior among scenarios will be compared to each other and generalized. Further, the suggestions for the Intersection Assistance System are given, based on the conducted theoretical and experimental analysis and advanced research in this field.

5.5.1 Similarity and Difference in Applied Visual Strategies among Scenarios

The subjectively collected data revealed that intersection scenarios present a highly demanding task for the driver. The individual dimensions of the mental workload were evaluated higher than 80% on average and individual evaluations even reached 100% for the time pressure trial. There is a high driver's desire to receive the support in these tasks. However, even though the drivers expressed a wish for an Intersection Assistance system, they did not have a clear concept of the possible functionality, except that they did not want a warning assistance.

The subjective evaluation of the task difficulty and the difficulty of orientation comply with each other and present one dimension for the driver. The subjective evaluations of the task difficulty differ significantly among scenarios. Their rank has almost the same order as the rank order of the objectively evaluated task difficulty by the means of the suggested heuristics in *section 5.3.3*. The only difference is that subjects underestimated the task difficulty of crossing the intersection when not being in right of way. Instead, the tasks of executing the left turns were evaluated as subjectively more demanding. The subjective risk of the incorrect evaluation and the risk of collision did not show any significant differences among the scenarios for $p < 0.05$.

The analysis of the objective data clearly showed the existence of both, bottom-up (data-driven) and top-down (knowledge-driven) eye movements mechanisms. It is concluded that the presence of the road users is the strongest shaping factor of the visual behavior. The data-driven behavior, the behavior driven by the presence of the other road users in the scene, is a predominant behavior. If more than 4 objects were present in the scene, the visual behavior was even fully data-driven: it was the same independently of the performed maneuver or right of way. The consequence in complex scenarios was the omission of the looks in the directions that have the right of way (see Figure 5.41(a) and 5.41(b)). In contrast, the top-down strategies, which present the active search of the scene and are the result of the drivers' mental models, were influenced by intersection parameters. The influence of the maneuver was hereby stronger than the influence of the right of way.

Approach phase. The visual behavior, which serves for the stabilization of the vehicle, depends mainly on the maneuver to be performed. In the *Approach* segment, drivers mainly focused on the middle ($1-2$ s) and on the far driving path (> 2 s) and to around 60% to its right side. In the time pressure trial, the highest ratio of gazes was directed to the far driving path. Here, the areas close to the vehicle were scanned just before the crossing. The most important tasks for the *Approach* segment are anticipatory tasks and the only visual task of the first category is focus on the traffic sign and corresponding adaptation of the behavior. However, with an exception of the *Stop sign*, only around 60% of participants did foveally focus on the regulation signs. For the time pressure trial, this percentage is less than 50%. For around 5% of the test runs, it can be assumed that the participants did not perceive the traffic sign at all and were not aware of the regulation of the right of way.

Deceleration phase. During the *Deceleration* segment, visual tasks of the first and second category had to be realized. The safe performance and correct anticipation in this phase is of essential importance for the safe performance of the complete driving task. It is in this phase when the drivers create the mental model of the whole scenario and select an appropriate reaction. Also, the accidents that resulted in the third and the fourth phase of intersection performance were usually caused by the errors committed in the *Deceleration* segment. But as the analysis showed, the resulting behavior in this segment differed quite from the hypothetically ideal one. The areas from where the vulnerable road users can come from were not foveally scanned. If the pedestrian was not present, it was not actively looked in that direction. The resulting behavior was the same independently of the right of way of the crossing pedestrians. They were probably expected to be seen peripherally. This is also true for the vehicles not having right of way. In general, only around 15% of participants did actively reassure themselves against the erroneous behavior of the others. In the time pressure trial this task was almost completely left out. Also, the influence of the time pressure was the strongest in this phase and the result was the omission of the essential tasks in this segment. In other segments the time pressure did not have such high influence. Hence, the driving tasks in the *Deceleration* segment are the vital tasks and their accomplishment should be supported by an Assistance System. The possible functionalities are discussed in the next section.

Turning phase. In the *Turning* segment the visual performance was characterized by focusing on the point in the middle of the crossing street. This point is labeled the *Anchor point* because it serves for the better orientation and stabilization of the vehicle while executing the turn. The glances in this segment were alternatively moving between *Anchor point* and the crossing pedestrians. The majority of the drivers focused on the crossing pedestrians, however, around 50% of them focused on only one of the pedestrians. The typical glance sequence for the right turn maneuver was a short glance to the left and then look to the right. In around 40% of the cases, between the glance to the left and to the right, there was a glance to the oncoming direction. For the left turn maneuver, the typical glance sequence was a look to the left, glance to the right, glance to the oncoming direction, and then look to the left. If having the right of way, the first look to the right is performed in only around 25% of cases. While performing these glances, drivers reached the middle of intersection and did not perform the necessary look to the right anymore. The influence of the other road users on the drivers' visual behavior was very high in this segment and it frequently caused a faulty glance sequence, resulting in overlooking of vehicles having right of way. Other faulty behavior was the behavior regarding the crossing pedestrian in this segment. In the time pressure trial, the pedestrian from the left side of the street was rarely focused on. Also, the crossing pedestrians were subjectively evaluated as one of the most hazardous objects in the scene. Therefore the potential for the assistance support exists in this segment as well.

Crossings and Exit phase. When having the task to cross the intersection, the drivers performed the crossing at once, meaning that the behavior between *Crossing I* and *Crossing II* did not differ notably. The drivers picked the appropriate time gap for both, the left, and the right traffic at once. The most critical omitted task in these segments is that drivers did not reassure themselves for the normative behavior of the other road users. The attention in this segment was mainly directed towards the right area of the nearer driving path. If the pedestrians were present on the second crossing, they were focused; otherwise the attention was again directed towards the further driving path. The errors committed in these segment were not as critical as in the previous segments and the urgency of the support is in these two segments lower than in the others. The similar conclusion is arrived at for the *Exit* segment. The drivers rarely showed critical behavior in *Exit* segment and the requirements on the assistance system in this phase are of less urgency.

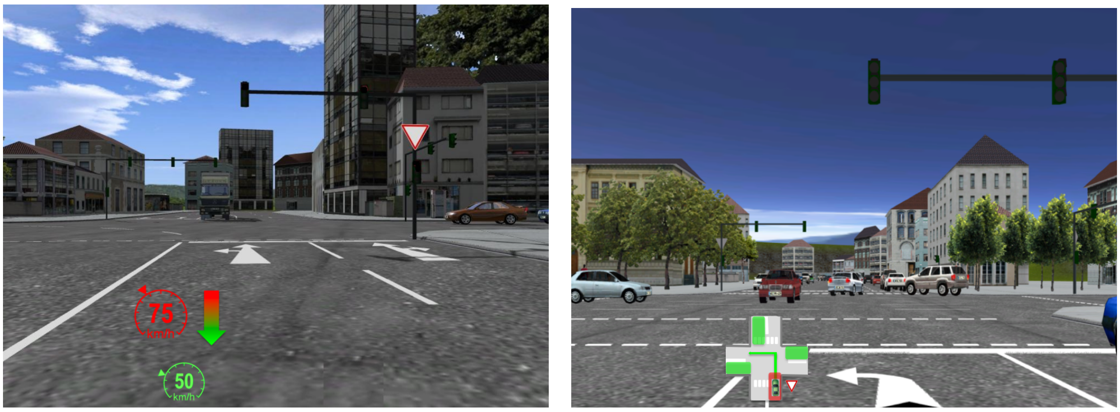
A noteworthy observation of the conducted analysis is that mainly the same persons showed the same behavior, be it foveal focusing on the traffic signs, omission of the particular tasks or the average number of glances during the segment. This supports the hypothesis that the high ratio of committed errors is of systematical nature and can be prevented. As such deficient behavior does not present a conscious violation but is a bad driving strategy developed through experience, a guiding, informative assistance, discussed in the *Chapter 2*, would be very beneficial for these drivers and would help them to improve the quality of mental models they apply.

In the following, the several ideas for the functionality of Intersection Assistance are given, based on the presented conclusions.

5.5.2 Suggestion for Intersection Assistance System

The *Deceleration* segment presents a phase in which the driver may benefit the most from an appropriate assistance support. This is concluded from the previous analysis, which showed that the errors committed in this segment frequently present the first errors in the following chain of errors that eventually result in an accident.

The high number of committed errors in this segment results from an inappropriate speed. Also, the influence of the time pressure was the highest in this segment by causing the driver to increase the speed. The result was the increased visual focus on the horizon area and dangerously insufficient scanning of the environment and junction area. Therefore a simple but highly beneficial form of an Intersection Assistance System may be an Assistance System that is suggesting the driver to reduce the speed in the *Deceleration* segment. [Davidse09] showed that an appropriate information, instead of warnings or autonomous system behavior can be highly efficient. Notifying the driver of the high speed should not result in a warning but instead the deviation from the appropriate speed could be shown. A symbolic sketch is given in Figure 5.48(a). Figure gives a simple visualization of the speed suggestion assistance in a Head-up Display. The exact presentation of such assistance is a topic which should be directly researched. Relevant presentations, but for different scenarios, can be found elsewhere, like in [Thoma10] or [Tönnis09]. Additional topic worth examination is delivering the message to the driver in other or additional modalities [Bengler01].



(a) (b)

Figure 5.48: *Suggestion for an Intersection Assistance system in the Deceleration phase (a) Speed suggestion, (b) Visualization of the priority roads*

Another possibility for an Assistance System to support the driver is to decrease the driver's workload by taking over the most demanding subtasks. From the analysis of the resulting behaviors, it is concluded that keeping the traffic rules in mind represents one of the most demanding task for the driver. For example, in the moment when the driver is in the middle of an intersection and there are traffic participants from all directions and the driver should additionally execute the turn and stabilize the vehicle, it is very demanding for the driver to be aware of the regulating rules and ranks of the present road users. Additionally, the experimental analysis has shown that sometimes drivers do not even perceive the regulation sign at all, neither foveally nor peripherally.

Therefore an assistance system, which is at critical moments showing the driver the directions he should give way to, relieves drivers' workload to a high extent. The driver should be given a clear cue on who has priority. If the situation is unclear or the driver forgets the rules in the critical moments, he will try to control the situation and the result is performance of unnecessary tasks and neglect of the important ones. Such behavior has resulted in several accidents in the conducted experiment. The simple sketch of such assistance is given in Figure 5.48(b). The sketch presents a bird's eye view of an intersection, with right of way roads marked with green color and the minority-approaching road marked with a red color. In this way the prioritization of the most relevant information is already done for the driver and he does not need to keep this fact in working memory. The bird's eye view has been shown in [Plavsic09b] to be the best solution for the presentations that require the understanding of the spatial relations. Again, the final visualization of such assistance requires an extensive research.

Another functionality of Intersection Assistance in the *Deceleration* segment can be the prevention of frequent errors committed during the *Turning* phase. For example, faulty glance sequences, performed by around 40% of participants when turning, can be eliminated by an appropriate assistance. One possible way to intuitively present the priority directions for scanning can be an animation of the hypothetically ideal glance sequence in HUD. Figure 5.49(a) presents a sketch of hypothetical assistance, but again the most appropriate visualization should involve the research of animations, timing, and different presentations. By giving the suggestion of the ideal glance sequence, the driver is released from many processes he should perform, and if designed properly it may present a very convenient teaching assistance.

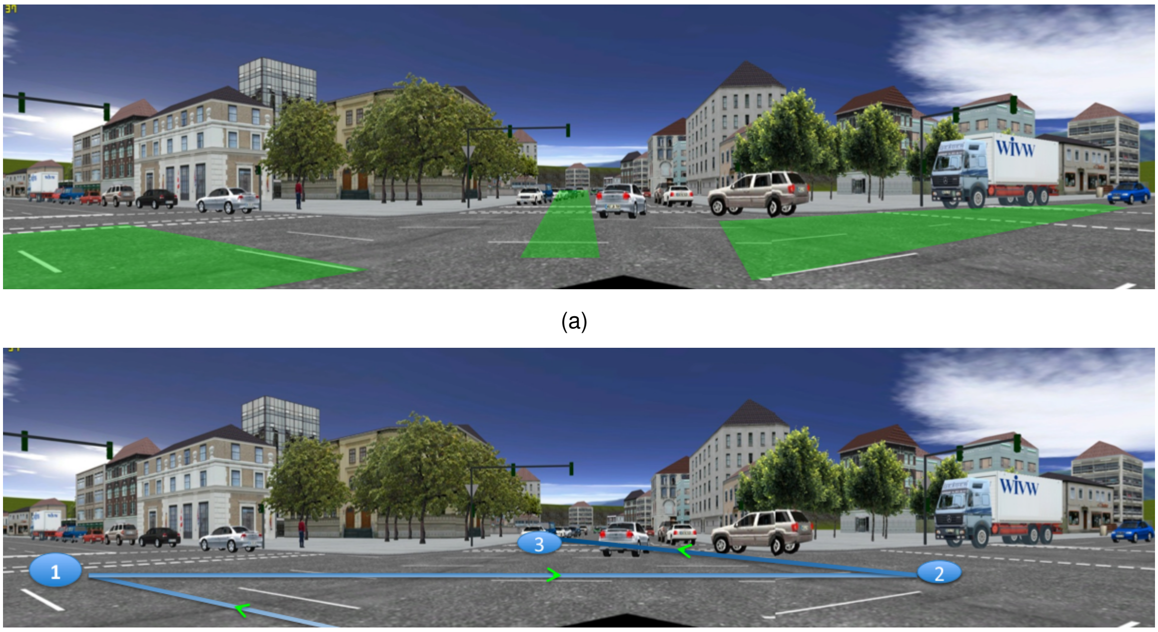
Another meaningful assistance system can be designed for the *Turning* segment. The usual error that drivers commit is neglecting the possible crossing pedestrians in this segment. Also subjectively, the pedestrians in this phase were evaluated as the information of the highest risk. An appropriate help can be a discreet reminder of the possible directions from which the vulnerable traffic participants can come from. A sketch is given in Figure 5.49(b). Further possible Assistance system in the *Turning* segment can be a system, which shows the optimal distance and time gap.

More expensive, but more comfortable HMI solution for the previously presented assistances are the visualizations in the contact-analog Head-up display, completely emerged into the traffic scene. Figure 5.50(a) presents a sketch of the contact-analog visualization of the priority roads and Figure 5.50(b) the sketch of the hypothetically ideal glance behavior for the performance of the left turn.

All suggested functionalities present the fairly simple solutions, which do not require sophisticated sensor and tracking technologies but only the detail navigation and GPS data. When considering the future C2X communication, even more functionalities are possible. The communication technologies can enable the vehicle to have information whether the crossing roads are clear or not and on which distance is the first crossing vehicle. A possible visualizations are already discussed within some current projects and two examples are presented in Figure 5.51(a) and Figure 5.51(b). Also as the analysis has shown, the drivers rely highly on the rule-compliant behavior of the others. This means that even a warning to the participants having right of way, when detecting the violating behavior of the others, can have a significant effect by at least reducing the collision severity. Still, such

(a) (b)

Figure 5.49: *Sketches of possible Intersection Assistance functionalities for the Deceleration and Turning segment (a) the animation of the hypothetically ideal glance behavior, (b) reminder of vulnerable road users in the Turning segment*



(a)

(b)

Figure 5.50: *Hypothetical visualizations of discussed Intersection Assistance functionalities in Contact-analog HUD (a) prioritization of roads, (b) ideal glance sequence*

assistances present at this moment only a futuristic vision, which cannot be implemented in the regular vehicles before ensuring the presence of Car2Car communication technologies in all vehicles. And this process can take decades.

Another possible communication assistance system that does not have to rely on the presence of C2X technologies in all the vehicles but only on the presence of communication technologies at

(a) (b)

Figure 5.51: *Possible futuristic Intersection Assistance systems using C2X technologies (a) a visualization suggested within [EUCAR] project, (b) visualization from BMW ConnectedDrive project [BMWPressclub]. For these functionalities all vehicles have to be equipped with C2X technologies*

intersection infrastructure can also have high safety benefit. For example, such assistance could indicate the occluded objects at intersections. Car2Inrastracture system could detect even vehicles not equipped with C2C technologies and inform the vehicles that already possess such systems. Such systems have already been installed in some Japan intersections, using video cameras. The resulting information is presented in Central Information Display (CID) as shown in Figure 5.52(a). In [Plavsic09b] and [Nestler09] different visualization and potential of such assistances are presented. A possible visualization is given in Figure 5.52(b).

(a) (b)

Figure 5.52: *Presentation of occluded objects at intersections with C2I technologies (a) visualization of one Japan intersection equipped with cameras [Taya05] , (b) possible visualization from [Plavsic09b]. For these functionalities not all vehicles have to be equipped but the driven vehicle and intersection infrastructure*

As shown, supporting the driver in negotiating an intersection may be done in several ways that highly differ in costs and requirements. The warning and autonomous assistances discussed in *Chapter 2* may result in driver's irritation or require a very high reliability of complex technologies. On the other side, the assistances suggested in this section, which solely rely on the navigation data and on-board sensors, if designed properly, may present a very efficient and low-cost solutions for increasing safety.

An assistance system offering the action recommendation or the necessary information in the early phase of approaching intersection has a cooperative character and by that it enhances the driver's skills, authority and competence. The final decision and action performance is left on the side of the driver and he is given only a discreet recommendation. Therefore, problems like users' irritation, false alarms or legal problems regarding the reactions of autonomous vehicle are passed around. Such assistance is expected to have high acceptance and at the same time prevent significant number of driver errors, as already indicated in works of [Davidse09] and [Popiv10] for rural road situations. Furthermore, the advanced versions of each of these assistances can be made, when having additional technologies on call. The presence of the technology in the vehicle, which precisely assess the risk of the situation, can increase the fidelity of an assistance and provide even more appropriate presentation of information. The implementation of learning character of these assistances may be possible in the future as well.

5.6 Summary

This chapter reports on the experimental analysis of the drivers' visual behavior in intersection scenarios, conducted in the fixed-base driving simulator. The analysis involves ten intersections, which differ in the right of way and maneuver. In two scenarios an additional varied variable is the leading vehicle. The scenarios were designed so that they include all traffic participants having right of way and, additionally, several traffic participants, who are not on the collision trajectory with the subject vehicle.

Twenty-four subjects participated in the study, and the participants drove two trials, the first one was the baseline trial and the second one was the trial under induced time pressure conditions. The objective of the conducted experiment is to analyze how do applied visual strategies differ depending on the maneuver, right of way, time pressure, and the presence of the leading vehicle. The focus was not only on the average behavior but also on the individual, specific behavior. Therefore it was also observed whether the behavior of individual participants differs between the baseline and the time pressure trial and whether the behavior at simple intersections relates to the behavior at complex intersections.

Prior to the experimental analysis, the theoretical analysis of the task performance at intersections was conducted. It is suggested to divide intersection area into five and four segments for the crossing/left-turn and right-turn maneuver, respectively. The analysis is then conducted and the results are compared relative to the segments and not to whole intersection. The suggested segments are: *Approach*, *Deceleration*, *Crossing/Turning*, *Crossing II*, and *Exit*. Each segment is characterized by a common objective and a decision that has to be made on the conscious level. The theoretical analysis determined the tasks to be realized in each segment on the level of the *driving situation*. The analysis in this thesis is focused on the visual behavior and for the dynamic characteristics of driver behavior appropriate references are given. Within the theoretical analysis, the heuristic for evaluating the task difficulty at intersection is suggested. The heuristic is based on the number of chunks of information that may simultaneously be present in the scene and reflects very well the subjective evaluation of the task difficulty.

Within the experimental analysis both subjective and objective data were collected. The subjective data referred to the measurement of the mental workload and subjective evaluation of the task difficulty, orientation, risk of the faulty evaluation and the subjective risk of collision for each scenario. The collected data undoubtedly showed that the task demand of particular intersection situations might exceed driver cognitive limits. Drivers may also subjectively feel overwhelmed when executing the maneuver at even simple intersections. The objective data refer to the recording and the analysis of glance movements. The analysis is focused on the discrepancies between the hypothetically ideal and the naturalistic behavior. For each intersection, the most critical omitted tasks are presented and discussed.

Based on the conducted analysis, several informative assistance systems are suggested. These assistances either motivate the driver in the *Deceleration* segments of intersection approach to reconsider the driving style before the warning is necessary, improves the applied driving strategy or relieve the driver from the most demanding subtasks. The intention to react is left on the driver side, which eliminates the problem of the low acceptance.

Furthermore, the presented analysis presents an important contribution regarding the computer simulation of the drivers' performance at intersections. The presented data should be understood as the orientation values for defining the appropriate way of how to model the driver cognition. They can be either used to extend the already existing simulation model of the drivers' performance or to populate the new model. The results of the search for an appropriate existing model are presented in the next chapter.

Chapter 6

Survey of Existing Cognitive Driver Models

The resulting analysis from the previous chapter should not be left in the form of numbers and diagrams but should be presented in the form, usable for the development of the Advanced Driver Assistance Systems. As discussed in the introductory chapter, for the development of an assistance system it is highly beneficial to have a computer simulation of driver cognitive behavior. For this purpose, the cognitive model should be suitable for the integration into dynamic environments. This chapter gives an overview of relevant driver models that account for and simulate the driver's cognition. The objective is to select a model, which can be further developed and extended with results from the previous section.

First, the motivation for the driver model is highlighted once more and then the available driver models, which are developed within existing cognitive architectures like ACT-R and Soar are presented. These models are developed on top of existing frameworks that build the basic elements of human cognition. The second section of this chapter deals with driver models, which are developed as stand-alone cognitive models, independently of existing cognitive architectures. In stand-alone models only aspects of human cognition needed for the particular application of the model are implemented.

None of the models was found to be suitable for further extension and adaptation as none of them fulfills the requirements to be simulative and open for adaptations. Yet, for the development of new models, a detailed knowledge of prevalent models is very beneficial. Therefore the concept and the functionality, followed by advantages and disadvantages of each model are discussed.

6.1 Why Modeling the Driver?

As already discussed in the introductory chapter, the driver should be directly involved into the development process of ADAS and should not present only the evaluating factor at the end of the process chain. Involvement of the driver in the development process may be done in several ways, from interviews, over paper and pencil based questionnaires to the conduction of experimental studies similar to the one presented in the previous chapter. For these results to be re-usable and applicable it is the best if they are presented in the computer simulation of the driver behavior. Such models can be iteratively improved and used for the development of ADAS.

In the process of ADAS development a plenty of experimental studies have to be conducted, in different phases of the design process. These are costly and complicated. A solution is to exchange a lot of tests with an appropriate driver model. This way, ADAS performance can be analyzed faster and at little cost in a variety of driving situations and under different conditions. Such models can help optimizing parameter values for certain performance measures or can be used to adjust the threshold values. Even more, the driver models form the basis for the classification of different driving types, like sporty or defensive ones. The ultimate goal is the creation of the model that operates in parallel with the driver and is able to predict driver behavior, mainly the committed errors. By that, the model would be able to adapt ADAS operation to the driver's state and intentions.

For the assistances on the guidance level of the driving task, the models simulating the driver cognition should be developed. This is a complex and long-term objective whose results cannot be expected any soon. Still, the importance of the modeling the driver cognition has been recognized and plenty of such models have developed over time, each of them for a specific purpose in mind and each of them with a specific level of details. In this chapter a survey of the most relevant such models regarding the driving task is given.

6.2 Driver Models in Cognitive Architectures

The most relevant driver models built within the cognitive architectures are the models developed in ACT-R, Soar, and QN-MHP cognitive architectures. A *Cognitive Architecture (CA)* is defined as *"a specification of the structure of the brain at a level of abstraction that explains how it achieves the function of the mind" [Anderson07]*. It is actually a computational theory of human cognition, which tries to explain human cognition by the development of the structure that underlies this cognition.

Cognitive architectures offer the advantage of already built-in constraints of human cognition and motor performance. They also offers structures like memory storage, perception, and motor action, believed to correspond to the structure of the human mind. The advantage of models developed within existent cognitive architectures is that they should be psychologically valid. However, the main problem with these models is that they are too complex. Cognitive modeling actually emerged as a technique to deal with and improve interaction between the user and the system in static environments. This has as a consequence a high system complexity and unsuitability for use in dynamic and real-time environments, as it is shown in the next section.

6.2.1 ACT-R

ACT-R *(Adaptive Control of Thought–Rational)* is probably the most popular cognitive architecture. It has been mainly developed by John Anderson at Carnegie Melon University [ACT-R]. The initial intention for the development of ACT-R was the same as for the majority of other cognitive architectures: to produce user models that will simulate human-computer interaction in different interfaces. From a programming point of view, it is a production system written in a programming language LISP. The production system is frequently used in Cognitive Architectures because it enables the implementation of mental model concepts and the prediction of behavior on both quantitative and qualitative levels. The production system consists of a set of rules about human behavior in form of IF (sensory prediction) THEN (action) statements, for example *if (saccade) then (no-perception)*. If a production's precondition matches the current state of the world, then the production is said to be triggered. If a production's action is executed, it is said to have fired.

ACT-R has an advantage that each of its processes, like production firing or retrieval from declarative memory is based on psychological theories and data. For example, a typical firing production rule takes 50 ms and the time needed to scan a part of a computer screen is calculated using Fitts' law. In that way ACT-R is able to simulate low-level human cognition in a very detail and is extremely useful tool for modeling traditional, experimental cognitive psychology data. A typical applications of ACT-R models are simulations of learning and memory for text and words, language comprehension, communication, and equation solving. The most famous application is *Cognitive Tutors for Mathematics* used to find out the difficulties that students have when solving equations. Another famous application is in the field of neuropsychology: the interpretation of *functional Magnetic Resonant Images (fMRI)* [ACT-R].

The structure of the ACT-R cognitive architecture is presented in Figure 6.1. It consists of several *modules*. *Modules* in ACT-R are associated with appropriate cortical regions: for example, a manual buffer is designed to match motor and somato-sensory cortical areas and the basal ganglia is considered to implement production rules [Anderson04]. Visual and manual modules are the most developed ones but also perceptual, memory and language modules are under constant development. Other components of ACT-R are *Buffers* and *Pattern matcher*. *Buffers* serve as an interface between modules and ACT-R accesses modules through buffers. Even though processes in ACT-R can be simulated in parallel, each buffer can have only one entity at the time and the content of the buffer at a given moment presents the state of the corresponding module at that moment. *Pattern Matcher* searches for a production that matches the current state of the buffer. ACT-R distinguishes between two types of knowledge organized as two memory modules: *declarative* knowledge presented in form of *Chunks* and *procedural* knowledge. The difference between these types of knowledge is discussed in *section 3.3.2*.

The cognition in ACT-R is realized by the successive execution of production rules. The monitoring module continuously perceives the objects from environment and sends information to the production over the visual buffer. Buffers of each module are passing information to the production system simulating in that way retrieval of information from the long-term memory. The context and the history of usage are influencing the speed of information retrieval from declarative knowledge. Even though,

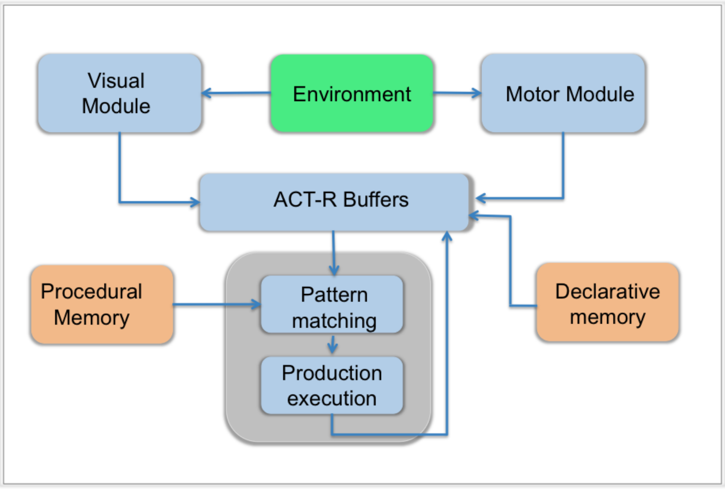


Figure 6.1: *The general architecture of the ACT-R system: each module is accessible through the buffer; Pattern matcher searches for production corresponding to the state of the buffer and the production rule with the highest benefit is "fired" [ACT-R]*

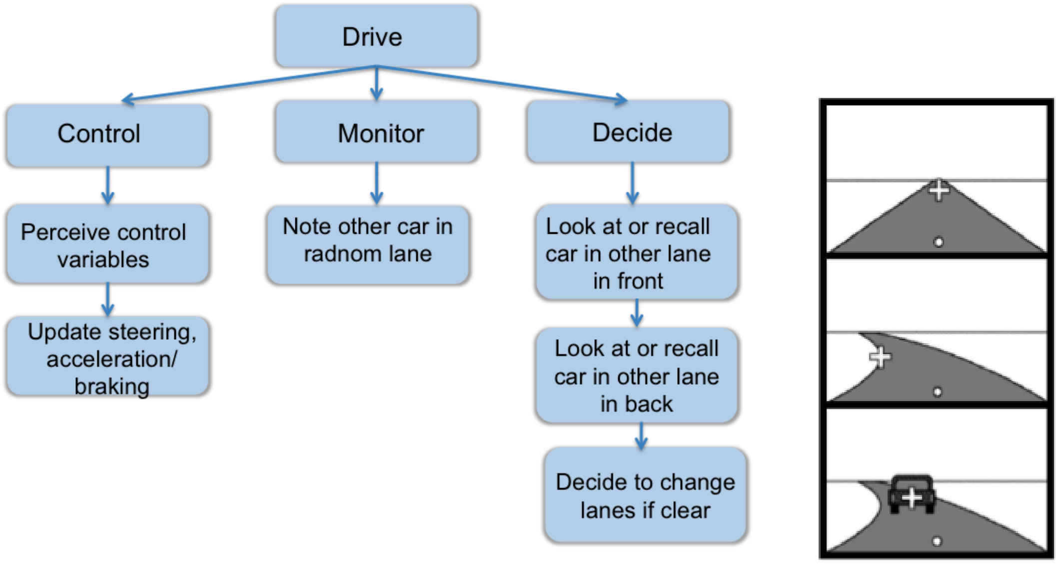
more production rules can fit into the buffer content, only one can be executed at a time. This presents the main drawback for usage in dynamic environments. If several production rules match the state of the buffer, relative costs and benefit of each production are estimated and the production with the highest priority is executed.

ACT-R Driver Model

The entire driver model is implemented as an ACT-R production system including relevant procedural and declarative knowledge. The driving task that ACT-R Driver model is able to accomplish is the highway driving on the three lanes as well as the lane change. The model is also able to simulate the phoning as the tertiary task. Other traffic participants can be included if they drive in the same direction. The vehicle model in ACT-R is a bicycle model for lateral dynamics and an energy balance model for longitudinal dynamics. The model is planned to simulate only highway behavior and as such it ignores the changes in the road curvature.

The structure of the model contains three components: *Controlling (manipulating)*, *Monitoring (supervision)*, and *Decision-making* component. Their functionality is briefly presented in Figure 6.2(a). These modules represent the driver behavior on the functional and planning level, which correspond to the stabilization-guidance and navigation level, respectively. The control module is operating on the functional level and is responsible for the interaction with the environment. The monitoring module and decision-making are operating on the planning level and are responsible for information processing and problem solving.

Control in ACT-R driver model is based on the two-level model of the steering (*two point visual control model*) from [Donges78]. This model is based on two points depicted in Figure 6.2(b):



(a) (b)

Figure 6.2: *Driver model in ACT-R (a) ACT-R driver components: Monitoring, Decision-making and Controlling, (b)Two point visual control model of driver steering*

- *Near point*: presents the focus of visual attention when determining the current placement within the lane. It is determined as a headway time of 0.5 s, and
- *Far point*: presents the focus of visual attention when viewing the road ahead. It can be one of the three points: lead car, tangent point on a curved road segment or vanishing point on a straight road with a maximum heading time of 4 s. It is designed so to be the closest to the near point in the terms of visual angle.

The shift of visual attention between these two points is calculated by visual attention module *EMMA (Eye Movements and Movement of Attention)*, responsible to predict the next eye movement [Salvucci00].

Steering of ACT-R model is realized with a controller similar to the standard PID (*Proportional - Integral - Derivative*) controller. PID controller calculates an "error" value as the difference between a measured process variable and a desired set-point. The controller attempts to minimize the error by adjusting the process control inputs. The ACT-R model calculates the change of the visual angles since the last update cycle, as well as elapsed time. In that way, the model steers the curves by maintaining a constant visual angle of the far point. The center of the lane is maintained by keeping the visual angle of the near point approximately to zero. *Speed* is controlled by only one variable, $acc \in [-1, 1]$, which presents the accelerator when taking positive values and the brake pedal when taking negative ones. It is calculated based on desired time headway. *Lane Change* is also implemented in ACT-R driver model and is simply solved by switching attention from the current to the near and far point into adjacent lane. Additionally, there is a factor representing a wish of how quickly driver wants to execute the lane change.

Monitoring is controlled with the parameter $P_{monitor}$. This parameter specifies the probability of the environment checks. If the models perceives a vehicle, it records it as a fact and by comparing previously stored facts the model can even estimate the relative velocity of that vehicle. *Decision Making* is responsible for determining whether to execute a lane change or not and whether and how hard to brake. The model can also decide to monitor a particular direction by analyzing gathered information gained by the *Monitoring module*.

Even though ACT-R enjoys great popularity for simulating traditional, experimental, cognitive psychological data, all application areas simulate quite simple tasks. When trying to model more complex tasks, such as driving, the serial processor of ACT-R causes bottlenecks concerning the speed of calculation. This makes it very hard to couple a model with the dynamic environments such as the driving simulators and almost impossible to model complex tasks like maneuvering an intersection. Already, when driving through narrow curves it is problematic to calculate the movement in real-time. Even though the ACT-R driver model can be applied to predict the effects of the secondary task (cellphone dialing) and also to account for the driver's distraction [Liu01], these achievements present at the moment the maximal practical usage of the model.

Also some conceptual parts of the model have been seriously criticized like usage of two visual point control models (see [Plavsic10b]). [Möbus07] also questions the validity of the experiment on which this model is based. Additionally, getting familiar with the ACT-R environment for extending or adapting the model requires significant amount of time and effort because of the complexity of the system and lack of documentation.

6.2.2 SOAR

Soar (*State, Operator And Result*) is a combined problem-solving oriented and production system cognitive architecture. This architecture emerged from the work of [Newell90] also at the Carnegie Mellon University. Currently, it is further developed at University of Michigan [SOAR]. Similar to ACT-R, Soar provides the framework and has mechanisms for problem-solving, learning, high-level motor control, visual orientation and specific for Soar, a multi-tasking mechanism.

Basic elements of Soar are states, operators and rules, which form so-called *problem space*. Soar also distinguishes between *Production memory* (corresponds to the long term-memory) and *Working memory*. Content of the working memory is the currently active operator and it can contain 7 to 8 Chunks at time. The purpose of operators is to execute rules. Each rule has a priority assigned. By executing production rules, the state of the model is changed. If more operators have the same priority level, a new mid-goal with its own end-goal is originated. In that way, Soar learns new production rules and stores them as Chunks in the procedural memory. For the next usage of learned rules, only boundary conditions have to be fulfilled and in that way the knowledge is generalized.

DRIVER

In order to prove that complex tasks like driving can be described as the problem-solving process, [Aasman95] developed a driver model in Soar, named DRIVER. Because of some, at the time, unresolved Soar issues, a bit modified architecture is developed for modeling the driving behavior in Soar. The model is supposed to have not only controlled and conscious strategy but also the subconscious cognition. As an exemplary scenario, a negotiation at an unordered intersection was chosen and the focus of the model was to simulate visual orientation strategies at such intersections.

DRIVER is comprised of modules presented in Figure 6.3. In the following they are briefly presented. The *Low Level Motor Module* is a module for controlling the virtual driver body by simulating and computing the time that body parts need for moving. The movement of the body is realized by *move operators*. These operators take commands from the working memory and transfer them to the *Low Level Motor Module* which than executes the commands. The *Motor Planning and Execution* is responsible for the gear-changing. The *Navigation Module* takes care of the route planning and its implementation, and *Integration and multitasking* is the module for the integration of the tasks and managing of the multi-tasking activity.

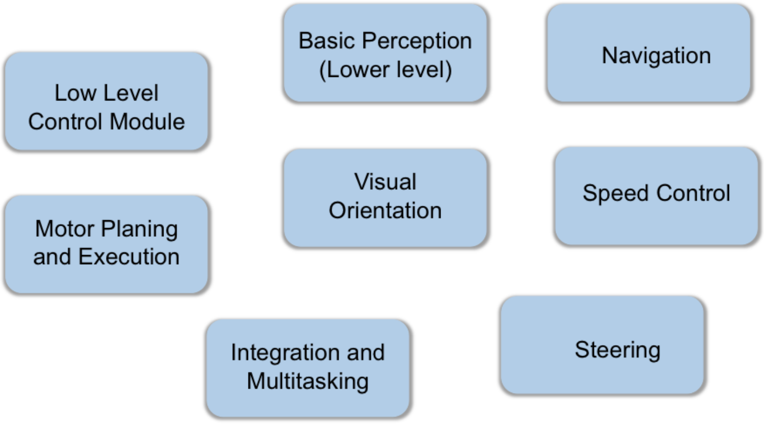


Figure 6.3: *The modules of Soar, which compose the driver cognitive model DRIVER*

Steering is implemented by the separate module and is implemented in a more accurate way than in ACT-R. The steering angle is calculated based on several cues: *heading angle, lateral deviation from ideal course*, and *Time to Line Crossing (TLC)*, TLC being the most important parameter. TLC is the point in the future path at which time the vehicle will cross the edge line of the road. With these parameters DRIVER is also able to handle curves. The model has an internal presentation of ideal course, which is then used to calculate the path error. *Speed Control* is consequently more complex than in ACT-R. It is grounded on the visual cues relevant for choosing the right speed. In Soar, three values are relevant: *integer value from the speedometer, Time To Intersection (TTI)*, and *sound of the engine*. Additionally, the mental model of the situation affects the decision on the appropriate speed as well.

The most relevant module of the cognitive driver model is *Basic Perception (Lower Level Perception)* and it is responsible for object recognition, attention, and basic eye and head movement control. It contains two fields: *Functional Visual Field* (FVF) (20°) and *Peripheral Visual Field* (PVF) $(210^\circ$ horizontally and 90° vertically) (see Figure 6.4). The fields are not directly connected to the physical perceptual systems and the adjective *functional* annotates that their sizes depend on circumstances like workload, stimuli and task. The sizes of the fields are derived from [Miura86]. If residing inside FVF, objects have 100% chance of being detected, but if residing within PVF objects have fewer chances to be detected. Information in the peripheral field is used to guide eye and head movement and the driver is forced to move the head to see things from the periphery. Objects in FVF have the following attributes: *Presence, Movement, Direction, Size, Color, Shape*, and *Object Type*, whereby objects in PVF are provided with only the first four attributes. The basic perception module also contains several constraints concerning visual processing. As there was no ready-made theory of eye movements, which could be directly used, several independent constraints were implemented. These are the basic visual constraints such as that during eye movement no new visual information can enter the working memory, that eye strain forces head to move or that times for eye and head movement depend on speed and moving distance.

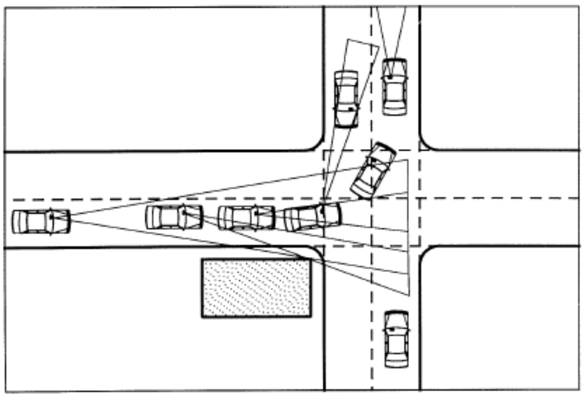


Figure 6.4: *Functional Visual Field (FVF) and Peripheral Visual Field (PVF) when approaching intersection. Vehicle is presented in different points of time [Aasman95]*

Visual Orientation is a part of DRIVER, which did not exist in Soar. It regulates the orientation at intersections and is built upon the *Basic Perception Module* but expanded with top-down strategies and environmental constraints. Visual control is realized with a so-called *attend* operator, which can be applied to an object. In this way the visited object is marked as noticed. Both, voluntary (knowledge-driven) and involuntary (data-driven) eye movements are possible. Data-driven control is default visual activity. Operators are generated for all objects in the functional field and for all moving objects in the peripheral field.

The Visual Orientation module is comprised from several top-down rules concerning orientation at intersections. All of them are coming from experimental results of [Harsenhorst88]. It is distinguished between *Default orientation rules* and *Maneuver orientation rules*, and between *local* and *global scan paths*. Local scan paths present the bottom-up controlled eye movements and global scan paths are indicating a search plan and are therefore top-down controlled. In non-critical situations, the default rules prevail and eyes are mostly directed to the objects in FVF. In critical situations (such as approaching an intersection), implemented intersection rules cause active search in remote areas, leading to global scans. If there is a moving object in the periphery, the operator is applied to it. Rules are focused on the differences between experienced and novices like:

- experienced drivers employ fixed strategies in negotiating intersections and shift less often main field of vision, or
- experienced drivers look at the relevant items in the traffic environments and pay earlier attention to the relevant objects than novices, and
- experienced drivers may rely on peripheral vision to a greater extent and are able to intentionally update position of the moving objects.

DRIVER is the only driver model in cognitive architectures, which can simulate driving through intersections. However, there are no publications about further DRIVER development since 1995 in spite of the agile development of the Soar architecture itself. Also, there are some significant problems with this model. Regarding the key element of the DRIVER, the visual orientation strategies, the most serious critic is that orientation on the base of FVF and PVF is overly simple. DRIVER is also short of accurate eye-movements and does not cover learning in visual orientation. Additionally, DRIVER also has a problem with working memory size and forgetting information. New Soar developments have overcome these problems, but nothing has been changed in DRIVER model itself.

6.2.3 QN-MHP

QN-MHP (*Queuing Network - Model Human Processor*) is a computational architecture, which combines mathematical theories and simulation methods of queuing networks (QN) with the Model Human Processor (MHP) [Liu06]. MHP is a symbolic, procedural, task description method based on GOMS. GOMS stands for Goals, Operators, Methods, and Selection rules and presents a model of human information-processing, which analyzes user's interaction with a computer by analyzing elementary actions that are to be realized [Card83].

QN-MHP is implemented in a *Promodel*, the commercially available software. Different cortical zones and functional modules of the human perceptual, cognitive, and motor information processing system are simulated with a network consisting of 20 processing units. The network is presented in Figure 6.5. Each server is responsible for the particular functionality and is characterized by different brain regions. For example, the first eight servers present the perceptual subnetwork. The routes between the servers present the neural routes between the corresponding brain regions. Because of its brain-like structure, QN-MHP enables visualization of internal information ”flow” inside the mind during driving activity. The visualization can be seen on QN-MHP webpage [QN-MHP]. Specific for QN-MHP is that the cognition is neither serial (as with ACT-R) nor executive and all processes are strictly transferred to neurobiological processes.

QN-MHP Driver Model

The architecture of QN-MHP has been used as the foundation for the implementation of a real-time steering model of the driving. This model is able to simulate the driving in real-time and has been tested within the driving simulator environments [Tsimhoni03]. The steering model is implemented as

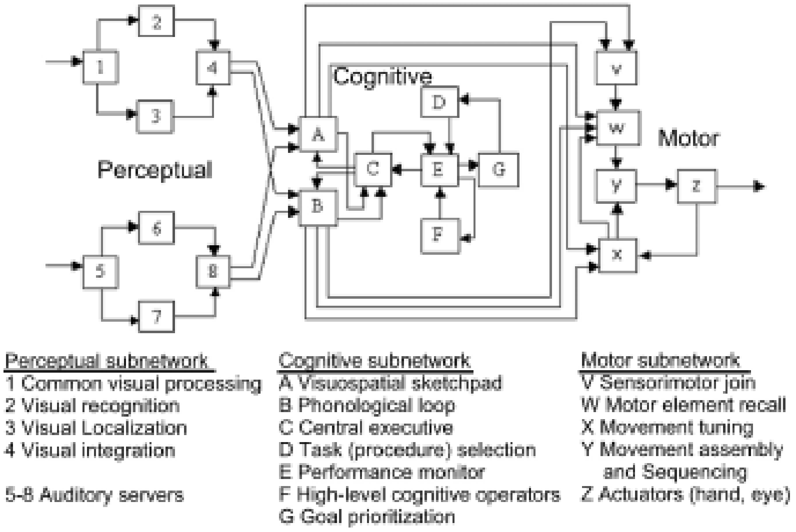


Figure 6.5: *General architecture of QN-MHP [Tsimhoni03], layout of the servers and communication flow; different cortical zones and functional modules are simulated with a network of 20 computers*

a goal-oriented task, whereby the goal (maintaining the lane) consists of three subgoals: coding of the vehicle position, choice of the steering strategy, and control of hand movements. The major input from an environment is perceived by the ambient visual system. These are mainly the areas around the lane markers in front of the vehicle. This complies with *Splay angle theory* from [Chatziastros99], already discussed in *Chapter 4.2.1*. The outputs of the model are calculated positions of the hands on the steering wheel and fixation coordinates of the eyes. The steering wheel is moved in the single-phase open-loop correction followed by closed-loop adjustments.

There are three data sets that are continuously perceived from the environment: *vehicle heading*, *lateral position*, and *road curvature*. Vehicle heading is implemented as a fixation of a far point down the road, 2 to 4 s, as in ACT-R. The lateral position is retrieved as the point 1 s in front of the driver, either at the lower center or near each of the lane markers. Road curvature is retrieved when eye fixates the tangent point of the curve. Steering actions are triggered as a consequence of the analysis of the driving scene and the comparison with the desired state.

Additionally, the model is also capable of simulating secondary driving tasks. Within future research is planned to expand the task with speed control and to take into account the influence of traffic as well as vestibular and auditory modality. Being a network architecture, queuing networks are particularly suited for modeling parallel activities and complex mental architectures. The advantage of the QN-MHP is truly concurrent simulation of a processing task and the possibility of real-time simulation. However, QN-MHP is developed at the University of Michigan and its usage is limited for this university.

6.3 Stand Alone Cognitive Driver Models

Described limitations and constraints of the previously presented models caused the development of cognitive architectures, which are completely ancillary to the purpose of driver modeling such as COSMODRIVE, ACME, or SSDRIVE. These models are presented in the following section.

6.3.1 COSMODRIVE

COSMODRIVE stands for *COgnitive Simulation MOdel of the DRIVEr*. It is being developed at the French Institute of research on transportation and safety [INRETS] in the programming language *SmallTalk*. It is mainly an explicative model of driver cognition and even though developed outside existing architectures, this model has no pretensions to be used for the development of driver assistance systems but more as ACT-R and Soar, for the explanation of driver cognition.

COSMODRIVE consists of seven modules depicted in Figure 6.6. *Strategic module* is responsible for planning and navigation task. It corresponds to *Navigation* module in Soar. This module has the global goals like desired time schedule and is responsible for generating the local goals that are further proceeded to the *Tactical module*. The *Tactical module* is the key module of the architecture, as it is responsible for the generation of mental models of the current driving situation. *Perception module* provides sensory data and processes the perceptive requests. Like Soar, it has both data-driven and knowledge-driven mechanisms. Top-down agent is allowing only certain objects, which have greater physical magnitudes to be passed into the tactical representations. Based on the priority, this module defines the most appropriate visual strategy, which permits the best response to the queries generated by expectations. *Operational module* is responsible for the implementation of steering and speed control. The crucial aspect of operational module is assessment of accident risk. Vehicle control is implemented by so called *Pure-pursuit point* [Amidi90], which is developed for automated car driving. If necessary, it activates the *Emergency module*. The *Emergency module* is activated only for critical situations and in that case it is a substitution of strategic and tactical modules together. The *Execution module* manages the vehicle commands and *Management and control module* allocates resources to the different processes, as all these modules share limited cognitive resources.

Except for described information processing elements, COSMODRIVE also has storage elements responsible for knowledge and retrieval of information like long-term and short-term memory. The knowledge in COSMODRIVE is organized in categories in a hierarchical way. The lowest level categories are the tasks, which are to be accomplished. The distinction between procedural and declarative knowledge also exists.

As with ACT-R and Soar, mental models are central elements of driver cognition in architecture of COSMODRIVE. In this architecture they are named *Current Tactical Representations (CTRs)*. They are preserved within the Tactical module. When knowing the elements that comprise the mental model, they can be directly programmed in *Small Talk*. The anticipation in COMSODRIVE is generated on the base of Current Tactical Representation. The anticipation agent builds different *An-*

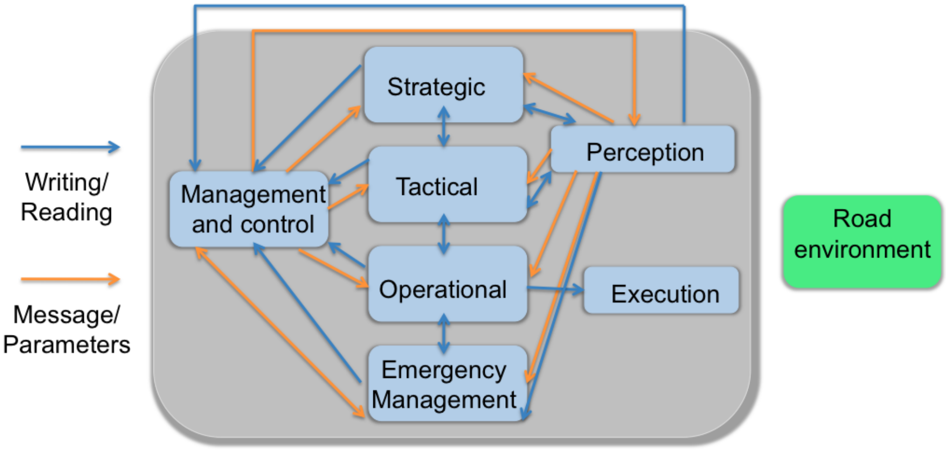


Figure 6.6: *General architecture of COSMODRIVE driver model*

ticipation Representations (AR), which all present a possible development of the current situation. The decision agent examines these different representations and selects one of them. Doing so, the decision agent is supervising the anticipation agent but it also plays a role in the AR derivation procedure by examining each new AR regarding risk and time saving. After the action is executed, operational module compares the action result with expectations. If the result does not fulfill its expectations, new *Current Tactical Representations (CTRs)* are generated by the *Tactical Representation Generator (TRG)* process. The procedure is then repeated.

For presentation of the modeling results, COSMODRIVE incorporated a dynamic 3D simulation for visualizing the driver's mental models. This simulation can extract relevant features from the driving scene, which comprise the mental model of the scene. Currently, a framework for cognitive analysis of car driving activity [Georgeon07] is being developed. The goal is to infer mental models and Situational Awareness from driving tasks (so-called *Traces*). This tool is supposed to automatically abstract the driving frame from objective data (driver behavior, vehicle state, environment conditions).

Although developed very precisely and even though it offers an outstanding platform for further development, COSMODRIVE is at the moment not an open tool. Current state of the model is developed only for testing the validity of a theoretical approach and is totally dedicated to specific scenarios in relation to the experiments conducted at INRETS. Another disadvantage is that the majority of the literature is available only in the French language. Therefore this system still cannot be applied for the development of Advanced Driver Assistance Systems. However, the simulated scenarios are left-turn intersection scenarios and as such, COSMODRIVE has a high relevance for this thesis. It proves that the described cognition can successfully simulate the performance of the intersection tasks and that the most relevant aspects have been taken into account.

PADRIC

PADRIC (*PATH DRIVer Cognitive*) is a driver model based on the structure of COSMODRIVE and developed by [PATH], a cooperation between Institute of Transportation Studies (ITS), University of

California, Berkeley, and [Caltrans]. PADRIC is integrated in a micro-simulation tool, SmartAHS. This is a program written in the programming language SHIFT and is dedicated to the simulation of automated driving. The focus of PADRIC model is the simulation of the highway driving. Therefore, COSMODRIVE model is simplified in many ways, and perception, tactical, operation, and execution modules are developed in more detail [Delorme01]. The model is populated by data provided by University of Michigan, Transportation Research Institute (UMTRI).

PADRIC has a hybrid-hierarchical structure, composed of four layers [Song00]. The key element of PADRIC is the visual module, based on the top-down visual control. The visual module is implemented by four processing states: *scaling the relative velocity of the leading vehicle*, *scaling of the velocity of side vehicles*, *scaling the relative velocity with rear vehicles*, and *processing in-vehicle displays*. Three parameters determine these states: the allocation of visual attention between states, the type of processing in one of them, and time spent on one state.

By having such a structure, the model can be used to simulate a critical situation caused by visual distraction on the highway (see [Delorme01]). Being an extension of the COSMODRIVE model, this model has more or less the same advantages and disadvantages as COSMODRIVE. Additional disadvantage of the model for our purpose is that it is focused exclusively on the driving task on the highway.

6.3.2 ACME

ACME is a driver model developed as an extension to the already existent microscopic model of traffic at Deutsches Zentrum für Luft- und Raumfahrt (DLR) [Krajzewicz05]. The goal was to develop a real-time simulation model of the driver, which can be used for numerous applications from traffic modeling to the analysis of safety critical driver states, but also for the development of new driver assistances.

The motivation for this model was the inadequacy of currently available driver models for stated purpose. The main application of the model is the integration into DLR's software for microscopic simulation of the traffic. Therefore the model is designed so that the simultaneous simulation of several models functions as fast as possible. At the moment of writing, it was possible to simulate about 20 vehicles around an intersection in simulation steps, which range from 10 to 100 ms [Cody07].

The focus of the model is to develop a combined view on the car following and lane-changing but also to implement all aspects of information processing relevant for the driving. The cognitive module of ACME driver is depicted in Figure 6.7. The model is composed of three substructures: *senses* (auditory and vision), *information processing*, and *action execution*. The visual processing consists of recognition of visible objects and algorithms for calculation of their visible quality. Objects, which have sufficient visible quality, are advanced to the simulation cognition. Further movement of these objects is then estimated and embedded in the *Internal Environment Presentation (IEP)* (the middle rectangle in Figure 6.7). By that, IEP corresponds to the concept of a mental model.

ACME also possesses an instance, which plans future actions. This instance is implemented in the tactical module and actions are derived based on the stored objects and estimated future events.

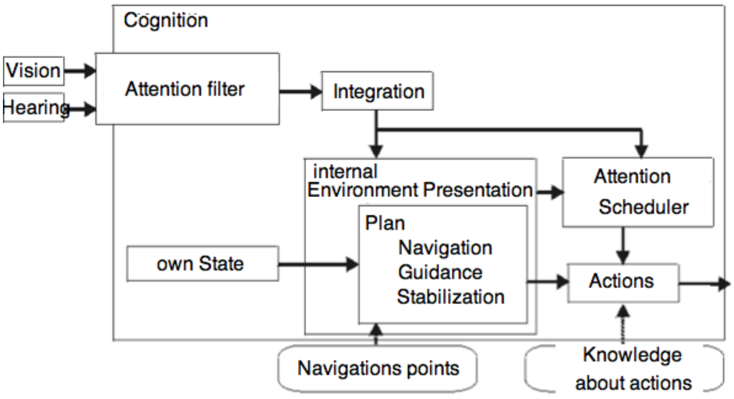


Figure 6.7: *Cognitive module of ACME driver model*

Stored objects and estimated events are first passed through the attention filter (see Figure 6.7). This filter controls the glance direction of the driver and in that way it controls the perception of information that are relevant for further driving. Derived actions are then forwarded to the simulation extremities.

The biggest disadvantage of ACME is that it is not open to third parties. Also the more detailed architecture description is not available. The model is still in the process of development and has not been validated yet.

6.3.3 PELOPS

PELOPS (*Program for the DEvelopment of LOngitudinal Traffic Processes in System Relevant Environment*) is a submicroscopic traffic simulation program developed in cooperation of BMW and Institute of Automotive Engineering at RTWH, Aachen University [IKA].

The purpose of the program is to analyze interactions between vehicle, driver, and environment, under the consideration of the influence of the automobile on the whole system. Figure 6.8 [PELOPS] depicts the interaction between these three elements. The driver model itself consists of the decision and the handling module. The decision module determines the parameters of the driving strategy like speed and lane selection. The handling module is then converting these parameters to vehicle specific controls like position of gas pedal, brake, or gear lever.

The driver model accounts for the task of car following and lane changing. The task of following distinguishes between four scenarios: not influenced driving, approaching, following the lead vehicle, and braking. For each scenario there are behavioral rules, which determine the reaction of the driver. Depending on the driven speed, thresholds parameters are defined. The most influential parameters of drivers are *Safety need* and *Satisfaction*. These parameters are evaluated for each driver in each moment depending on other parameters, desired speed, and relative speed of the following vehicle. The model is populated with a database of several hundreds of standard types of drivers.

PELOPS can be applied to investigate the fuel consumption and emission, as well as the design and the analysis of driver assistance systems for traffic congestion. The advantage of PELOPS model

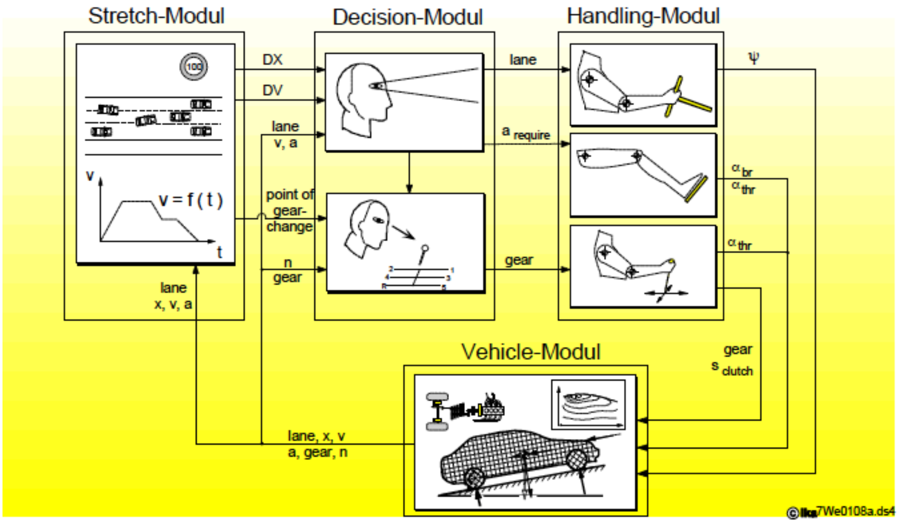


Figure 6.8: *General architecture of PELOPS [Neunzig00]: traffic system (stretch-module), driver model (decision-making and handling module) and vehicle model*

is that it can simulate traffic flow in a high accuracy and it can account for complex maneuvers like ”Stop &Go”. Yet, no modeling of driver behavior in relation to intersections is present in the available literature about PELOPS. Also, even though this model describes and can account for hundreds of different driver types, there is no explicative modeling of behavioral processes and especially not of cognitive processes, which are necessary to model an intersection task.

6.3.4 SSDRIVE

SSDRIVE (*Simple Simulation of Driver Performance*) is a driver model developed with a primary purpose to be a predictive tool for driver behavior [Cacciabue07]. Therefore the goal was to develop real-time simulation and prediction model of dynamic driver-vehicle-environment interactions with a focus on driver errors. Another objective of the model is to account for behavioral adaptation to different types of ADAS.

The procedure selected for SSDRIVE development is Goals-Means Task Analysis (GMTA), which is then modeled in object-oriented programming language. GMTA considers driving not as a hierarchical structure of driving tasks but as an interlinked connection of dynamically changing goals. The procedure distinguishes between *tasks* and *elementary functions*. For example, a task is *attaining lower speed* and elementary function is *brake* or *change gear*. SSDRIVE distinguishes between permanent (’keeping safety margins’) and automatic, skill-based tasks. Permanent tasks are launched on simulation start and automatic tasks depend on decision making and intentions.

SSDRIVE relies on the typical information-processing paradigm: perception, interpretation of information, formulation of goals, selection of tasks, and execution of actions. Cognitive functions are implemented in a fairly simple way, based on the distinction between *normal* and *descriptive driver behavior*. The normal behavior is simulated when there is no behavioral adaption to ADAS and level of driver impairment is zero or very low. The key element of normal driver behavior is the formulation of intentions. The cost/benefit rule is used for prioritization of driving tasks.

If an error occurs or driver impairment or behavioral adaptations are relevant, the mode changes into the descriptive simulation, which is parametrically defined. The sequence of information processing steps remains unchanged but the parameters controlling driver behavior has to be re-evaluated. Therefore, the main challenges of SSDRIVE development are numerical and analytical expressions for these parameters. Following parameters are evaluated: *Attitudes/personality*, *Experience/competence*, *Task demand*, *Driver state*, and *Situation awareness*. The value of these parameters is evaluated by fuzzy logic functions and correlations aare then associated to three-level fuzzy value: low, acceptable, or high. First two parameters are static and do not change and latter three parameters are described with following functions:

$Task\ demand = f(Traffic\ Complexity, Weather, Light, Speed, Driving\ direction),$
$Driver\ state = g(Lane\ Keeping, Drive\ Duration, Weather, Traffic\ Complexity, Speed)$
$Situational\ Awareness = l(Driver\ State, Distraction, Task\ Demand).$

Intentions are implemented as a cost-benefit function of the minimum time to reach the objective. For example, speed is regulated so that the vehicle is driven at the highest ”intended” speed. Decision making process picks up the constant value of the highest intended speed. The dynamic sequence of driver actions depends on *Satisfaction* parameter of pre- and post-actions.

The error-generation process is at default level associated only with *Driver Impairment Level* (DIL), which depends on all five mentioned driver parameters. An error occurs when DIL=1. Every time a relevant event happens, subjective and objective conditions change and DIL value is recalculated. The type and modes of errors are to be defined by the user of the program. This means that the variety of potential errors is not given within SSDRIVE. They are still under research and development. Typical errors that can be simulated and defined at input are: incorrect setting of ADAS/IVIS, improper acceleration or excessive/insufficient steering.

SSDRIVE has a very good modeling approach regarding its purpose but the model is at the beginning of its development and has still not been validated. Also, SSDRIVE is not available for free usage and adaptation.

6.3.5 Other models

Apart from models developed to simulate the whole driving task, there are plenty of models developed to account for a part of the driving task. [Cacciabue03] presented a model, developed as a part of European program EUCLIDE, with purpose to help in the design of anti-collision warning system. The model used for EUCLIDE driver is so-called *Reference Model of Cognition (RMC)* accounting for perception, interpretation, planning and execution [Cacciabue04]. However, this model has not been further developed after the project has ended.

Another similar model is *DRIVABILITY*, the model which started within [AWAKE] project and was further developed in [AIDE]. The goal was to develop a real-time driver-monitoring device able to predict driver’s fatigue and the current risk level. The model considers following characteristics as the most relevant ones: *Individual resources*, *Knowledge/skills level*, *Environmental factors*, *Workload*, and *Risk awareness*. This is similar to the SSDRIVE model. These contributors are combined in the equation for the calculation of the *Drivability index (DI)*, used to describe the driver state at any moment:

$$DI = IRI \times \frac{KSI}{2} \times \frac{WI}{2} \times \frac{EFI+RAI}{6},$$

where IRI stands for individual resource index, KSI for knowledge/skills index, WI is workload index, EFI the environmental factors index, and RAI is risk awareness [Panou07]. *Drivability Index* corresponds to *Driver Impairment Level* in SSDRIVE.

One another example of ”partial” driver model, already used for the development of driver assistances, is a MATLAB simulation of drivers' braking behavior in critical situations [Schmitt07]. The model is validated by comparison to the data gained in field experiments and is applied for the development of the *Emergency brake assistance*. Similar approach was presented by [Schulz07], who developed a model for adjusting warning and braking strategies. Yet, another approaches are trying to predict planned maneuvers on the base of driving dynamics data like [Blaschke07] or [Farid06]. Especially popular are Hidden-Markov Models (HMM) approaches like in [Kuge06] and [Zou06]. Anyhow, these works showed that usage of only dynamics data still does not deliver satisfactory results and the merging with other approaches is necessary.

A significant contribution to human behavior analysis has been done by scientists from the field of artificial intelligence. Some tasks like the decision-making process, humans are performing, by far, better than any machine. Therefore, when designing robots, the goal is to accredit them with human cognition. This has inspired scientists to research the way, the humans perform these tasks from the informatics and engineering side. Examples are decision making processes at intersections done in works of [Stanard01] or [Liu07].

6.4 Conclusion

The models presented in this chapter occupy variety of different approaches. However, they are either not appropriate for the simulation of the human cognition and cannot be integrated into dynamic environment or are not free for usage and no extensions and adaptations are possible. One on side, ACT-R and Soar do not offer the possibility to couple them in arbitrary dynamic environment, are closed in themselves and because of two high level of abstraction are too slow and not usable for more complex applications such as the performance of the driving task at intersection. On the other side, the models, fulfilling stated requirements, are not freely available.

Therefore it is necessary to develop an individual model for the simulation of the driver cognition on the guidance level. Based on the conducted analysis and knowledge about presented models, the guidelines for such a model are presented in the next chapter.

Chapter 7

Recommendation for the Computer Simulation of Driver Cognition

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Two main objectives of this thesis are: (1) the analysis of drivers' behavior at intersections as a prerequisite for definition of possible application scenarios and functional characteristics of an Intersection Assistance System, and (2) specification of requirements and guidelines for the driver model to be used in the development process of driver assistances. The first objective has been discussed in the previous chapters. This chapter elaborates on the second objective. The motivation and basic requirements for the driver model have been discussed previously. In summary, these requirements are that the model should be applicable for a computer simulation, predictive, and explicatory. The available models of driver cognition have been analyzed in the previous chapter and none of them was found to be suitable for further extension. Therefore, the necessity for a new cognitive model that fulfills stated criteria and is available for use, adaptations and extensions is identified.

In this chapter, first the approach and guidelines for the development of the model are defined. Following up this step, an architecture of the model is proposed. The proposed model incorporates some of the good characteristics of the models described in the previous chapter. The elements of the driving task at intersection and elements of the driver cognition that should be included in the simulation are discussed, as well as their level of detail. Furthermore, rules and parameters of the drivers' visual behavior at intersections are proposed as the basis for the simulation of visual behavior. Already implemented connection of the model with the driving simulator and the implementation of the driving tasks on the stabilization level are briefly commented at the end of this chapter.

7.1 Approach and Guidelines for the Model Development

This section summarizes the discussions and findings of the previous chapters. Based on the summary, recommendations are made for the design of the driver model, which can be applied in the development process of Advanced Driver Assistance Systems. First, the detailed requirements on the model are defined and the architecture of the system is proposed. Afterwards, the recommendations for its modeling are presented.

7.1.1 General Architecture

The development of the precise and complete driver model is a continual, iterative process. The majority of models presented in the previous chapter required more than 10 years of continuous development. Figure 7.1 presents a generic process of the development of the driver model. As depicted, the first step of the model development is to clearly set an objective. After the objective of the model is set, the task analysis regarding this objective can be conducted. Based on the analysis results, the requirements of the model can be specified and the relevant systems software architecture can be proposed. In the step that follows, the model is implemented in the computable form and populated by parameters. Afterwards the model can be calibrated by comparison of the simulation with the experimental results. Obtained results are to be used for iterative development of the refined model version in further details. Within this thesis the first three steps are realized and the focus of this chapter is on the third step. In the following text, relevant questions concerning the requirements on the model are discussed.

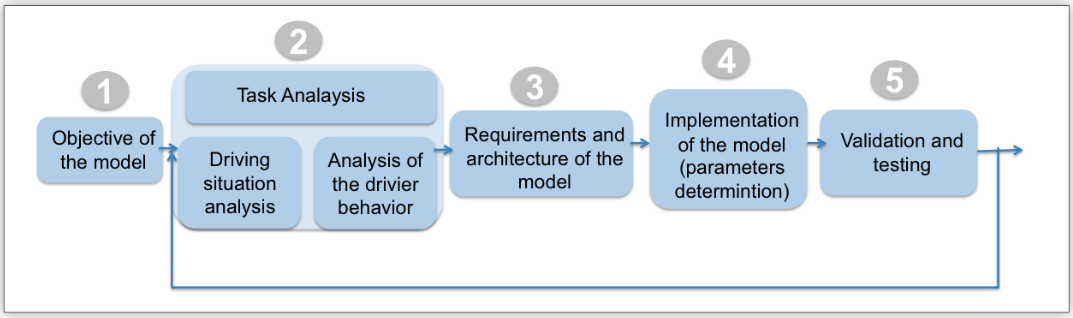


Figure 7.1: *The iterative process of the model development*

The objective of the model. The objective of the model is to support the development process of driver assistances on the guidance level. Hence is the focus of the model the cognitive level of driver behavior. Still, the model should not neglect the appropriate simulation of the stabilization and navigation levels of the driving task. Further, the model should be suitable for the connection with dynamic environments, like driving simulators, and eventually for the operation in real world vehicles. Therefore, the important requirement on the model is that it should be computer-simulative in real-time. For testing driver assistance systems, implemented model should behave as human, simulating the part of the task for which the assistance is intended. For this, the simulation in real-time is not necessary. For the development of driver assistance systems, the model should be capable to simulate and predict driver's erroneous behavior but also to help explain the reasons for such a behavior. Consequently, the model can be used to determine the application of the possible assistances, and to test and tune their parameters.

The detail level of the model. Starting from the level of detail given, for example, in ACT-R, would lead to unjustifiable effort for the stated objective. In the other hand, bringing the data from experiments together like in PELOPS, would limit the flexibility of the model and would not account for the drivers' cognition. The most suitable approach is when the model employs the knowledge of the detailed cognitive structure but simulates the performance on the higher level. The model should tend to integrate all the aspects of driver behavior and it should be therefore developed using both, the Top-Down as well as the Bottom-Up approaches concurrently.

The model should possess the normative behavior for particular traffic scenarios and it should know and recognize driver naturalistic behavior, as well as typical cause-consequence rules for the resulted behavior in particular situation. It should include both probabilistic and deterministic description of the driver behavior. The naturalistic driver behavior is to be modeled on the level of *driving situation* and can be described in the form of probabilistic functions, which can be derived from the experimental analysis. This way the model can be used to simulate the average behavior of the test sample. However, it is necessary not to focus only on mean values but on the individually specific behavior. Human behavior is highly contextual and characterized by high inter- and intra-individual differences. These differences can be captured by the model in the form of specific rules. For the description of the deterministic behavior, the production system proved to be suitable. This means that the individual and situation specific behavior can be implemented as a set of IF-THEN rules, so that the driving behavior can be simulated and predicted even in unknown situations. This way, the errors that are the consequence of the constellation of rare circumstances are captured, too.

Which form should the model have? The form should be selected, which is appropriate for embracing the sophisticated elements of the driver cognition, suitable for continuous extension and improvement, as well as convenient for the connection with various simulating environments. The interface between the model and the environment (the input and output functions) has to be clearly defined. By that, the model can be used with an arbitrary simulator environment and eventually in the field applications.

To avoid the destiny of the other models, the model has to be open for further adaptations and extensions and should be extensively documented. Therefore, the aspect that should not be underestimated is the availability and simplicity of the programming tools with which the model is developed. The parties interested in the further development should not invest too much time getting into the tools or learning the programming language. In addition, the model should be well structured so that it is modular and that it can be further extended by the new findings. With modularity, the simulation in real time should be enabled by principles of scalability and concurrency.

One of the computer science structures that fulfills all the named requirements is *Multi-agent system (MAS)*. The MAS presents a loosely coupled network of intelligent, autonomous agents, which enables their interconnection and intercooperation [Weiss99]. The MAS is a decentralized system where activities can be conducted simultaneously and as such, it does not suffer from the typical problems of serial-structured systems. This way the complexity of the human cognition is fully grasped and the structure of the system can be kept modular and transparent.

The proposed structure of a model of the driver cognition is presented in Figure 7.2. The model is based on the analysis conducted in *Chapter3*. The elements of the models present the separate cognitive agents within a MAS. This structure can be used as a "blueprint" of the model. The connections between elements are left out from the picture to keep it simple but they are explained in the text that follows.

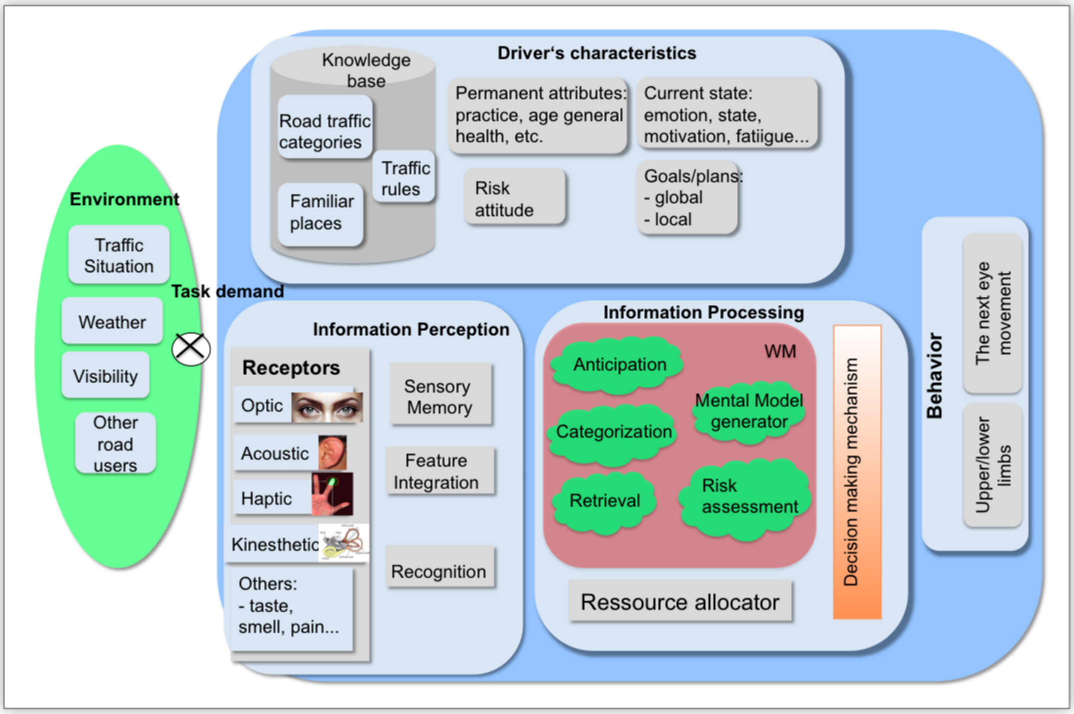


Figure 7.2: *The suggested structure of the driver model in the form of Multi-agent system*

All elements of the driver cognition, which are performed within the *Working memory*, are labeled as *Processing agents*. Processing agents operate concurrently in cooperation with each other, sharing the same resources distributed by the *Resource allocator*. The Resource allocator can be modeled as the *Multiple-resource model* from [Wickens02] presented in *section 3.3.2*. The driver's senses can be modeled as the *Perceptive agents*. The third types of agents are *Operative agents*, which serve to control the movement of driver's eyes, head, and extremities.

The driver's experience and from this experience the available mental models can be presented as production rules, as discussed in *Chapter 3*. The driver's state can be described by different parameters with different weight factors. In the first iteration, the driver cognitive state can be modeled by one value, for example, by the result of fuzzy logic function of the *Performance Shaping Factors*. An example of how to model driver cognitive states using fuzzy logic is given in [Irmscher04].

The suggested structure can account for the behavior of the both experienced and novice drivers. It is not the structure but the parameters of the model, which are changing. The experience can be presented within the knowledge base as the set of if-then rules connected to each traffic situation. Such software structure enables a continuous extension of the model without having to modify the already developed structure. Also, each agent can in first iteration be developed as simple ”black box”, with input and output parameters and the detailed modeling can be done at later point of time, simultaneously to each other.

Intersection specific behavior. In the previous paragraphs, it has been recommended to model the driver behavior on the level of *driving situation*. This means that the complete information-perception and processing mechanisms should be separately modeled for each of the segments of intersection maneuver: *Approach*, *Deceleration*, *Turning/Crossing* and *Exit*. Each of these segments presents a separate driving situation with own rules, conditions, and boundary parameters.

Consequently, by proceeding through an intersection, the driver model is advancing through a sequence of model states. These states should not to be mistaken with the typical usage of the term cognitive state, which describes the individual state of a person, like motivated or tired. When referring to either a states of being motivated or tired, it is emphasized in this text that the cognitive state of a driver is in question. Regarding the modeling procedure in this thesis, the cognitive states are directly connected to the driving situation. At intersection, each model state corresponds to the spatial segment of performing the maneuver and is characterized by a common goal. The goal, physical characteristics, and the demand of the segment are influencing the processes that are to be performed. Therefore, the model should include the goal and demands for each state as well as all activities that the driver has to fulfill in order to come to the next state. For each model state the normative and naturalistic driver behavior should be implemented. The goals, tasks to be realized, and normative behavior for each of the segments have already been defined in *Chapter 5*.

Furthermore, the environmental characteristics like curvature, visibility, whether, and other parameters discussed in *section 3.3.4* present input parameters for the model and their influence has to be included as well. In the first approximation, these values can be summed up in the task demand level, which is then an input value for the model.

In the following text, the approach to model the cognitive agents and cognitive states is proposed. In general, cognitive agents can be understood as hardware and cognitive states as software entities. Each of the agents goes through different model states and has individual operating regime and processes in each state.

7.1.2 Modeling the Agents

The term *cognitive agent* covers a broad range of software structures. Some authors consider cognitive agents to be simply the software structures that are equipped with cognitive features like reasoning, expecting, or anticipating [Franklin97]. Other authors consider the cognitive agents to be the software structures that have the ability to learn and to deal with novel inputs and unexpected situations [Riemsdijk06]. For this thesis, the cognitive agent presents the software structure *”that is* *situated in some environment and that is capable of flexible, autonomous action in that environment in order to meet its design objectives"* [Jennings99].

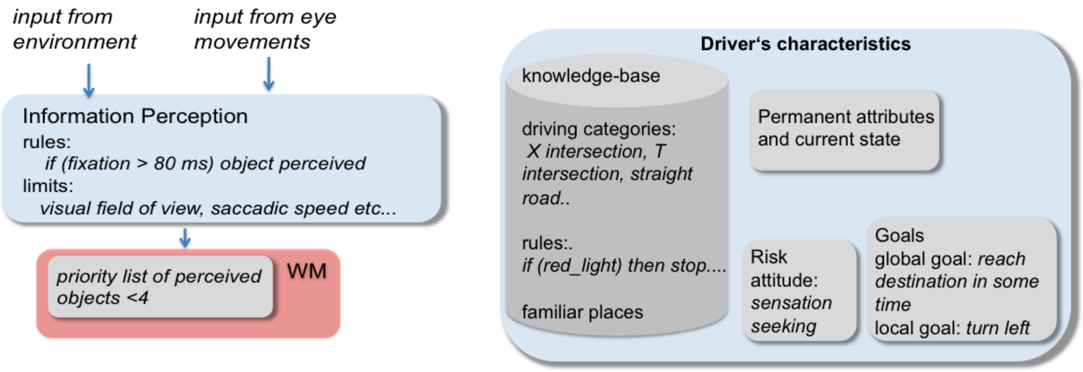
Following this definition, all structure elements of the driver model presented in Figure 7.2 are separately designed as cognitive agents. These elements can be classified into four groups:

- *Perceptive cognitive agents*: Optic, Acoustic, and Vestibular receptors agents;
- *Processing cognitive agents*: Categorization, Retrieval, Mental model generator, Anticipation, Risk assessment, and Decision making agents;
- *Operative cognitive agents*: Eye movements and Movements of upper and down limbs agents;
- *Driver's characteristics agents*: Knowledge base, Permanent attributes and Current state agents.

The receptors agents are responsible for receiving the input from environment. They can simultaneously perceive the arbitrary number of stimulus. Their characteristics are already given by their analysis in *Chapter 3*. The input and output parameters have been clearly identified. Also, each receptor is characterized by features and limits of the corresponding sensory memory. The focus of this work is on the visual perception, therefore, the suggestion for its implementation is further given.

In the first step, the *Optic* receptors, the *Feature integration* module, and *Recognition* structure from Figure 7.2 are together modeled as an *Information perception agent*. This agent is composed of rules, goals, and constraints used to determine which real world objects and features are consciously perceived from the environment; for example, whether the right of way, type of intersection, or position of the objects are perceived. *Information perception agent* selects the object according to defined physical perception limits, perception rules, and specified goals. One constrain of the *Information perception agent* is the minimum fixation duration necessary for the conscious perception. An example of other limitation is that no information perception during saccadic eye movements is possible. The description of peripheral and foveal field of views and their characteristics belongs also to constraints of the *Information perception agent*. Depending whether they are in the foveal or peripheral field of view, the features of physical objects can be perceived in a different way. These features also include the estimation ranges of the distances and speeds depending on their position in relation to the driver. An exemplary snippet of *Information perception agent* is given in Figure 7.3(a).

If the object passed the selection, it is moved to the *Working memory*. Each of the processes in the *Working memory*: *Categorization*, *Retrieval*, *Anticipation*, *Risk assessment*, and *Decision making* is simulated as an autonomous agent. The listed processes belong to the category of *Processing cognitive agents* and all of them comply with the constraints of the *Working memory*. The *Working memory* is modeled as the board within which all the processes are performed. The output results of each of the processes are "written" to this board and are made available to all of the agents. The memory board is a subject to the certain constraints. For example, *Working memory* can keep up to four priority list objects (see Figure 7.3(a)). These objects can be deleted from the memory if not being refreshed over certain period of time. Thanks to this, an important feature of the human mind is modeled: if the driver is not aware of the relevance of the information, he/she would tend to forget it immediately. The priority lists depend upon the current goals and the goals are set for each group of tasks. Depending on the current goal, the model takes a particular *cognitive state*. This is explained in the next section *7.1.3: Modeling the states*.



(a) (b)

Figure 7.3: *Modeling example (a) Information perception agent, and (b) Driver's characteristics and state*

The perceived object from *Information perception agent* is directly forwarded to the *Categorization agent*. This agent categorizes the situation or object based on the driver's knowledge base and sends it further to the *Mental Model generator*, which is fitting the object in the scene. This foundation enables also the simulation of the phenomena such as *Change blindness*. This can happen when, for example, the priority list of the *Information perception agent* does not allow the tagging of the fixated object as perceived or when the *Mental Model generator* does not manage to fit the object in the mental model of the scene. The *Risk decision*, *Decision making*, and *Anticipation agents* are modeled as presented in *Chapter 3*.

The driver's characteristics can also be implemented in the form of several agents, as presented in Figure 7.3(b), and the driver's knowledge can be implemented as the structural database of the traffic situations. On the highest level the driver differs between intersections, highways, and longitudinal roads. Intersections are further branched into rural, urban intersections, and roundabouts. Urban intersections are further divided based on the regulation types into intersections with right of way and intersections where the driver has to yield, or based on geometrical properties, for example, into X and T-intersections. Each level is related to a corresponding normative behavior in the form of if-then rules. For example, the knowledge layer of intersections is connected with the knowledge that there is a crossing traffic. The layer beneath is connected to the corresponding rules of the particular intersection type, for example: *if (red light) then stop* or *if (no traffic sign) then yield to the right*. In this way, the model knows the normative behavior in each particular traffic situation. The driving frames discussed in *section 3.1.2* and resulting mental models are formed based on this structured knowledge. The more the experience the model gains, the more mental models of one situation can be formed and the more accurate they are. For this, it is highly beneficial to implement the learning capability of *Mental model generator* agent in form of some machine learning algorithm like neural networks.

As discussed, the naturalistic driver behavior is to be modeled on the level of the *driving situation* and should contain both deterministic and probabilistic description of the behavior. Described rules and limits presented up to now belong to the deterministic description and present the normative driver behavior. The modeled behavior in the particular driving situation should not occupy only the normative but also the naturalistic driver behavior. The naturalistic driver behavior can be modeled probabilistically: connected to each mental model of the particular situation is the probability distribution describing the usual driver behavior. The probability distributions are mainly the result of the empiric research. Several such functions, which describe driver common visual behavior at intersections, can be formed based on the results from *Chapter 5*. An example of the simplest probability function is: *if (have right of way) and (go straight) then 0.8*P*(do not look for the crossing traffic)*. The coefficient 0.8 is a rough estimation, based on the fact that in *Scenario 1* only 20% of the subjects looked for the crossing traffic. The parameter P additionally influences the factor of checking for the crossing traffic. This value may represent the driver cognitive state: his emotions, motivations, goals and/or experience or for example the environmental characteristics like bad visibility. All of these parameters, in the first iteration, can be modeled as one fuzzy value that influences the other functions of the model. In that way, if driver's state is impaired the probability for non-normative behavior increases.

On the lowest level of the database structure of traffic situations regarding intersections are the particular segments: *Approach*, *Deceleration*, *Crossing*, *Turning*, and *Exit*. The deterministic and probabilistic driver behavior should be modeled for each segment separately because each segment is defined by a specific goal. The modeling of the driver cognition with respect to these segments is the topic of the following subsection.

7.1.3 Modeling the States

By performing the maneuver at intersection, the driver is fulfilling a set of the consecutive goals. Depending on the spatial segment in which the driver is at a moment, different goals are to be achieved and different cognitive agents of the model are activated. Each agent is always operating towards achieving a particular goal. Whenever the goal is achieved, another agent is activated or the particular agent sets the new goal. Of course, the parallel operation of several agents is possible. All the agents are operating towards the same major goal, which depend on the part of the maneuver that is executed at the moment. Each model state is characterized by one major goal, for example, to stop at the crossing. Whenever the major goal is achieved, the driver model advances to the next state, which is characterized by the new major goal. The internal state of each of the agents is updated after every action, affecting by that the local goals.

The states, through which the driver advances while performing the task at the intersection, correspond to the proposed division of segments presented in *Chapter 5*: *Approach*, *Deceleration*, *Crossing*, and *Exit*. *Section 5.3.1* argues that this division is chosen because each of the segments is characterized by the subtasks, which are all leading to the same goal and in each segment one conscious decision has to be made. This segmentation proved to be very helpful for the analysis. However, few modifications improve the model. First, the *Approach* segment is divided into two states:

- *Intersection recognized*, and
- *Type of intersection recognized*.

For the analysis of the driver behavior from the video recordings, there is no sense to distinguish between these two states because they cannot be differentiated from each other. However, since these two states influence the further driver behavior in a different manner, for the cognitive modeling it is beneficial to distinguish these two states. The second modification refers to the *Crossing* segment. *Crossing I* and *Crossing II* segments are modeled as one state because the analysis in *Chapter 5* has shown that that driver behavior does not differ for these two states. The last difference between the states for the cognitive model and segments used for the analysis in *Chapter 5* is the distinction between the *Deceleration* segment without the stop and the *Deceleration* segment with the stop.

The discussed states are modeled as *Finite state machine (FSM)* sequence of states. The FSM is a computer science model that describes the behavior of a system, which has limited number of defined conditions or modes and where the transition from one mode to another depends upon the external set of circumstances [Wagner06]. FSM has found a wide application in the areas ranging from the Web design to automation and robotics. The current state is determined by the past states of the system. As such, it maintains certain memory content or it has information about all of the previous states. When using the FSM it is possible to deal both, with the continuous and the discrete events at the same time and to make the distinction between the states and processes leading to the current state.

In general, the driving task at intersection can be divided into a number of different states. As discussed in *section 5.3.1*, a good compromise is to divide the driving task at intersections into the states so that each state covers a set of tasks that all lead to one common goal and a conscious decision. For cognitive modeling, these states are:

- *Approach*,
- *Deceleration (State 4)*,
- *Stop (State 5)*, and
- *Cross/Turn (State 6)*.

The *Approach* is further divided into :

- *Free Driving (State 1)*,
- *Intersection recognized (State 2)*, and
- *Type of Intersection recognized (State 3)*.

The *Free Driving* state describes also the behavior in the *Exit segment*. The *Cross/Turn* can also be named *Acceleration* state. Figure 7.4 shows an example of the spatial distribution of these segments on an example of crossing intersection. The segments are determined and described by temporal factors, discussed in *section 5.3.1* such as Time To Intersection (TTI) or Distance To Intersection (DTI). For the states, which are following the road crossing point, TTI becomes negative and consequently different parameter is needed. Therefor, a parameter analog to TTI is introduced: *Time From Intersection (TFI)* or expressed in metric data *Distance From Intersection (DFI)*.

An example of modeling the task at intersection by the means of FSM is given in Figure 7.5. Figure 7.5 presents the FSM model for crossing the intersection and depicts the causal relationships between different states. This mapping covers both states and processes and illustrates how the cognitive model of the driver can be grounded in the performance of the task at intersection. Each state is

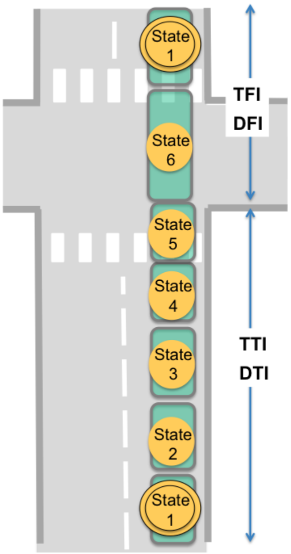


Figure 7.4: *The spatial distribution of different states while performing the task at intersection on the example of crossing*

characterized by a specific goal to be reached. The tasks, to be realized within each state, are modeled as repetitive actions described by *loop* functions in Figure 7.5. Within each loop cognitive agents perform particular actions, and as long as the driver is one state, the actions within *loop* functions are repeated.

The model is advanced to the next state by the state transition function. The state transition function is the conditional function presented with the blue arrow and named either as *condition_x_input (cxi)* or *condition_x_output (cxo)*. For example, the function *c1o* (depicted in Figure 7.5) is the conditional function *condition_1_output*, which, when being positive, moves the model out of the *State 1*.

Figure 7.5 shows that between the transition of *State 1* to *State 2* there is a *Categorization*, and between *State 2* and *State 3* there is a *Retrieval* agent. This is not the case for the transitions between the other states. Strictly speaking, both *Categorization* and *Retrieval* agents should not appear between the states but are the part of corresponding *loop* functions, together with other cognitive agents that are being updated within the corresponding loop functions. They are placed outside the loop for the first two states, in order to emphasize their importance for the successful performance of the task and for the movement to the next state. For the other states these two agents are less relevant.

In the following, each state and its characteristics are illustrated on an example of crossing an intersection. For the execution of the right turn, the *State 6 (Crossing)* is exchanged by the *State 6 (Turning)* and for the left turn, there is one additional state: *State 7 (Turning)*.

State 1: Free driving. Free driving presents the starting state of the FSM model and it is depicted by a double circle. This state describes the longitudinal driving task before an intersection can be seen. It is mainly conducted on the skill-based level. The upper part of Figure 7.6 presents a short sketch of the *State 1*. In this state the driver focuses the road ahead, steers, and regulates the speed.

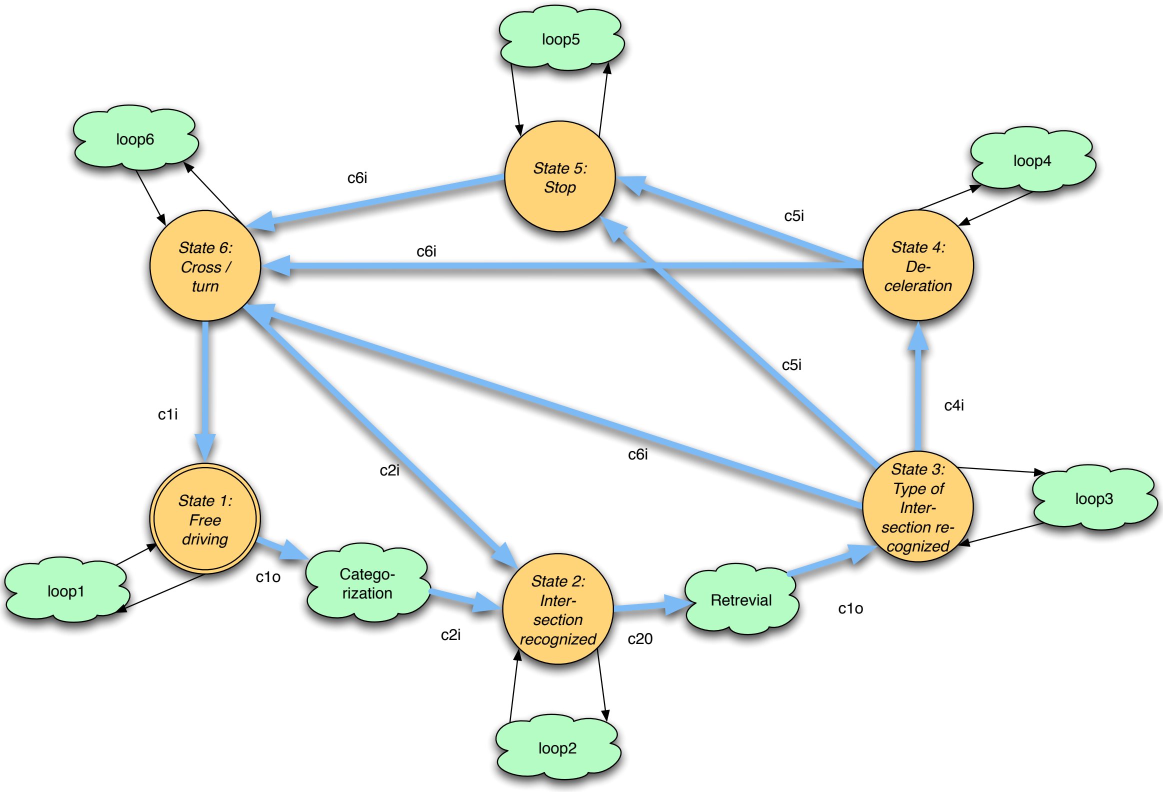


Figure 7.5: *Temporal and causal distribution of states on an example of crossing the intersection, presented in the form of Finite State Machine. Cross/Turn state is also named Acceleration state*

Corresponding agents are responsible for dedicated tasks. For example, the *Stabilization agent* recalculates the lateral position of the vehicle, the *Speed regulation agent* chooses an appropriate speed, and the *Anticipation agent* anticipates the happenings in front of the driver on the skill-based level. All these agents are continuously functioning within borders of *State 1* and are together described by the repetitive *loop1* function (compare to Figure 7.5). This function occupies the operation of all cognitive agents of the driver model within *State 1*. Since the focus of this thesis is on the eye movements, the behavior of the *Eye movements agent* will be presented in more detail for each state rather than the processes in each loop. In the first state, the control of eye movements exists in three modes: straight driving, curve driving, and the presence of the leading vehicle (see Figure 7.6).

The conditional function *(c10) conditional_1_output* (presented by a blue arrow in Figure 7.5) is a repetitive function, responsible for the activation of the *Categorization* agent. It queries whether the crossing roads have been perceived. When activated, the *Categorization agent* categorizes the perceived crossing as a familiar or non-familiar intersection. Each agent is characterized by different input and output functions, labeled as *Input_x* and *Output_x*. Accordingly, the input of *Categorization* agent is *Input_c* and the output is labeled *Output_c*. This is presented in the lower part of the Figure 7.6. The essential element of the *Output_c* is the category of the perceived crossing which moves the model into *State 2: Intersection recognized*. The output of the *Categorization agent* regarding

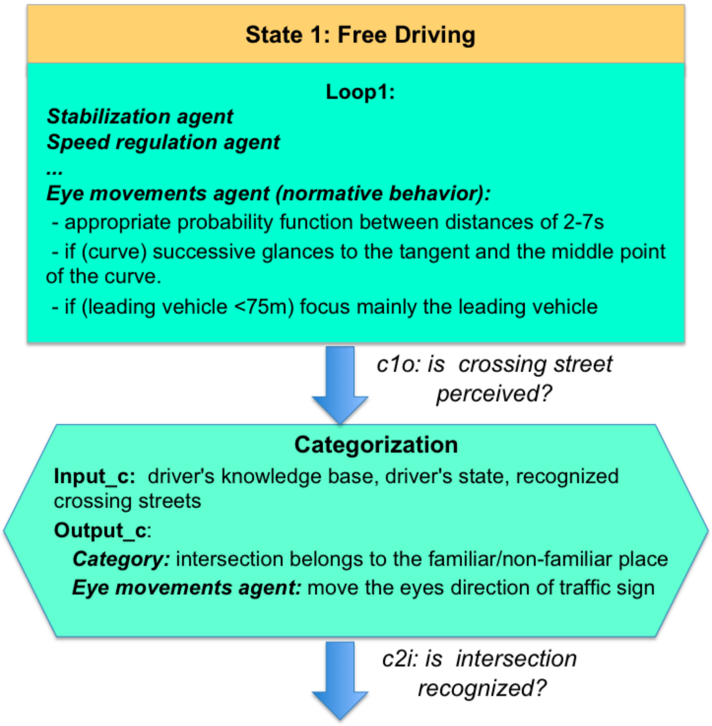


Figure 7.6: *Cognitive state 1: Free Driving. The loop occupies all the agents within one state and is named so because of its repetitiveness. Categorization agent belong to the State 1*

the *Eye movements agent* is the command to move the eyes to look for the traffic signs or other features characterizing the regulation of the intersection near the intersection on the right pavement (see Figure 7.6).

State 2: Intersection recognized. The function *c2i* from Figure 7.6 becomes positive when it receives the output of the *Categorization agent*, proceeding by that the model into the second state *Intersection recognized*. In this state the driver looks for further intersection characteristics. According to the model of the normative driver behavior, the appropriate prioritization of information in this segment has the following order: traffic sign (1), crossing vulnerable road users (2), crossing traffic (3), oncoming vehicles, and (4) farther driving path/leading vehicle (5). Figure 7.7 presents the short snippet of *State2*. In the Figure, only the *Eye movements agent* is presented, but other agents are active as well within *loop2*. The numbers in the brackets in Figure 7.7 are the priority levels of the eye movement function and eyes are moving based on the appropriate probabilities between these categories.

After the intersection is recognized, the crucial task is to recognize the type of the regulation by recognizing the traffic sign. The recognition of the traffic sign activates the *Retrieval agent* by a conditional function *c20* (see Figure 7.7). This function queries whether the traffic sign is recognized; otherwise the model is looping in the same state.

The *Retrieval agent* is responsible for retrieving the normative rules for the recognized type of inter-

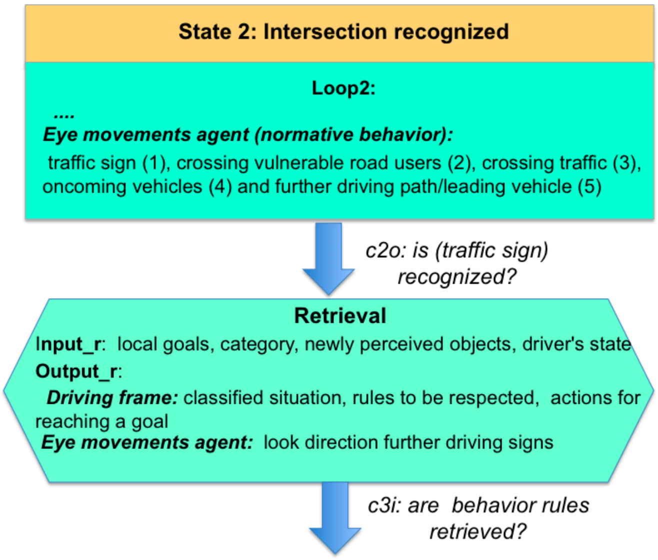


Figure 7.7: *Cognitive state 2: intersection recognized. Within loop2 only Eye movements agents is here presented although the function occupies all the other agents as well. Retrieval agent belongs to the State 2*

section and maneuver from the driver's knowledge base. The output of *Retrieval agent* is the current *driving frame* (see *section 3.3.2*) and commands to the eyes to look for further traffic signs and intersection specific features (see Figure 7.7). When the rules are retrieved the model is moved to *State 3: Intersection type recognized*.

State 3: Intersection type recognized. The output of *Retrieval agent, output_r*, when positive, moves the model to the third state: *Intersection type recognized*. The basic characteristics of *State 3* are given in Figure 7.8. The *loop3* function is similar to the repetitive function of *State 2*. This means that the agents carry out the similar activities as in *State 2*. The biggest difference is that the focus on the traffic signs has a lower priority. Also, the difference is that in this state the *Anticipation* and *Mental Model creation agents* are activated on the rule-based level. In the previous states these agents were also active, but, under normal circumstances only on the skill-based level. The input for *Anticipation* and *Mental Model creation agent* in *State 3* are new cues from the environment, driving frame, and driver's state. The output is the Mental model of the situation, which consists of the driving frame and two anticipatory parts: *Action-perception* and *Perception-action*. This has been described in detail in *section 3.3.2*.

The output of the *Mental model generator* and *Anticipation agent* is labeled *Output_mm*. Regarding the *Eye movements agent*, the output is to monitor the perceived objects and by that to evaluate their distance. The evaluation of the distance happens also within the *Anticipation agent*. Within *Decision making agent*, the estimated distance is compared with the expected change of the distance. Each mental model is connected to the probability function of the typical driver behavior. Therefore the model can either execute the normative or naturalistic driver behavior for the particular situation.

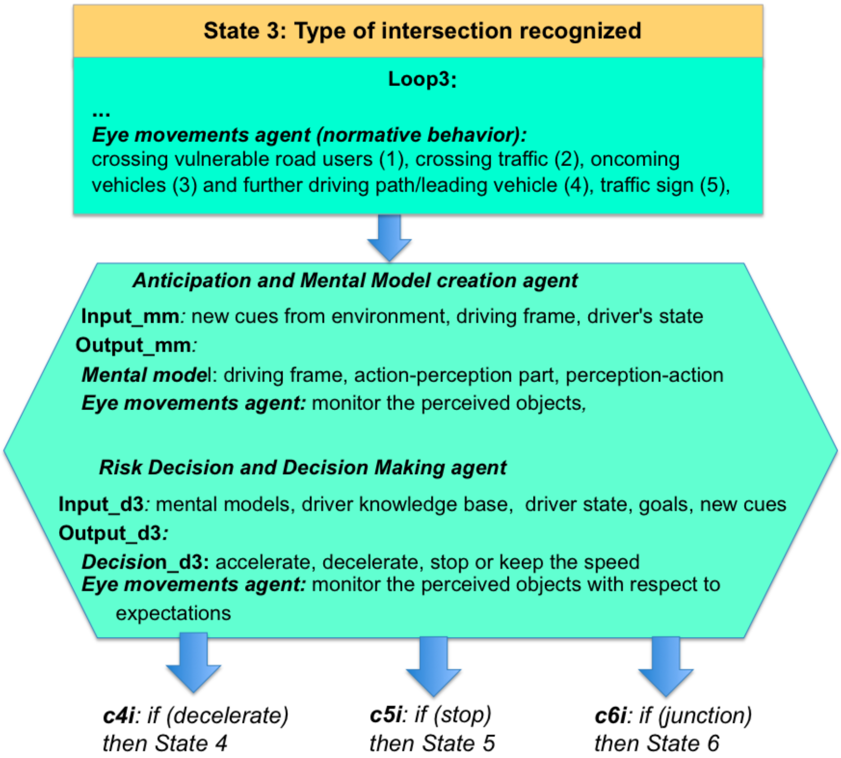


Figure 7.8: *Cognitive state 3: Type of intersection recognized. Activities of agents within loop3 function are similar to activities within loop2 function. Mental model generator, Anticipation and Decision making agent are activated on the rule-based level*

As already discussed, the *Approach segment (Free Driving (State 1)*, *Intersection recognized (State 2)*, and *Type of Intersection recognized (State 3))* consists of several cognitive states but one decision that has to be made on the rule-based level. This decision is made within the third model state and is labeled *decision_3* (see Figure 7.8). The decision can be to either accelerate, decelerate, stop, or keep the speed. The decision making process is activated by *Risk assessment* and *Decision making agents*. They are activated by the creation of the mental model, meaning by the output of *Mental model generator*. It is important here to understand that these agents have been operating also in the previous states but they were not operating on the rule-based but on the skill-based level. The *Risk assessment agent* evaluates the costs and benefits of each of the possible actions in relation to the retrieved mental model. Based on the output of *Risk assessment agent*, the *Decision agent* selects the appropriate action.

The inputs for the decision process *(input_d3)* are retrieved mental models, driver knowledge base, driver's state, goals, and new cues from the environment. The model is then advanced either to the state *Deceleration (State 4)* or to the *Stop (State 5)*, depending on the made decision *(output_d3)*. If the driver decides to keep the speed he is remaining in the same state as long as he does not reach the junction. By reaching the junction the model is directly advanced to the *State 6 (Crossing/Acceleration)*.

State 4: Deceleration. *State 4* is activated by the positive conditional function *c4i*. The function *c4i* becomes positive when the output of *Decision agent* in *State 3* is to decelerate. Concerning the dynamical characteristics of the deceleration phase, [Aasman95] and [vanderHorst90] found that drivers follow a fixed sequence of car-device actions, but the timing is determined by local conditions. These have already been described in *Chapter 5*. Regarding the visual behavior within this state, the eyes movement is modeled as a function between the following points: crossing vulnerable road users (1), crossing traffic (2), oncoming traffic (3), further driving path / leading vehicle (4), and traffic sign (5). This is sketched in Figure 7.9.

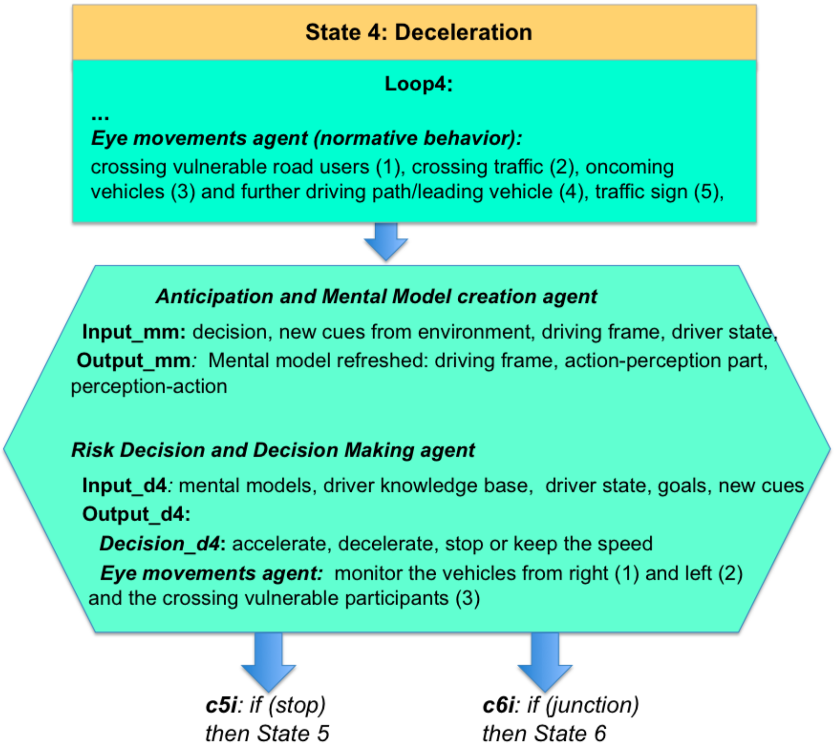
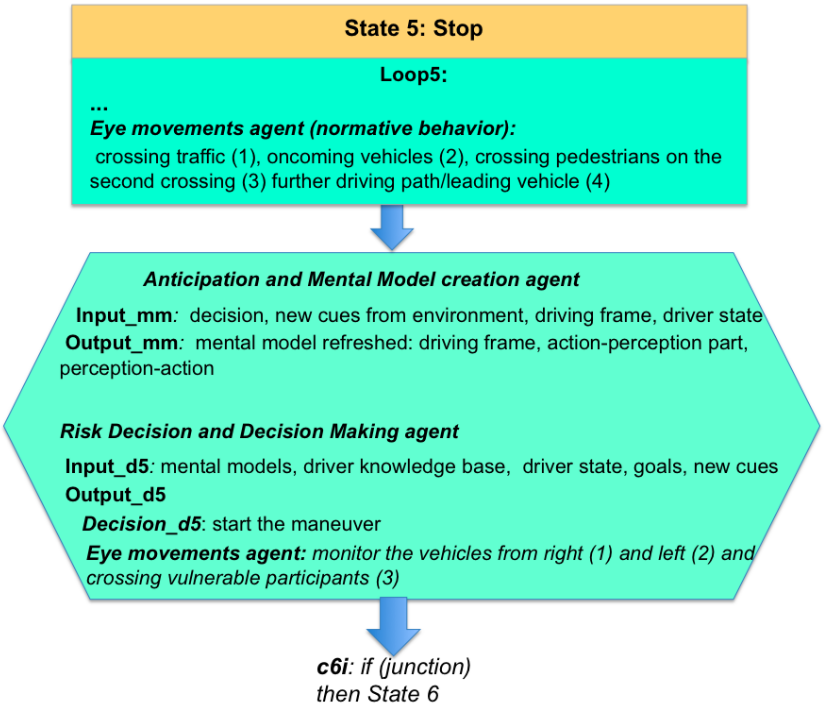


Figure 7.9: *Cognitive state 4: Deceleration. Short snippet of Eye movements agent within loop4 and new inputs and outputs of Anticipation, Decision making and Mental model generator agents*

The *Risk assessment* and *Decision making agents* are restarted with new inputs. The *Decision making* evaluates whether the unfolding of the situation develops according to expectations. If yes, the model is looping in the same state because the decision does not have to be re-made on the conscious level. If the situation develops differently than expected, the *Mental model generator* is activated again and the more appropriate mental model of the situation is retrieved on the rule-based level, or in critical situation even on knowledge-based level. After this is done the *Risk assessment* and *Decision making agents* decide again whether to stop, decelerate, or keep the speed. When the crossing roads are reached, the function *c6i* becomes positive and the model is directly moved to *State 6*. If the model performed a halt, the function *c5i* proceeds the model into *State 5: Stop*.

State 5: Stop. The driver model reaches *State 5* with the decision to stop. This state differs from the other states because of different eye movements and different decisions that can be made. The *Anticipation*, *Mental model creation*, *Risk assessment*, and *Decision making agent* are fulfilling similar operations as in *State 4*. This is sketched in Figure 7.10.



State 5: Stop

Loop5:

...

Eye movements agent (normative behavior):

crossing traffic (1), oncoming vehicles (2), crossing pedestrians on the second crossing (3) further driving path/leading vehicle (4)

Anticipation and Mental Model creation agent

Input_mm: decision, new cues from environment, driving frame, driver state

Output_mm: mental model refreshed: driving frame, action-perception part, perception-action

Risk Decision and Decision Making agent

Input_d5: mental models, driver knowledge base, driver state, goals, new cues

Output_d5

Decision_d5: start the maneuver

Eye movements agent: *monitor the vehicles from right (1) and left (2) and crossing vulnerable participants (3)*

c6i*: if (junction) then State 6*

Figure 7.10: *Cognitive state 5: Stop. The loop5 function with Eye movements agents and new inputs and outputs of Anticipation, Decision making and Mental model generator agents*

After the driver has stopped, the *Decision making agent* is re-activated. The new decision that should be made, (*decision_d5*), refers to choosing an appropriate time gap and to starting the maneuver and accelerating. In the moment the maneuver is started the *condition_6_input (c6i)* becomes positive and advances the driver to the next state. In the presented example, it is the *Crossing/Acceleration* state. For the right turns it is the *Turning* state. The output of the *Decision agent* regarding *Eye movements agent* depends upon the planned maneuver and an input from *Information perception agent*.

State 6: Crossing/Accelerating. The model enters *State 6* either when the *Decision making agent* starts the maneuver in *State 5* or when the crossing roads are reached. This state presents the exemplary state of crossing the intersection. As mentioned, for the right turn a supplementary and for left turn an additional state exists. The *State 6* occupies both segments *Crossing I* and *Crossing II* as performed visual behavior does not differ very much in these segments and most probably no new conscious decision is made within *Crossing II* segment. The drivers mainly decided upon the crossing depending of the whole junction area and not upon the first and then second half separately.

The activities of cognitive agents in this state are similar to the activities of agents in previous states. The activities of relevant cognitive agents are sketched in Figure 7.11. The *Decision making agent* evaluates whether the unfolding of the situation develops according the expectations and if it deduces

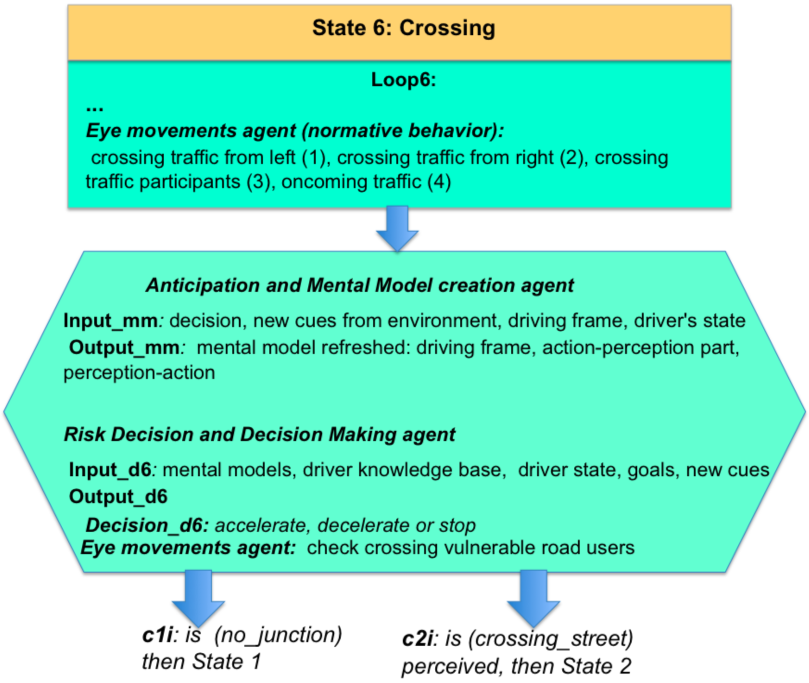


Figure 7.11: *Cognitive state 6: Crossing/Accelerating. The prioritization of eye movements and new inputs and outputs of Anticipation, Decision making and Mental model generator agents*

that the chosen time gaps were wrong, it may decide to stop or accelerate. Further, it also decides on the behavior towards the possible crossing vulnerable road users on the second pedestrian crossing. Therefore, the *Eye movements agent* receives an input to look for the possible crossing pedestrians.

If the model does not have to stop to give way to the crossing pedestrians the driver model is moved to the starting state *Free driving* by leaving the junction area. This is the case when no other crossing roads are perceived, otherwise the model advances directly to *State2: Intersection recognized*.

In similar way, the performance of other maneuvers at intersection can be modeled. The activities of cognitive agents realized within each state can be always modeled in more details and more agents can be included. To get the better understanding of the whole picture, rudimentary rules for the *Eye movements agent* has been given here. In the further section, the modeling of the *Eye movement agent* is discussed in more detail.

7.1.4 Modelling the Operative Cognitive Agents

Throughout this thesis, the main reason for drivers' erroneous behavior being in information perception is argued. Also, it was argued that the eye movements present the only observable output of driver's cognitive processes on the guidance level. Therefore by focusing on the modeling of eye movements and on visual strategies, the most relevant elements of driver behavior are covered. This is why an additional attention is given to discussing the design of the *Eye movements agent*.

In *Chapter 4* it was discussed that modeling and trying to predict the next eye movement in a fully deterministic manner is a complex problem and still no successful algorithm has been developed. Therefore the approach suggested here is to model both deterministic and probabilistic, and both normative and naturalistic eye movement behavior. Depending on the situation, both normative and usually performed eye movement behavior can be either deterministically or probabilistically modeled.

The basic structure of the *Eye movements operator agent* is presented in Figure 7.12. Both, top-down and bottom-up control mechanisms of eye movements are included. Top-down commands involve normative as well as naturalistic driver behavior. The normative driver behavior is modeled by the output of already discussed cognitive processes. They depend upon the state in which the model currently is. Corresponding to the previous discussion, they are presented by different *loops* and output functions of cognitive agents like *output_c* or *output_r*, as well as by outputs of *Anticipation* and *Mental model generator agents* and various decision making processes (*output_dx*). The particular output commands to the *Eye movements agent* have been given in the previous section.

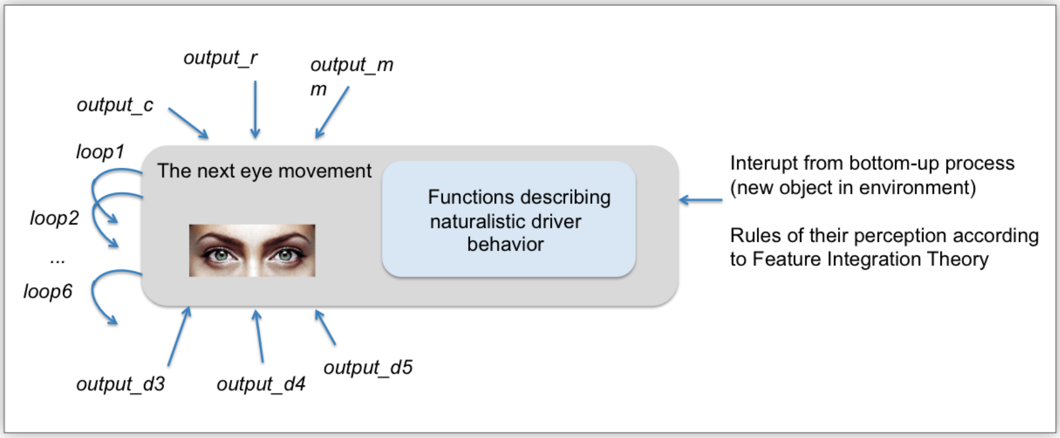


Figure 7.12: *The simulation of the next eye movement. The basic structure of Eye movements agent with defined input and output parameters*

The naturalistic drivers' behavior can be described in the form of different rules, which are related to the chosen mental model of the situation. These rules are either general or maneuver dependent rules and they can always overrule the normative visual behavior. In this way a sort of *Error watcher* can be realized. The task of this element would be to compare the normative and resulting behavior and to report about their differences. By this, the propagations of an error leading to an accident can be followed.

Top-down eye movements present a default visual behavior but they can anytime be interrupted by bottom-up commands. The bottom-up commands describe the data-driven control of eye movements and can be also expressed as rules with different priority levels. These rules may for example include the elements of *Feature integration theory* discussed in *section 4.1* or similar theories, which are known to describe exogenous control of attention, like from [Gibson73] or [Goldstein99]. An example of bottom-up rule is that the glance on the moving object is preferred over glance on the stationary object, or that glance on the moving object in the foveal field is preferred to glance on the moving object in the peripheral field of view. The rules can be also driving specific like that the vehicles with right of way have preference over vehicles, which do not have right of way.

As discussed previously, the rules of naturalistic drivers' behavior can also be formed based on the experimental analysis. The general rules of the usual driver visual behavior can be taken from the conducted experiment in *Chapter 5*. Nonetheless, the experimental analysis was conducted in the driving simulator and not in the field experiment. Also, the resolution of the applied eye tracking system and the number of test persons is not sufficient for claiming upon the validity of suggested rules and functions. Therefore they are to be implemented as general as possible, more as tendency descriptions than the absolute values. Still, they are beneficial because similar descriptions of eye movements mechanisms at intersections cannot be found in publicly available literature.

As the last point of this discussion, the suggestion for the categorization of the eye movements at intersection is given, based on the conducted analysis. The eye movements and by that the committed visual tasks at intersection can be categorized into:

- *Data-driven glances (I)*, glances, which are not consciously controlled,
- *Stabilization glances (II)*: glances, which serve to the stabilization of the vehicle (assessing trajectory or focusing on the *anchor point*),
- *Evaluative glances (III)*: glances, which serve for evaluating the distance or speed of object or intersection (focusing on the junction area or focusing on the *Focus of Expansion point*),
- *Anticipatory glances (IV)*: glances, which serve to evaluate and perceive environment, relevant for the task that is not directly to be performed (focusing on the second pedestrian crossing on an intersection entry or focusing on the crossing streets already in *Approach* segment),
- *Active scanning of participants having right of way (V)*:
    - of vehicles (Va),
    - of vulnerable road users (Vb),
- *Active scanning of participants not having right of way (VI)*:
    - of vehicles (VIa),
    - of vulnerable road users (VIb), and
- *Irrelevant glances (VII)*.

The first step in defining the probability functions of the naturalistic driver behavior is to, based on the segment, the task to be accomplished, and the presence of the other road users, determine the priority for each of the presented categories. Some of the tasks belong to more than one category; especially the tasks of the second and third category cannot be clearly distinguished from each other. For example, focusing on the *Focus of Expansion* point serves as much for the stabilization of the vehicle as it serves for the evaluation of speed and distance.

By this, the main guidelines and recommendations for the implementation of the cognitive model that can be used for the development of driver assistance systems have been presented and the second objective of the thesis is covered as well. For the completeness and as an indication of the future work, the implementation of the driver model already done at the Chair of Ergonomics is shortly presented in the next section.

7.2 Implemented Functionality

The efforts towards the construction of the new driver model have already started at the Chair of Ergonomics. The first step included the definition of the interface to the driving simulator and implementation of the steering behavior. These are briefly presented within this section.

A general structure and communication rules between the driver model and the driving simulator software (SILAB) were defined in diploma thesis of [Popova08]. The requirements on the software architecture are set based on the software ergonomic criteria:

- *Extensibility*: the model is planned to be developed step by step during a long period of time. Each new feature will require a new solution. These solutions should not require any change in the current structure of the program but should be developed as add-on components;
- *Modularity*: for testing of new approaches and theories, the appropriate elements of the program should be exchangeable. Therefore, specific features are to be programmed as standalone modules with clear interfaces to the rest of the model;
- *Simple configuration*: for the modularity and exchangeability of elements, the communication between modules should be clearly defined, simple to use and adapt.

Within this thesis the interface of the driver model to the driving simulator is implemented in C++ (the same program language used by SILAB) and C#. Advantage of C# is that the programmer does not need to take care of memory allocations. C# is also compatible with C++ and the other .NET languages, has a good structure, and is relatively easy to learn. The model is named *DriMoS (Driver Model Simulation)*.

The structure of DriMos consists of several modules:

- *Configuration*, it is an XML file and it is loaded upon initialization. It consists of a description of all modules and their states. Each module has own function and communicates with other modules through the configuration file;
- *Loader* is responsible for the correct initialization of the program. When the program has to be run on a different computer, the location of the *.dll* modules needs to be updated in the xml archive. This xml archive also contains the IP addresses of the computers running DriMoS and SILAB, as well as the communication ports;
- *Communication Module* enables exchange of data between SILAB and DriMoS over UDP sockets. Exchange of data happens over IP and port number, which are defined in SILAB configuration file; and
- *Street reader* possesses information about the street course. SILAB has a special feature, which enables to change the driving course on fly, depending on the development of the scenario. This means that the course parts are loaded fractionally during simulation and not all at once at the beginning. Exactly this flexibility causes one of the biggest disadvantages for development of the driver model. Namely, SILAB is not giving any online information about the actual street course [Popova08]. As explained in Chapter 5.1.1, course definition occurs in the configuration file. The data from configuration file are transformed into coordinate system of

SILAB, but it is not possible to access data online. Nevertheless, on the base of indirect data (vehicle position, deviation from the ideal lane, and the width of the road), the street course can be calculated in advance but it is necessary to drive through the course once and record the data. Coordinates are saved in text file, which can be loaded together with DriMoS *(street.txt)*.

- *Driver* presents the heart of the program. In the original version from [Popova08], *Decision-making* and *Visual control* module are separate parts of the structure. This is moved to the *Driver module* as indivisible part of driver's cognition and the Figure 7.2 presents the suggestion of how the cognitive part of this element should be modeled.

Apart from being described in the *Configuration Module*, each module has additional configuration file containing specific parameters. Also, each module has its own interface, responsible for methods, characteristics, and events. In that way, the advantages of object oriented programming are applied in the best way: interfaces are shared between modules, modules can be easily exchanged, and new interfaces can be added.

Modeling Control Behavior

Even though the focus of the presented model is the driver behavior on the guidance level, the controlling level should not be neglected but should be implemented in such way to comply with the model on the guidance level. For the control driver model that is the part of the driver cognitive model, an input should comply with the scientific findings concerning the driver's perception of the stabilization cues. In the following the short description of the way the stabilization level is implemented in DriMoS is presented. For further information see [Plavsic10b].

Depending on the speed, on the traffic situation and on the driver experience, the visual cues used for the evaluation of the lateral distance and speeds differ. For experienced driver, the most important ones are: the velocity, yaw angle, the radius of the curvature the vehicle is following, and the radius of the curvature of the upcoming road segment. These values are contained in the parameter named *Time to Line Crossing (TLC)*. As explained in *Chapter 6*, TLC is the point in the future path at which time the vehicle will cross the edge line of the road. Even more, experienced drivers can directly deduce TLC from the optical flow. Therefore, the TLC presents a parameter that is connecting the stabilization and guidance level of the driving task and as such it is used for modeling of the driver behavior on the stabilization level.

Based on TLC data, steering wheel corrections are calculated within work of [Guzman09]. The driver control behavior is modeled by a *Proportional-Integral-Derivative (PID)* controller, which is found to be appropriate for describing human operating behavior [Wolf09]. The turning at intersections is also implemented and in this case the PID controller takes the lateral distance as an entry parameter. The reason is that SILAB manages rural roads (*Courses*) and intersection areas *(Area2)* in a different way and does not deliver the same parameters for both of them. The problem with *Area2* is that SILAB does not give the lateral velocity for it. The longitudinal control is also modeled and coupled to the lateral control. The speed is controlled by regulating the gas pedal with PID controller. The controller assures that when approaching an intersection the car does not overpass the speed of 35 to 40 km/h and that at the moment of entering the junction area the car has a speed of maximum 17 km/h. Additionally, a foundation for the implementation of visual attention was done. For the implementation of visual perception the *Street Reader* module was used. In that way it was possible to calculate the eye position of the driver in the SILAB X and Y coordinate system and to provide an interface for modeling the visual behavior.

The basic implementations, already conducted at the Chair of Ergonomics, offer a good base for the further development of the driver cognitive model. The generic structure, the interface with the driving simulator, and the stabilization level of the model have been achieved with moderately fast Personal Computers. The future work involves a long-term process of iterative development of the guidance level. This thesis has contributed by setting its foundation and recommendations for further modeling.

7.3 Summary

Within this chapter the recommendations and guidelines for the computer simulation of driver cognition for assistance at intersections are given. The modeling of the driver presents a continuous process of merging comprehensive scientific findings about the driver behavior. This is how the presented model should also be understood.

First, the general recommendations for the model were given. It is suggested for the model to produce both normative and naturalistic driver behavior. The normative driver behavior should be implemented as deterministic and probabilistic production system as an output of various cognitive processes. The naturalistic driver behavior is related to the selected mental model of situation and the functions describing this behavior are the results of empirical research. As such, the model can produce both average and individually specific behavior and accounts for the random as well as for systematic erroneous behavior. Hence, the model is unique and resolves the disadvantages of various models presented in the previous chapter.

Further, the architecture of the driver model has been suggested. It is proposed to simulate driver cognition in the form of *Multi-agent system*, where different elements of the driver cognition are modeled by autonomous cognitive agents. In this way, the complexity of human cognition is grasped and the software structure can be developed in such a way to be transparent, modular, and easily extensible.

It has also been shown how the driver model can be spatially, temporally, and causally mapped into the performance of intersection task. It is further proposed to simulate the intersection task performance by *Finite State Machine*, because this structure enables clear distinctions between states and processes and deals with both discrete and continuous processes at the same time. In an example of crossing the intersection, the activities of the agents within the driver model and the transition functions for proceeding the model from one state to another are discussed. More detail recommendations are given for the implementation of the *Eye movements agent*.

At the end, the implementation of the driver model and already implemented connection to the driving simulator at the Chair of Ergonomics is briefly presented. This implementation presents a solid foundation for further work, which should consist of iterative implementations of driver cognition.

Chapter 8

Summary and Further Work

The objective of this thesis is to analyze two subject matters. The first one being the analysis of driver behavior at intersection scenarios for defining the appropriate functionality of the Intersection Assistance System. The second objective refers to the specifications of the requirements for the computer simulation of driver cognition to be used in the process of assistance development.

The research of human cognition regarding the driving task has become increasingly popular since the technical progress has enabled the creation of the *Advanced Driver Assistance Systems (ADAS)* that can support the driver on the guidance level of the driving task. The recent technical breakthrough of preciser and reliable sensors, and communication technologies has enabled the creation of assistance systems for intersection scenarios. Within several European projects, numerous prototypes of communication-based Intersection Assistances have been realized. Having the technical feasibility on call, the challenge is to use this potential in the best way. It is almost not over-exaggerated when stated that some assistance systems for the guidance level of the driving task that appeared on the market were designed according to principle ”We have a solution, we only need the problem for it.” Not putting the user in the center of the development process caused users’ reluctance. While such assistances may have reduced some of the driver errors, they have on the other hand also increased the risk for the new types of errors to be committed. To avoid such issues, the driver should be put in the center of the development process.

When designing an assistance system for the guidance level, human-centered design implies the analysis and the modeling of the cognitive driver behavior. Maneuvers at intersections are among the most demanding situations in driving. Up to now, only a minor number of studies have analyzed driver behavior at intersections in detail. One reason for this is that systematic analysis in field experiments is very difficult to conduct, and the other reason is that prevailing simulation software was up to recently not ripe for the simulation of the urban scenarios with the satisfactory quality. Another reason is a lack of methods for analyzing the human cognitive processes while driving. With the steady improvements of driving simulator software, experimental studies are becoming more reasonable and driver behavior at intersections can be analyzed in more detail.

The reported efforts to design an Intersection Assistance system, without a deep analysis of driver cognition and performance, were not satisfactory. On the one side, the warning assistances for turning maneuvers were either issuing the warning when it was too late to prevent the collision or at the moment when it irritated the driver. On the other side, the often discussed solution of autonomous assistances that perform a full brake in case of an immediate collision risk, requires a high reliability of applied sensor systems and automatic technologies. Additionally, it is considered as undesirable solution because of the unresolved legal issues. Also, the suggested solution for these problems, the adaptation of the warnings on the driver and driving situation, showed to be very complex to solve.

As a motivation for this thesis a completely new approach is suggested: Informative-Warning Assistance System, which has a cognitive model of driver behavior in its core and which offers an appropriate information at the right moment, thus leaving the reaction on the side of an active driver. Such an assistance needs to know which information the drivers require the most in a particular driving situation and at particular moment. Thus, the assistance requires the knowledge about the normative and typical drivers' behavior, both dynamic and cognitive. The dynamic characteristics of drivers' behavior at intersections have been fairly analyzed in the available literature, not only in the simulator environments but also in field experiments. On the contrary, cognitive driver behavior regarding the driving task was not that much in scientific focus, especially not related to the performance at intersections. This thesis therefore, deals with the basic analysis of human cognition while performing the driving task at intersection, both theoretically and experimentally.

The first step was the preparation for the analysis to which belong: (1) the determination of appropriate classification of intersection scenarios, and (2) development of an appropriate theoretical model of human cognition. In contrast to the situations in the longitudinal traffic, there are no available data sets for the classification of intersection scenarios that account for the presence of the other road users. Thus the driving situations at intersections are classified on the level of traffic situations. The intersections are grouped based on the type of roads connecting them, maneuver, and the regulation of the right of way. The relevant processes of human cognition from information perception to resulting behavior have been identified and analyzed. Reaching different stages of Situational Awareness is modeled and explained on an example of crossing an intersection. The key in this process is the selection and creation of mental models. The presented analysis breaks down the inputs and outputs of the mental models and enables the analysis of their formation. The developed theoretic model presents a base for the computer simulation of driver behavior suggested in the *Chapter 7*.

Within the theoretical analysis, several different aspects and theories describing the driver performance are brought together: Situation Awareness, the workload, task difficulty, risk perception, typical information-processing paradigm, and it is explained how they relate to each other. Furthermore, the heuristic for evaluating the task difficulty at intersections is suggested. The objective task difficulty of each of the selected scenarios is estimated by suggested heuristic and compared to the subjective evaluation of the risk. The results showed that these two parameters had the similar value for each scenario, except that the objective difficulty of crossing intersection when not in right of way was slightly underestimated by the drivers. The theoretical analysis has further identified the essential parameters influencing drivers' behavior at intersections: right of way, maneuver, the presence of the other road users, and time pressure.

The conducted experimental analysis has investigated the influence of these parameters on the resulted behavior. On the guidance level of the driving task, the only observable resulting behavior are the eye movements. Even though connected with various methodological and technological difficulties, the analysis of eye movements presents the best way to gain the insight into the driver's cognitive processes. The majority of accidents arises from the difficulties in information perception and not information processing. Therefore the analysis of eye movements is chosen as the method to achieve the goals of this thesis and to analyze the cognitive behavior at intersection scenarios. The focus is on the comparison of ideal and applied visual strategies. In that way the omitted tasks and committed errors are identified, which present the cardinal aspects of the resulted behavior. The ideal behavior is defined based on the tasks that are to be accomplished in each segment of the intersection. The tasks for each segment are determined, and based on the normative behavior, a priority level is assigned to every task. The intersection maneuver is divided into five segments and each of these segments is characterized by a common goal and a conscious decision to be made. These segments are labeled: *Approach*, *Deceleration*, *Crossing I*, *Crossing II* or *Turning*, and *Exit*.

Within the experimental study, the behavior of 24 participants in 10 different intersection scenarios has been analyzed in the baseline trial and the trial with induced time pressure conditions. Applied NASA TLX scale implied very high subjectively experienced workload on the participants, especially in the trial with time pressure. The collected data undoubtedly concluded that the task demand of particular intersection situations might exceed driver cognitive limits. The support of an assistance system is both objectively and subjectively highly desirable. Participants however expressed resumption towards warning systems. As no stable pattern and no method for the comparison of subjective and objective risk exist, the risk was measured indirectly by the *task demand* and *perceived workload*. The analysis revealed that the subjective evaluation of the task difficulty and orientation comply with each other. The subjective risk of incorrect evaluation and the risk of collision did not show any significant differences among the scenarios for $p < 0.05$.

The detail analysis of visual behavior confirms the presence of both *bottom-up (data-driven)* and *top-down (knowledge-driven)* eye movements mechanisms. The presence of the other road users was the most influential factor on the visual behavior. For more than 4 objects in the scene, the visual behavior was fully data-driven. The data-driven glances did not depend upon the intersection parameters. The knowledge driven glances, which result from the driver's mental models and cognitive processes, were influenced by intersection parameters. The executed maneuver had a stronger influence on the knowledge-driven glances than the right of way. The typical duration of the glances depended on the segment, the task, and the intersection. However the duration of all glances was in the range of $0,2$ to $0,8$ s. Only the glances to the leading vehicle were up to $1,8$ s. When no other road users were present, the majority of glances belonged to the middle $(1-2$ s) and far driving path $(> 2$ s), and, in around 60% to the right side of the driving path. Anticipatory glances were only present when there were no other road users in the scene, otherwise the anticipatory glances were left out and full attention was given to the current task and segment. The conducted analysis showed a relation between drivers' errors and applied visual strategies. The most critical errors were committed during the *Deceleration* segment. It has been shown that even though the majority of accidents happened while turning or crossing the intersection, the accidents were the consequences of the errors committed in the *Deceleration* segment. As explained earlier, the activation of the inner model happens already in the approaching segment of intersection. The recognition of the type of intersection and regulative rules triggers specific behavioral schemata, developed by experience in relation to the current driver situation. An appropriate assistance can improve the approaching strategy and the selection of appropriate mental model and by that improve the corresponding behavioral schemata. A troubling characteristic of the naturalistic behavior is observed in the drivers' behavior concerning the traffic signs. With an exception of the *Stop sign*, only around 60% of participants did foveally focus on the regulation sign and for around 5% of test runs, it is assumed that they did not perceive it at all. Not seldom did drivers overlook the regulation traffic sign or approached the intersection with too high speed.

In general, the results showed that the naturalistic behavior strongly differs from the hypothetically ideal behavior. While executing the turn, a typical sequence of glances is observed. The sequence and timing of the glances was often inadequate and was, after the errors in the *Deceleration* segment, the second biggest reason for committed accidents. Principally, 4 to 5 short glances are performed in this segment. The third biggest error group was caused by the high reliance on the rule-compliant behavior of the others. These errors did not result in an accident in the conducted experiment because the other road users drove according to rules. Nonetheless these errors should absolutely be prevented by an Assistance system. Only 7% to 15% of drivers per scenario did reassure themselves against the erroneous behavior of the other road users. Of importance for designing the supportive assistance is that this number does not depend on the regulation type of intersection and the right of way. The vulnerable traffic participants were expected to be seen peripherally and were not actively scanned for, independent of whether they have right of way or not. It is also observed that the inter-individual visual behavior has a stable pattern. The performance in the simple scenarios of individual participants is related to the performance in complex scenarios and the performance in the baseline is related to the performance under time pressure conditions at the same scenario. This indicates that errors leading to accident are rather of systematic than random nature and are the consequences of the wrongly applied strategies. Such errors have an advantage that they can be addressed by a support system.

Based on the observations and acquired data, several functionalities for Intersection Assistance systems are suggested. Assisting the driver can be done in several ways, differing in the costs and the reliability requirements. The majority of suggested assistances does not require more than the GPS and on-board sensors data. These assistances intend to increase driver's attention and situation awareness in the approaching phase of intersection. They should prevent the initial errors of the frequently following error chain that can, under rare circumstances, lead to an accident. The intention is to leave as much initiative as possible on a side of the driver. An assistance system functioning in this way has a cooperative character and by that it enhances the driver's skills, authority, and competence. Such an approach prevents the creation of a numerous different and separate assistances for the same driving situation like *Assistance for Left turn*, *Assistance for Stop sign*, or *Assistance for Crossing*, but enables the assistance depending on the possibility for driver error, increasing by that either comfort, efficiency, and safety.

The second goal of the thesis is covered by the elicitation of the requirements of the computable, cognitive driver model. The proposal was to select the most appropriate among already existing cognitive models and to extend it with the cognitive driver model for intersections. The basic requirements of such a model are that it should be an integrative model of driver behavior, applicable in dynamic environments, and implemented according to software ergonomics standards. Even though several different models exist to account for the human cognition, only a few account for the cognition relevant to the driving task and they are either too complex and slow for use in dynamic environments or are not available for the third parties usage. From closer examination of existing models, a demand for the development of individual model emerged.

Therefore within this thesis, the guidelines and recommendations for the computer simulation of driver cognition are given. As the model should take account for the normative and the naturalistic behavior of the drivers, it is suggested to approach the model with both, Top-Down and Bottom-Up methods, simultaneously, and to implement both deterministic and probabilistic functions of the driver behavior. It is demonstrated how the model can simulate the average behavior of the test sample but also the individually specific behavior and how it can produce both random and systematic errors. Identifying and predicting erroneous human behavior is deduced to be the crucial aspect of the driver model for the usage in the development of driver assistance systems. The computer model should also enable the analysis of the consequences of particular chosen mental models when giving mental models as user input into simulation. The development of such model is a long-term, complex, and time-consuming process. Anyhow, by developing the computer simulation of driver cognition, the core element of the Intersection Assistance is set. The ultimate goal is an assistance system that observes the situation together with the driver, assess its risk, and by knowing the drivers' typical and normative behavior, it selects the appropriate information to present it to the driver in a suitable way and in the right moment.

It is suggested to design such a model as *Multi-agent system*, consisting of autonomous cognitive agents. In this way the model is designed transparently, modularly, and extensible. Each cognitive agent presents an element of the driver's cognition and is responsible for the specific cognitive process. The driver's experience and, from this experience, the available mental models are modeled as a set of production rules. Like so, the mental models can be given as an input to the simulation and an effect of different models can be evaluated. Further, the driver's state is described by different parameters with different weight factors. In the first iteration, the driver's state can be modeled by only one value, determined, for example, by fuzzy logic function of the *Performance Shaping Factors*. It is also suggested to model the intersection task performance by *Finite State Machine* because this structure enables clear distinction between states and processes and deals with both discrete and continuous processes at the same time. In that way the driver model is spatially, temporally, and causally mapped onto the performance of intersection task and all the relevant aspects of the performance are captured.

The future work in the first step involves the implementation of the suggested cognitive model into computable form. This is a long-term process and should be realized iteratively. Also, it should be considered in which way the learning capability could be implemented into the model. Further experimental investigations are necessary regarding the analysis of driver's visual behavior at intersections. The conclusions arrived at in this study should be validated in the field experiment. As the short-term goal, it can be investigated whether a clustering of the drivers, based on the applied visual strategies, could be made. Further complement to this work is a systematic analysis of the influence of the other road users on the resulting visual strategies. The results of such an analysis enable the required classification of intersection scenarios based on the driving situation. Nonetheless, the essential work is to be done in solving the methodological issues of such experimental and theoretical analyses. These refer in the first place in defining the methods for a systematic analysis of driving situations with so many influences. Especially challenging is to answer the following questions: Which situations can be taken as representative for typical and critical situations?, What is the difference between them?, How to produce the criticality of driving situations?, and How to provoke drivers' erroneous behavior, relevant for the investigation of traffic safety? The difficulties regarding the apparatus, like triggering logic of the driving simulator, and the time consuming analysis of video data, should be eliminated in parallel. Also, it should be worked on establishing the methods for the analysis of cognitive processes and for the creations of the mental models. Furthermore, during the work on this thesis no appropriate method for the comparison of eye movements, especially of their sequence was found and a valuable contribution can be done in this area.

This thesis offers a good understanding of the driver cognition and applied visual strategies when performing the tasks at intersections. The presented work offers stimulating results for the development of driver assistances that are efficient and at the same time accepted by users, not only for intersections but also for other driving situations on the guidance level. In relation to these issues, the resulting discussion suggests the direction in which further research should go, and unveils the crucial methodological issues that are to be investigated. Moreover, elements of performed analysis go beyond intersection scenarios and driver behavior, and present relevant scientific issues regarding the user cognition, corresponding assistances, and traffic safety in general.

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Appendix A

Classification of Intersections

Taxonomy

Nr.	Taxonomy	Index Information processing	Index Vehicle operation
36	C1-K0	63	14
37	C1-K0-V	62	14
38	C1-K0-H	71	16
39	C1-K0-H+V	71	16
40	C1-K0-E	83	18
41	C1-K1	76	24
42	C1-K1-F	78	22
43	C1-K1-V	75	22
44	C1-K1-H	83	21
45	C1-K1-E	78	22
46	C1-K3	68	14
47	C1-K3-V	67	14
48	C1-K3-H	78	17
49	C1-K3-F	72	18
50	C1-K4	92	22
51	C1-K4-H	92	23
52	C2-K0	64	12
53	C2-K0-H	58	15
54	C2-K0-E	75	16
55	C2-K1	73	22
56	C2-K1-F	81	22
57	C2-K1-V	72	22
58	C2-K1-H	88	19
59	C2-K1-E	84	20
60	C2-K2	82	21
61	C2-K3	65	15
62	C2-K3-F	78	20
63	C2-K3-H	82	18
64	C2-K3-E	74	18
65	C2-K4	91	23
66	C3-K0	68	11
67	C3-K0-V	58	14
68	C3-K0-H	78	15
69	C3-K0-E	71	17
70	C3-K1	76	21
71	C3-K2	82	21
72	C3-K3	66	14
73	C3-K3-F	78	20
74	C3-K3-H	82	18
75	C3-K4	88	23
76	C4-K0	64	14
77	C4-K0-V	58	14
78	C4-K0-H	78	15
79	C4-H0-K+V	74	16
80	C4-K0-E	72	14
81	C4-K1	79	22
82	C4-K1-F	83	22
83	C4-K1-V	77	22
84	C4-K1-H	79	23
85	C4-K1-E	76	22
86	C4-K2	78	20
87	C4-K2-E	80	21
88	C4-K3	75	17
89	C4-K3-F	81	20
90	C4-K3-H	75	18
91	C4-K3-E	76	17
92	C4-K4	90	24
93	C4-K4-E	93	23
94	C5-K0	75	13
95	C5-K0-V	72	14
96	C5-K0-H	71	14
97	C5-K0-E	81	17
98	C5-K1	88	21
99	C5-K1-F	86	21
100	C5-K1-E	95	23
101	C5-K2	84	21
102	C5-K3	79	14
103	C5-K3-F	80	20
104	C5-K3-H	82	16
105	C5-K3-E	90	17
106	C5-K4	97	25
107	C6-K0	63	12
108	C6-K0-E	80	17
109	C6-K0-H	74	16
110	C6-K1	80	20
111	C6-K1-H	84	20
112	C6-K2	80	22
113	C6-K2-E	84	22
114	C6-K3	75	17
115	C6-K3-F	78	19
116	C6-K3-H	75	17
117	C6-K3-E	74	17
118	C6-K4	90	25
119	C6-K4-F	90	23
120	C6-K4-E	90	24
121	C7-K0	60	13
122	C7-K0-H	67	17
123	C7-K0-E	75	18
124	C7-K1	72	21
125	C7-K2	76	20
126	C7-K2-F	84	21
127	C7-K2-E	83	20
128	C7-K3	63	16
129	C7-K3-H	81	22
130	C7-K3-E	72	18
131	C7-K4	79	19
132	C7-K4-F	85	21
133	C7-K4-H	80	23
134	C7-K4-E	86	22

Evaluation

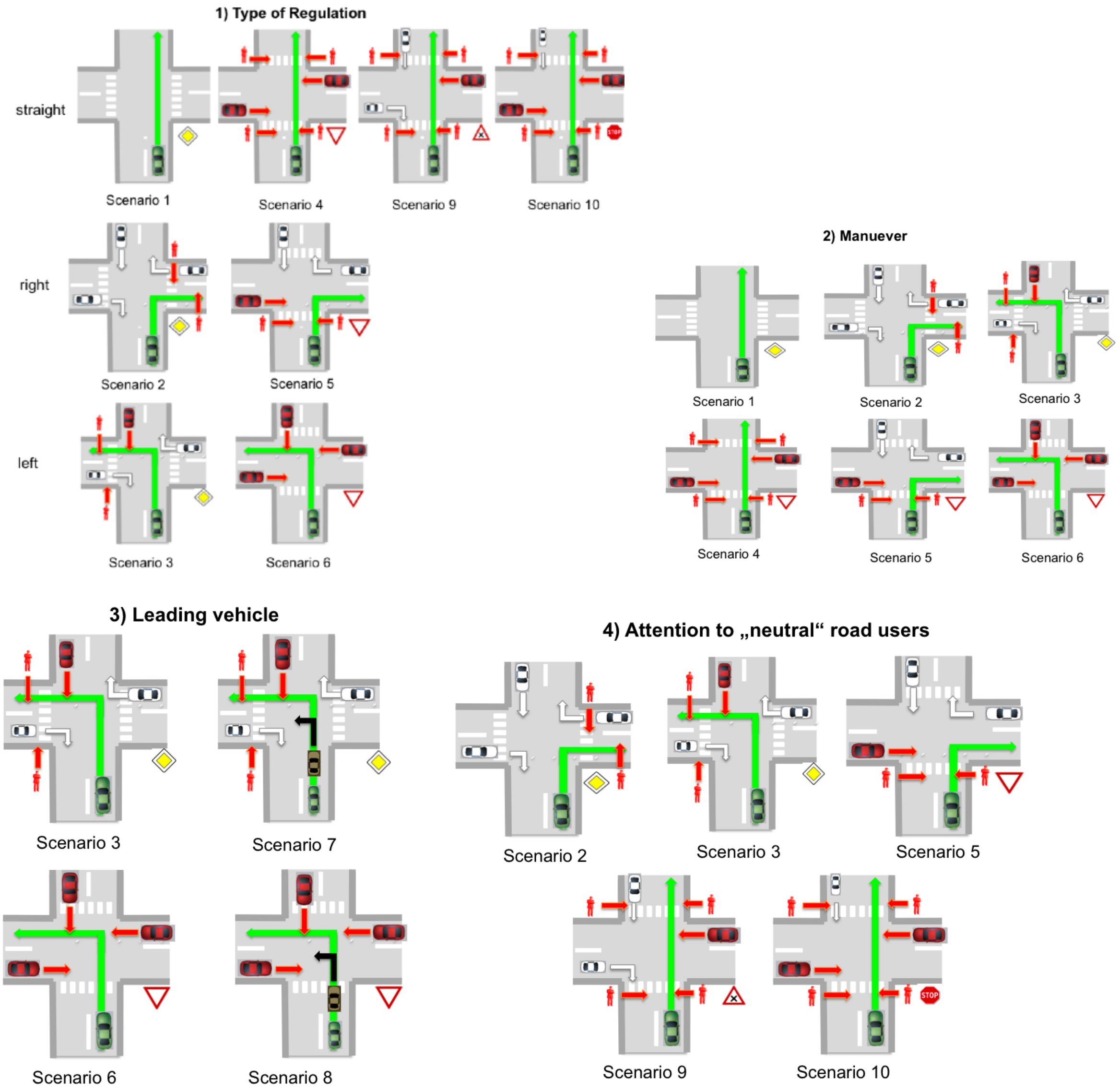


Figure A.2: *Scenarios to be compared with respect to (a) right of way, (b) maneuver, (c) presence of the leading vehicle, and (d) ”neutral” road users*

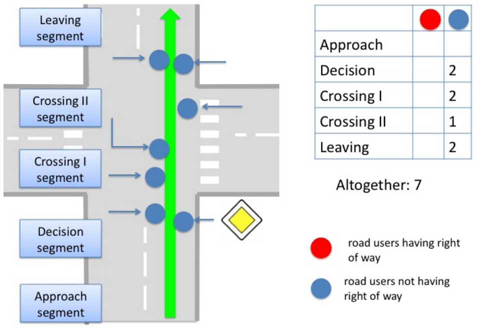
Error List

	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TP10	TP11	TP12	TP13	TP14	TP15	TP16	TP17	TP18	TP19	TP20	TP21	TP22	TP23	TP24
Approach Segment																								
Visual Errors																								
focus intersection area (III)																								
focus crossing line area (III)																								
look for the directional traffic signs (I)																								
check for the type of regulation sign (I)																								
check line postings (I)																								
scan environment (I)																								
not observing the leading vehicle (I)																								
Other Errors																								
too high speed																								
variable/unsteady speed																								
not keeping the lane																								
small distance to the leading vehicle																								
strict following of the lead vehicle																								
hinder pedestrians																								
hinder other traffic participants																								
Deceleration Segment																								
Visual Errors																								
check for vulnerable traffic participants from left (I)																								
check for vulnerable traffic participants from left (I)																								
focusing stopping line (I)																								
observe stopping trajectory																								
check for the possible crossing traffic (III)																								
not observing the leading vehicle (I)																								
Other Errors																								

too high speed																								
variable/unsteady speed																								
not decelerating																								
too strong deceleration																								
not stopping when necessary																								
not keeping the lane																								
small distance to the leading vehicle																								
strict following of the lead vehicle																								
hinder pedestrians																								
hinder other traffic participants																								
Crossing I Segment																								
Visual Errors																								
not checking for the crossing traffic from left (I)																								
not checking for the crossing traffic from right (I)																								
not observing if vehicle from the left behave normative (II)																								
not observing the traffic from the right																								
not observe possible crossing vulnerable traffic participants																								
observing leading vehicle																								
assess trajectory																								
Other Errors																								
wrong time gap																								
not keeping the lane																								
too fast driving																								
too slow driving																								
small distance to the leading vehicle																								
start crossing too late																								
strict following of the lead vehicle																								
hinder other traffic participants																								
Crossing II Segment																								

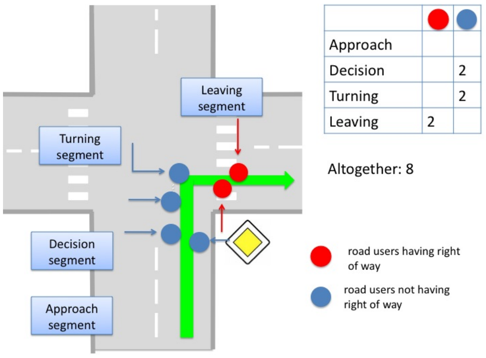
Visual Errors																								
not checking for hidden vulnerable traffic participants (I)																								
not observing further driving path (I)																								
observe oncoming traffic (III)																								
assess trajectory																								
observe lead vehicle (I)																								
Other Errors																								
too strong acceleration																								
variable/unsteady speed																								
not keeping the lane																								
small distance to the leading vehicle																								
strict following of the lead vehicle																								
hinder other traffic participants																								
hinder pedestrians																								
Exit Segment																								
Visual Errors																								
not checking for hidden vulnerable traffic participants (I)																								
not observing further driving path (I)																								
observe oncoming traffic (III)																								
assess trajectory																								
observe lead vehicle (I)																								
Other Errors																								
too strong acceleration																								
variable/unsteady speed																								
not keeping the lane																								
small distance to the leading vehicle																								
strict following of the lead vehicle																								
hinder other traffic participants																								
hinder pedestrians																								

Chunck points



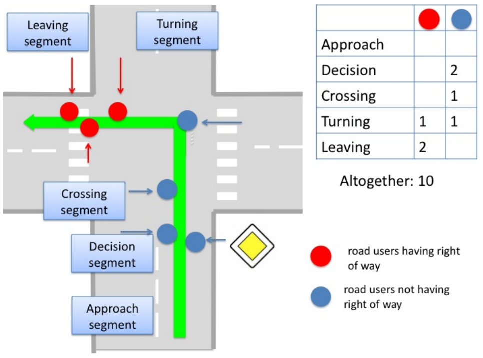
	🔴	🔵
Approach		
Decision		2
Crossing I		2
Crossing II		1
Leaving		2

(a)



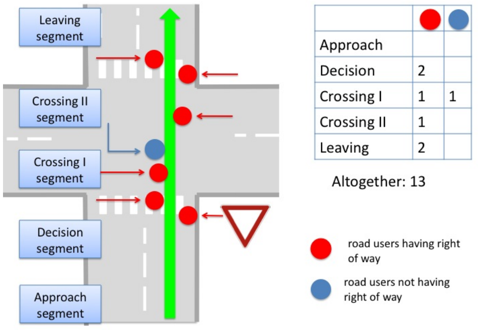
	🔴	🔵
Approach		
Decision		2
Turning		2
Leaving	2	

(b)



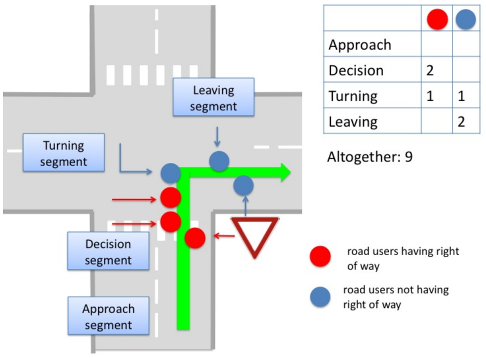
	🔴	🔵
Approach		
Decision		2
Crossing		1
Turning	1	1
Leaving	2	

(c)



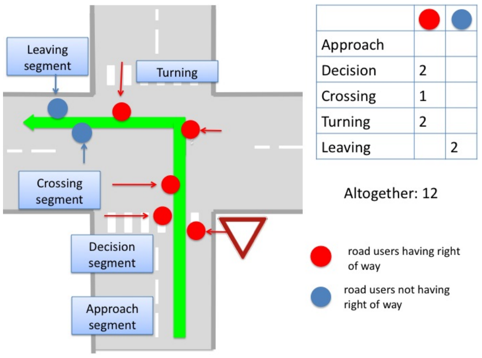
	🔴	🔵
Approach		
Decision	2	
Crossing I	1	1
Crossing II	1	
Leaving	2	

(d)



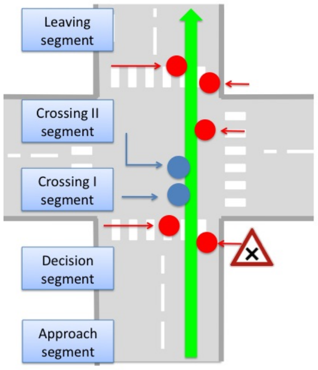
	🔴	🔵
Approach		
Decision	2	
Turning	1	1
Leaving		2

(e)



	🔴	🔵
Approach		
Decision	2	
Crossing	1	
Turning	2	
Leaving		2

(f)



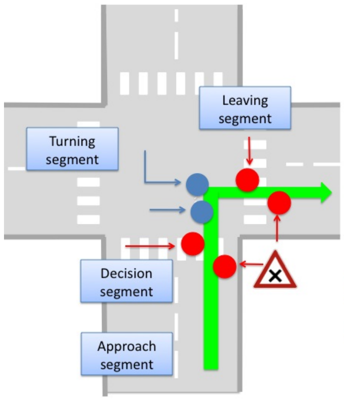
	🔴	🔵
Approach		
Decision	2	
Crossing I		2
Crossing II	1	
Leaving	2	

Altogether: 12

🔴 road users having right of way

🔵 road users not having right of way

(g)



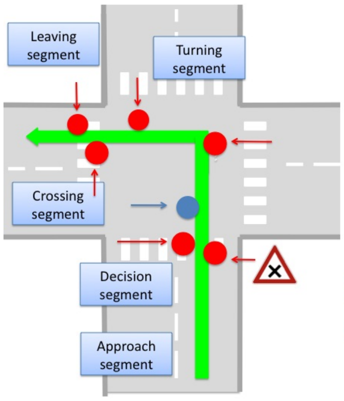
	🔴	🔵
Approach		
Decision	2	
Turning		2
Leaving	2	

Altogether: 10

🔴 road users having right of way

🔵 road users not having right of way

(h)



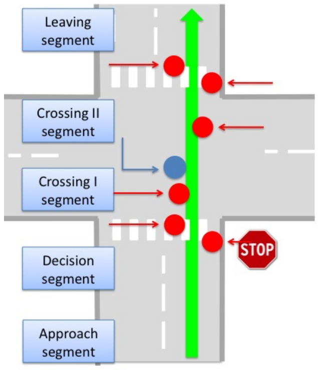
	🔴	🔵
Approach		
Decision	2	
Crossing		1
Turning	2	
Leaving	2	

Altogether: 13

🔴 road users having right of way

🔵 road users not having right of way

(i)



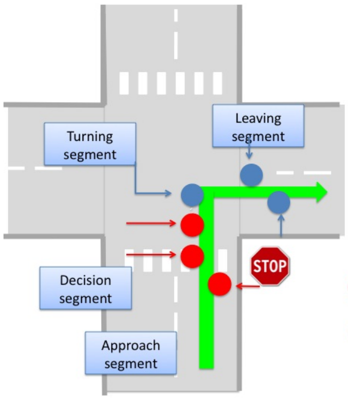
	🔴	🔵
Approach		
Decision	2	
Crossing I	1	1
Crossing II	1	
Leaving	2	

Altogether: 13

🔴 road users having right of way

🔵 road users not having right of way

(j)



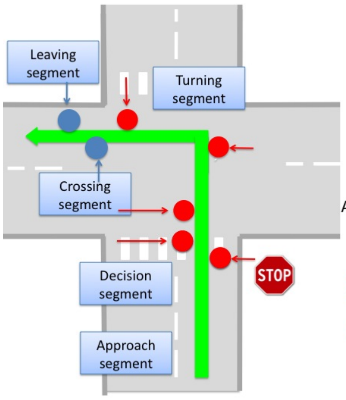
	🔴	🔵
Approach		
Decision	2	
Turning	1	1
Leaving		2

Altogether: 9

🔴 road users having right of way

🔵 road users not having right of way

(k)



	🔴	🔵
Approach		
Decision	2	
Crossing	1	
Turning	2	
Leaving		2

Altogether: 12

🔴 road users having right of way

🔵 road users not having right of way

(l)

Appendix B

Visual analysis

	Mean						STDEV			
Scenario 1 (Baseline)	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion	Max glance duration (s)	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	6	28,57	1,83	0,87	28,79	1,03	0,98	1,02	21,72	1,06
Middle lane	13	61,90	1,69	0,84	33,80	0,93	0,95	0,72	28,39	0,73
Far lane	13	61,90	1,54	0,44	25,44	0,52	0,78	0,31	20,93	0,41
Traffic sign	11	52,38	1,64	0,33	19,42	0,43	0,81	0,19	14,11	0,29
Street + junction left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street + junction right	3	14,29	1,33	0,44	12,22	0,47	0,58	0,35	7,68	0,33
Pedestrian crossing + areas I,J	4	19,05	1,25	0,43	16,58	0,44	0,50	0,21	13,10	0,19
Deceleration										
Close lane	1	4,76	1,00	0,88	29,33	0,88	0,00	0,00	0,00	0,00
Middle lane	12	57,14	1,83	0,39	25,11	0,55	0,94	0,17	15,99	0,32
Far lane	13	61,90	1,46	0,49	22,15	0,52	0,52	0,27	10,32	0,27
Traffic sign	11	52,38	1,27	0,36	15,76	0,42	0,47	0,17	11,74	0,28
1st pedestrian crossing	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area I	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area J	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2nd pedestrian crossing + K, L	7	33,33	1,14	0,41	15,62	0,45	0,38	0,21	9,23	0,24
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Junction left	3	14,29	1,00	0,27	8,89	0,27	0,00	0,10	3,36	0,10
Junction right	14	66,67	1,43	0,25	12,19	0,30	0,76	0,13	8,98	0,21
Crossing I										
Close lane	1	4,76	1,00	0,20	10,00	0,20	0,00	0,00	0,00	0,00
Middle lane	5	23,81	1,40	0,36	29,20	0,47	0,55	0,22	26,33	0,34
Far lane	10	47,62	1,20	0,49	27,60	0,50	0,42	0,43	21,14	0,43
2nd pedestrian crossing	3	14,29	1,00	0,37	18,67	0,37	0,00	0,20	9,87	0,20
Pedestrian area K	3	14,29	1,00	0,31	15,33	0,31	0,00	0,14	7,02	0,14
Pedestrian area L	6	28,57	1,33	0,49	33,67	0,55	0,52	0,25	20,02	0,28
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Junction left	3	14,29	1,33	0,21	14,67	0,25	0,58	0,05	8,33	0,10
Junction right	4	19,05	1,00	0,46	23,00	0,46	0,00	0,21	10,39	0,21
Crossing II										
Close lane	1	4,76	1,00	0,60	46,88	0,60	0,00	0,00	0,00	0,00
Middle lane	4	19,05	1,25	0,25	29,65	0,29	0,50	0,13	24,46	0,20
Far lane	12	57,14	1,25	0,25	26,11	0,29	0,45	0,09	17,76	0,16
2nd pedestrian crossing	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area K	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area L	8	36,36	1,25	0,45	37,31	0,49	0,71	0,24	22,47	0,23
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Junction left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exit										
Close lane	2	9,52	1,00	0,62	12,34	0,62	0,00	0,59	4,83	0,59
Middle lane	4	19,05	2,00	0,41	26,24	0,55	1,15	0,08	11,30	0,12
Far lane	13	61,90	1,31	0,52	28,69	0,56	0,63	0,36	18,65	0,35
Oncoming lane	6	28,57	1,50	0,27	15,29	0,29	0,84	0,17	8,14	0,17

Scenario 1 (Time pressure)	Mean						STDEV				
	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	glance proporotion (%)	Max glance duration (s)	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration	Max glance duration
Approach											
Close lane	3	14,29	1,00	2,31	73,12	2,31	0,00	1,84	46,56	1,84	1,84
Middle lane	4	19,05	1,00	0,42	53,17	0,42	0,00	0,33	54,08	0,33	0,33
Far lane	11	52,38	1,17	0,55	59,22	0,59	0,40	0,26	30,32	0,27	0,27
Traffic sign	8	47,62	3,33	0,48	42,79	0,56	0,71	0,16	12,08	0,22	0,22
Street + junction left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street + junction right	2	9,52	5,00	0,36	15,00	0,88	2,12	0,25	10,61	0,11	0,11
Pedestrian crossing + areas I and J	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Deceleration											
Close lane	3	14,29	1,33	0,43	17,78	0,47	0,58	0,36	11,50	0,34	0,34
Middle lane	11	52,38	1,69	0,58	32,22	0,78	0,64	0,36	18,67	0,42	0,42
Far lane	11	52,38	1,64	0,47	27,03	0,61	0,81	0,33	21,45	0,53	0,53
Traffic sign	9	42,86	1,42	0,42	24,89	0,58	1,08	0,40	14,79	0,47	0,47
1st pedestrian crossing	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area I	2	9,52	1,00	0,20	6,67	0,20					
Pedestrian area J	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2nd pedestrian crossing + K, L	6	28,57	1,00	0,27	8,89	0,27	0,00	0,16	5,44	0,16	0,16
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	1	4,76	1,00	0,24	8,00	0,24	0,00	0,00	0,00	0,00	0,00
Junction left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Junction right	9	42,86	1,03	0,28	9,95	0,27					
Crossing I											
Close lane	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Middle lane	10	47,62	1,40	0,69	41,80	0,72	0,70	0,59	28,15	0,57	0,57
Far lane	10	47,62	1,20	0,61	35,60	0,66	0,42	0,52	27,08	0,52	0,52
2nd pedestrian crossing	2	9,52	1,00	0,24	12,00	0,24	0,00	0,11	5,66	0,11	0,11
Pedestrian area K	5	23,81	1,20	0,22	13,60	0,24	0,45	0,04	7,13	0,07	0,07
Pedestrian area L	9	42,86	1,56	0,27	20,89	0,32	0,90	0,16	15,53	0,23	0,23
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	2	9,52	1,00	0,28	14,00	0,28	0,00	0,06	2,83	0,06	0,06
Junction left	3	14,29	1,00	0,41	20,67	0,41	0,00	0,34	16,77	0,34	0,34
Junction right	7	33,33	1,00	0,22	11,14	0,22	0,00	0,13	6,31	0,13	0,13
Crossing II											
Close lane	1	4,76	2,00	0,32	72,73	0,40	0,00	0,00	0,00	0,00	0,00
Middle lane	7	33,33	1,14	0,50	52,41	0,52	0,38	0,30	25,82	0,29	0,29
Far lane	9	42,86	1,00	0,50	53,09	0,50	0,00	0,28	30,99	0,28	0,28
2nd pedestrian crossing	1	4,76	1,00	0,04	5,26	0,04	0,00	0,00	0,00	0,00	0,00
Pedestrian area K	1	4,76	1,00	0,04	4,17	0,04	0,00	0,00	0,00	0,00	0,00
Pedestrian area L	4	19,05	1,25	0,23	25,30	0,24	0,50	0,15	17,39	0,17	0,17
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Junction left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exit											
Close lane	1	4,76	1,00	0,48	42,86	0,48	0,00	0,00	0,00	0,00	0,00
Middle lane	4	19,05	1,00	0,33	24,47	0,33	0,00	0,17	12,73	0,17	0,17
Far lane	13	61,90	1,23	0,56	47,48	0,60	0,44	0,37	26,96	0,36	0,36
Oncoming lane	2	9,52	1,00	0,16	14,22	0,16	0,00	0,00	3,47	0,00	0,00

Scenario 2 (Baseline)	Mean						STDEV			
	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion	Max glance duration (s)	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)
Approach										
Close lane	4	19,05	1,00	0,31	7,58	0,31	0,00	0,12	4,16	0,12
Middle lane	16	76,19	1,20	0,73	20,39	0,59	0,60	0,91	32,18	0,47
Far lane	12	57,14	1,31	2,02	8,08	0,41	0,51	5,74	5,90	0,30
Traffic sign	4	19,05	1,40	0,44	11,39	0,48	0,55	0,26	7,83	0,25
Street + junction left	7	33,33	1,14	0,37	11,03	0,38	0,38	0,23	10,12	0,22
Street + junction right	12	57,14	1,70	1,07	9,13	0,43	1,19	2,68	8,25	0,38
Pedestrian crossing + areas I and J	11	52,38	1,25	0,36	11,57	0,38	0,45	0,19	9,03	0,20
Oncoming vehicle/direction	13	61,9	1,54	0,27	6,99	0,32	0,97	0,14	3,49	0,15
Deceleration										
Close lane	4	19,05	1,75	0,27	9,28	0,37	0,50	0,15	5,66	0,32
Middle lane	9	42,86	1,22	0,39	9,59	0,41	0,44	0,17	4,78	0,19
Far lane	3	14,29	1,33	0,31	8,92	0,49	0,58	0,27	10,22	0,58
Traffic sign	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1st pedestrian crossing	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area I	5	23,81	1,20	0,30	7,52	0,30	0,45	0,15	3,39	0,15
Pedestrian area J	16	76,19	1,63	0,37	13,00	0,40	0,81	0,18	7,39	0,19
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Junction left	9	42,86	1,00	0,35	8,91	0,35	0,00	0,20	7,36	0,20
Junction right	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Oncoming vehicle/direction	12	57,14	1,54	0,28	10,03	0,31	0,66	0,15	5,91	0,15
Vehicle from left	9	42,86	1,00	0,37	8,74	0,37	0,00	0,21	4,29	0,21
Vehicle from right	7	33,33	1,14	0,20	4,81	0,21	0,38	0,06	2,44	0,05
2nd pedestrian crossing + K, L	10	47,62	1,77	0,47	15,35	0,50	1,69	0,29	10,95	0,28
Turning										
Close lane	2	9,52	1,00	0,28	1,97	0,28	0,00	0,23	2,27	0,23
Middle lane	3	14,29	1,67	0,30	17,50	0,40	1,15	0,16	11,35	0,21
Far lane	2	9,52	1,50	0,13	4,37	0,16	0,71	0,01	6,04	0,06
Pedestrian from left, area L	16	76,19	2,00	0,46	30,71	0,66	1,30	0,33	25,16	0,49
Pedestrian from right area J	13	61,90								
Street + junction left	5	23,81	1,20	0,30	9,08	0,32	0,45	0,12	5,42	0,12
Oncoming vehicle/direction	8	38,10	1,38	0,40	17,38	0,43	0,74	0,44	24,53	0,43
Vehicle from right	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exit										
Close lane	3	14,29	1,33	0,41	9,67	0,41	0,58	0,04	8,15	0,05
Middle lane	6	28,57	1,83	0,59	22,87	0,90	1,17	0,42	15,89	0,76
Far lane	14	66,67	1,50	0,55	23,49	0,71	0,65	0,50	22,02	0,70
Opposite lane	9	42,86	1,33	0,33	12,89	0,42	0,50	0,18	9,50	0,34

Scenario 2 (Time pressure)	Mean						STDEV			
	Number of test persons	Percentage of test	Average number	Mean glance duration	Percenteged glance	Max glance duration	Number of test persons	Percentage of test	Average number	Mean glance duration
Approach										
Close lane	4	19,05	1,25	0,48	26,59	0,56	0,50	0,40	18,71	0,54
Middle lane	9	42,86	1,22	0,58	27,76	0,60	0,48	0,31	14,87	0,30
Far lane	8	38,10	1,25	0,29	31,71	0,30	0,46	0,23	40,25	0,23
Traffic sign	2	9,52	1,00	0,64	22,39	0,64	0,00	0,06	14,56	0,06
Street + junction left	1	4,76	1,00	0,20	5,26	0,20	0,00	0,00	0,00	0,00
Street + junction right	3	14,29	1,33	0,29	15,41	0,31	0,58	0,12	13,36	0,10
Pedestrian crossing + areas I and J	7	33,33	1,29	0,26	10,80	0,29	0,76	0,21	8,71	0,23
Oncoming vehicle	7	33,33	1,43	0,46	16,73	0,56	0,53	0,22	10,35	0,35
Deceleration										
Close lane	5	23,81	1,60	0,64	24,59	0,67	0,89	0,89	28,54	0,88
Middle lane	6	28,57	1,17	0,43	13,67	0,47	0,41	0,26	8,68	0,28
Far lane	6	28,57	1,33	0,23	8,85	0,26	0,52	0,06	2,59	0,09
Traffic sign	4	19,05	1,00	0,29	9,67	0,29	0,00	0,13	4,41	0,13
1st pedestrian crossing	5	23,81	1,00	0,39	13,07	0,39	0,00	0,11	3,70	0,11
Pedestrian area I	4	19,05	1,20	0,39	14,13	0,39	0,45	0,21	5,93	0,21
Pedestrian area J	16	76,19	1,20	0,33	12,53	0,34	0,45	0,18	6,01	0,17
Street left	2	9,52	1,00	0,24	8,00	0,24	0,00	0,17	5,66	0,17
Street right	1	4,76	1,00	0,40	13,33	0,40	0,00	0,00	0,00	0,00
Junction left	7	33,33	1,00	0,29	8,46	0,29	0,00	0,16	5,05	0,16
Junction right	14	66,67	1,50	0,42	19,39	0,47	0,65	0,36	17,10	0,36
Oncoming vehicle	10	47,62	1,20	0,31	10,05	0,32	0,42	0,16	5,09	0,15
Vehicle from left	3	14,29	1,33	0,23	8,21	0,25	0,58	0,08	4,45	0,08
Vehicle from right	3	14,29	1,00	0,55	12,24	0,55	0,00	0,54	7,81	0,54
2nd pedestrian crossing + K, L	12	57,14	1,42	0,39	14,32	0,44	0,51	0,23	11,18	0,26
Turning										
Close lane	4	19,05	1,25	0,63	35,50	0,66	0,50	0,84	40,64	0,82
Middle lane	6	28,57	1,00	0,33	16,00	0,33	0,00	0,14	7,48	0,14
Far lane	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian from left, area L	15	71,43	1,41	0,39	25,49	0,45	0,62	0,18	13,05	0,22
Pedestrian from right area J	12	57,14	1,00	0,28	14,00	0,28	0,00	0,17	8,72	0,17
Street + junction left	4	19,05	1,00	0,22	11,00	0,22	0,00	0,12	6,22	0,12
Oncoming vehicle	9	42,86	1,00	0,29	14,53	0,29	0,00	0,14	7,24	0,14
Vehicle from right	1	4,76	1,00	0,12	6,00	0,12	0,00	0,00	0,00	0,00
Exit										
Close lane	5	23,81	1,00	0,65	20,65	0,65	0,00	0,67	28,76	0,67
Middle lane	8	38,10	1,38	0,88	21,67	0,96	0,74	0,44	11,14	0,38
Far lane	14	66,67	1,21	0,72	20,84	0,77	0,58	0,50	13,72	0,52
Opposite lane	8	38,10	1,38	0,35	14,73	0,38	0,74	0,10	8,80	0,09

	Mean						STDEV			
Scenario 3 (Baseline)	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Perceteged glance proporotion	Max glance duration [s]	Average number of glances	Mean glance duration	Perceteged glance proporotion	Max glance duration
Approach										
Close lane	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Middle lane	10	47,62	1,70	0,26	15,10	0,29	0,82	0,09	8,92	0,11
Far lane	13	61,90	1,69	0,55	22,89	0,70	1,03	0,42	13,06	0,44
Street + junction left	9	42,86	1,10	0,26	7,39	0,27	0,33	0,13	6,33	0,14
Street + junction right	7	33,33	1,00	0,33	15,12	0,33	0,00	0,25	16,93	0,25
Pedestrian crossing + I, J	4	19,05	1,50	0,22	8,21	0,23	0,58	0,12	7,37	0,13
Street + junction left	12	57,14	1,16	0,35	10,27	0,38	0,37	0,20	6,30	0,25
Oncoming vehicle/direction	12	57,14	1,75	0,43	16,44	0,53	0,97	0,37	10,00	0,41
Deceleration										
Close lane	4	19,05	1,00	0,60	10,28	0,60	0,00	0,26	9,60	0,26
Middle lane	9	42,86	2,20	0,49	17,78	0,69	1,22	0,27	12,10	0,43
Far lane	9	42,86	1,78	0,34	15,75	0,40	0,83	0,24	14,57	0,27
Traffic sign	2	9,52	1,00	0,20	1,83	0,20	0,00	0,11	0,94	0,11
1st Pedestrian crossing	8	38,10	1,17	0,45	9,47	0,48	0,39	0,26	6,01	0,29
Pedestrian area I	12	57,14	1,50	0,47	12,98	0,53	0,65	0,25	18,32	0,29
Pedestrian area J	4	19,05	1,50	0,35	14,92	0,41	0,58	0,12	13,28	0,19
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Junction left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Junction right	12	57,14	1,17	0,34	7,89	0,35	0,39	0,35	10,68	0,36
Oncoming vehicle/direction	16	76,19	2,08	0,36	9,77	0,50	1,44	0,21	8,04	0,37
Vehicle from left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Vehicle from right	5	23,81	1,40	0,47	7,04	0,49	0,89	0,41	2,65	0,38
2nd pedestrian crossing + K, L	6	28,57	1,83	0,46	7,44	0,61	0,75	0,20	3,67	0,32
Crossing I										
Close lane	4	19,05	1,00	0,20	5,38	0,20	0,00	0,13	2,14	0,13
Middle lane	8	38,10	1,13	0,23	6,43	0,27	0,35	0,11	4,90	0,19
Far lane	4	19,05	1,00	0,54	25,20	0,54	0,00	0,30	17,77	0,30
2nd pedestrian crossing	8	38,10	1,38	0,38	11,63	0,47	0,52	0,29	10,63	0,47
Pedestrian area K	3	14,29	1,00	0,23	9,17	0,23	0,00	0,15	9,64	0,15
Pedestrian area L	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	7	33,33	1,00	0,32	14,38	0,32	0,00	0,09	6,81	0,09
Junction/vehicle left	13	61,90	1,31	0,42	23,61	0,47	0,48	0,18	17,43	0,21
Junction/vehicle right	6	28,57	1,14	0,30	9,03	0,38	0,38	0,19	5,25	0,39
Turn										
Close lane	5	23,81	1,40	0,24	7,90	0,26	0,55	0,21	7,94	0,24
Middle lane	3	14,29	1,00	0,16	3,51	0,16	0,00	0,07	0,99	0,07
Far lane	1	4,76	2,00	0,26	9,85	0,32	0,00	0,00	0,00	0,00
Pedestrian area I	6	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian K	2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian crossing	14	66,67	1,28	0,45	12,71	0,47	0,53	0,26	7,00	0,26
Oncoming vehicle	4	19,00	1,20	0,74	23,72	0,84	0,45	0,54	22,50	0,56
Vehicle from left (if visible)	4	19,05	1,25	0,24	8,37	0,28	0,50	0,14	4,92	0,21
Exit										
Close lane	10	47,62	1,40	0,56	26,98	0,82	0,70	0,58	26,82	1,18
Middle lane	14	66,67	1,36	0,48	23,46	0,54	0,50	0,42	19,01	0,47
Far lane	4	19,05	1,25	0,38	16,62	0,43	0,50	0,19	18,03	0,27
Opposite lane	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Scenario 3 (Time pressure)	Mean						STDEV			
	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion (%)	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	2	9,52	2,50	0,35	50,56	0,38	2,12	0,01	69,92	0,03
Middle lane	11	52,38	1,91	0,53	23,50	0,65	1,20	0,33	23,18	0,43
Far lane	7	33,33	3,29	0,80	29,72	1,22	2,36	0,26	35,25	0,55
Street + junction left	6	28,57	1,17	0,39	9,73	0,40	0,41	0,09	8,73	0,09
Street + junction right	2	9,52	1,50	0,27	4,23	0,36	0,71	0,07	5,33	0,06
Pedestrian crossing + areas I, J	3	14,29	2,33	0,37	1,09	0,76	1,15	0,26	0,99	0,73
Street + junction left	9	42,86	1,12	0,38	13,22	0,38	0,33	0,17	8,61	0,17
Oncoming vehicle/direction	7	33,33	1,89	0,23	4,34	0,28	1,05	0,08	6,19	0,10
Deceleration										
Close lane	6	28,57	1,17	0,66	19,13	0,68	0,41	0,41	14,76	0,39
Middle lane	7	33,33	1,86	0,55	26,02	0,61	0,90	0,38	18,36	0,35
Far lane	11	52,38	1,36	0,47	19,07	0,55	0,81	0,49	20,68	0,59
Traffic sign	4	19,05	1,25	0,28	11,00	0,30	0,50	0,16	5,26	0,15
1st Pedestrian crossing	8	38,10	1,50	0,37	14,82	0,40	0,76	0,29	10,87	0,28
Pedestrian area I	7	33,33	1,29	0,23	8,04	0,23	0,49	0,10	3,19	0,10
Pedestrian area J	6	28,57	1,17	0,27	9,76	0,27	0,41	0,10	5,78	0,10
Street left	2	9,52	1,00	0,18	2,03	0,18	0,00	0,08	1,19	0,08
Street right	1	4,76	1,00	0,36	8,26	0,36	0,00	0,00	0,00	0,00
Junction left	4	19,05	1,00	0,25	5,58	0,25	0,00	0,11	2,10	0,11
Junction right	7	33,33	1,00	0,31	8,71	0,31	0,00	0,14	6,28	0,14
Oncoming vehicle/direction	15	71,43	1,41	0,37	13,58	0,41	0,62	0,33	14,52	0,34
Vehicle from left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Vehicle from right	3	14,29	1,33	0,20	5,42	0,24	0,58	0,08	1,34	0,14
2nd pedestrian crossing + K, L	9	42,86	1,00	0,40	9,19	0,40	0,00	0,28	6,84	0,28
Crossing I										
Close lane	4	18,18	1,50	0,55	30,50	0,57	1,00	0,81	38,62	0,79
Middle lane	7	31,82	1,14	0,47	23,12	0,51	0,38	0,33	18,87	0,35
Far lane	2	9,09	1,00	0,24	12,00	0,24	0,00	0,06	2,83	0,06
2nd pedestrian crossing	2	9,09	1,00	0,24	9,58	0,24	0,00	0,17	11,90	0,17
Pedestrian area K	2	9,09	1,50	0,13	10,00	0,14	0,71	0,01	5,66	0,03
Pedestrian area L	2	9,09	1,00	0,16	4,08	0,16	0,00	0,06	2,71	0,06
Street left	1	4,55	1,00	0,52	26,00	0,52	0,00	0,00	0,00	0,00
Street right	1	4,55	1,00	0,36	11,69	0,36	0,00	0,00	0,00	0,00
Junction/vehicle left	10	45,45	1,20	0,40	20,67	0,42	0,42	0,21	12,05	0,20
Junction/vehicle right	5	22,73	0,59	1,07	3,84	6,38	0,52	0,10	6,45	0,11
Oncoming vehicle	13	59,00								
Turn										
Close lane	8	36,36	1,50	0,60	27,30	0,63	1,41	0,49	19,47	0,49
Middle lane	1	4,55	1,00	0,40	6,45	0,40	0,00	0,00	0,00	0,00
Far lane	1	4,55	1,00	0,20	2,91	0,20	0,00	0,00	0,00	0,00
Pedestrian area I	10	22,73	1,17	0,30	5,50	0,33	0,41	0,10	1,63	0,10
Pedestrian K	1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian crossing	3	13,64	1,67	0,61	25,21	0,64	0,58	0,40	12,21	0,38
Oncoming vehicle	11	50,00	1,75	1,48	47,22	1,86	0,87	1,01	25,91	1,01
Vehicle from left (if visible)	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exit										
Close lane	10	45,45	1,10	0,46	21,29	0,49	0,32	0,34	28,85	0,36
Middle lane	12	54,55	1,42	0,69	23,65	0,77	0,51	0,55	13,18	0,56
Far lane	3	13,64	1,67	0,84	31,48	0,91	1,15	0,41	21,00	0,30
Opposite lane	1	4,55	1,00	0,12	3,61	0,12	0,00	0,00	0,00	0,00

Scenario 4 (Baseline)	Mean						STDEV			
	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	2	9,52	1,00	0,20	5,92	0,20	0,00	0,06	0,21	0,06
Middle lane	4	19,05	1,25	0,45	15,16	0,60	0,50	0,16	12,07	0,44
Far lane	17	80,95	1,65	0,56	28,01	0,72	0,70	0,56	22,14	0,67
Traffic sign	4	19,05	1,00	0,61	21,76	0,61	0,00	0,46	15,90	0,46
Street + junction left	2	9,52	1,00	0,20	11,86	0,20	0,00	0,11	12,35	0,11
Street + junction right	4	19,05	1,00	0,69	15,65	0,69	0,00	0,90	17,28	0,90
Pedestrian crossing	5	23,81	1,20	0,44	16,01	0,44	0,45	0,41	11,13	0,41
Pedestrain I	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian J	3	14,29	1,33	0,24	12,06	0,29	0,58	0,11	13,18	0,20
Deceleration										
Close lane	11	52,38	1,91	0,47	15,63	0,60	1,30	0,26	12,70	0,34
Middle lane	7	33,33	1,43	0,48	11,06	0,50	0,53	0,41	6,57	0,40
Far lane	12	57,14	1,58	0,33	9,16	0,37	0,90	0,10	5,27	0,13
Traffic sign	1	4,76	1,00	0,12	1,55	0,12	0,00	0,00	0,00	0,00
1st Pedestrian crossing	14	66,67	1,79	0,57	14,76	0,82	0,79	0,42	13,57	0,67
Pedestrian area I	4	19,05	1,33	0,36	5,83	0,39	0,52	0,15	2,90	0,15
Pedestrian area J	11	52,38	1,33	0,75	17,93	0,92	0,49	0,49	14,44	0,64
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	9	42,86	1,33	0,30	5,38	0,35	0,71	0,10	3,95	0,19
Junction left	9	42,86	1,22	0,52	12,69	0,55	0,44	0,44	12,05	0,42
Junction right	8	38,10	1,75	0,24	5,43	0,31	0,46	0,14	2,97	0,22
Oncoming vehicle/direction	4	19,05	1,00	0,23	2,85	0,23	0,00	0,11	1,34	0,11
Vehicle from left	6	28,57	1,00	0,23	6,01	0,23	0,00	0,17	6,48	0,17
Vehicle from right	4	19,05	1,25	0,34	11,44	0,34	0,50	0,24	8,16	0,24
2nd pedestrian crossing + K,L	17	80,95	2,07	0,63	13,21	0,67	0,51	0,27	7,59	0,29
Crossing I										
Close lane	6	28,57	1,33	0,30	19,70	0,37	0,52	0,15	14,99	0,23
Middle lane	4	19,05	1,25	0,46	23,63	0,54	0,50	0,30	17,62	0,42
Far lane	4	19,05	1,75	0,24	16,00	0,34	0,50	0,12	7,12	0,26
2nd pedestrian crossing	4	18,18	1,00	0,35	14,00	0,35	0,00	0,25	7,07	0,25
Pedestrian area K	2	9,52	2,50	0,16	18,09	0,30	0,71	0,06	16,84	0,20
Pedestrian area L	3	14,29	1,33	0,14	7,00	0,17	0,58	0,02	1,00	0,06
Street left	3	14,29	1,33	0,25	13,78	0,27	0,58	0,13	6,01	0,12
Street right	17	80,95	1,06	0,56	22,88	0,57	0,24	0,38	11,51	0,38
Junction/vehicle left	14	66,67	1,21	0,44	21,24	0,47	0,43	0,37	15,71	0,40
Junction/vehicle right	5	23,81	1,00	0,24	10,02	0,24	0,00	0,15	6,23	0,15
Crossing II										
Close lane	2	23,81	1,40	0,74	33,99	0,90	0,55	0,85	37,41	0,82
Middle lane	4	33,33	1,43	0,29	17,58	0,31	0,53	0,12	18,54	0,13
Far lane	17	23,81	1,40	0,47	32,97	0,50	0,55	0,27	27,57	0,29
2nd pedestrian crossing	4	59,09	1,19	0,36	17,00	0,37	0,40	0,28	12,25	0,27
Pedestrian area K	13	61,90	1,44	0,39	20,45	0,42	0,73	0,24	14,68	0,23
Pedestrian area L	15	71,43	1,25	0,30	17,44	0,34	0,45	0,13	15,24	0,19
Street left	5	14,29	1,33	0,28	9,24	0,40	0,58	0,12	6,41	0,32
Junction/vehicle left	0	9,52	2,50	0,51	19,19	1,06	0,71	0,09	3,57	0,37
Exit										
Close lane	4	19,05	2,00	0,43	41,36	0,57	0,82	0,22	27,26	0,29
Middle lane	6	28,57	1,17	0,40	15,39	0,41	0,41	0,33	10,53	0,33
Far lane	7	33,33	1,71	0,36	20,55	0,39	0,76	0,18	14,73	0,20
Oncoming lane	9	42,86	1,11	0,30	11,17	0,31	0,33	0,13	6,48	0,13

	Mean						STDEV			
Scenario 4 (Time pressure)	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	1	4,55	4,00	0,59	1,85	1,60	0,00	0,00	0,00	0,00
Middle lane	5	22,73	2,40	0,28	27,28	0,43	2,61	0,17	24,62	0,45
Far lane	8	36,36	2,38	0,37	24,26	0,44	2,39	0,15	12,59	0,26
Traffic sign	3	13,64	1,00	0,19	8,83	0,19	0,00	0,06	2,19	0,06
Street + junction left	2	9,09	2,00	0,51	4,48	0,84	1,41	0,26	4,04	0,74
Street + junction right	4	18,18	1,75	0,42	14,63	0,68	1,50	0,33	20,90	0,67
Pedestrian crossing	2	9,09	1,50	0,90	24,26	0,96	0,71	0,93	33,78	0,85
Pedestrain I	2	9,09	1,00	0,54	5,74	0,54	0,00	0,08	7,45	0,08
Pedestrian J	4	18,18	1,25	0,35	17,49	0,38	0,50	0,17	7,50	0,14
Deceleration										
Close lane	2	9,09	1,00	0,24	6,06	0,24	0,00	0,11	1,02	0,11
Middle lane	9	40,91	1,44	0,68	27,82	0,74	0,53	0,76	25,19	0,76
Far lane	8	36,36	1,13	0,55	19,72	0,57	0,35	0,37	19,03	0,39
Traffic sign	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1st Pedestrian crossing	8	36,36	1,22	0,38	14,35	0,41	0,44	0,29	10,34	0,28
Pedestrian area I	5	22,73	1,00	0,23	7,73	0,23	0,00	0,09	2,89	0,09
Pedestrian area J	4	18,18	1,50	0,20	8,42	0,22	0,58	0,07	6,07	0,10
Street left	1	4,55	2,00	0,32	13,56	0,40	0,00	0,00	0,00	0,00
Street right	3	13,64	1,33	0,23	8,56	0,25	0,58	0,06	2,92	0,08
Junction left	6	27,27	1,17	0,42	11,51	0,43	0,41	0,13	3,19	0,15
Junction right	11	50,00	1,36	0,38	13,61	0,40	0,92	0,19	7,11	0,18
Oncoming vehicle/direction	4	18,18	1,75	0,24	14,51	0,30	0,96	0,10	11,76	0,19
Vehicle from left	5	22,73	1,00	0,26	7,74	0,26	0,00	0,09	3,12	0,09
Vehicle from right	8	36,36	1,40	0,21	8,20	0,24	0,70	0,10	4,83	0,11
2nd pedestrian crossing + areas K and L	9	40,91	1,25	0,46	13,59	0,49	0,45	0,51	17,61	0,51
Crossing I										
Close lane	4	18,18	1,25	0,14	7,25	0,16	0,50	0,04	4,50	0,08
Middle lane	5	22,73	1,20	0,30	19,78	0,30	0,55	0,16	14,61	0,17
Far lane	6	27,27	1,17	0,43	21,50	0,49	0,57	0,26	14,64	0,29
2nd pedestrian crossing	3	13,64	1,00	0,29	5,75	0,29	0,00	0,29	2,20	0,29
Pedestrian area K	2	9,09	1,00	0,12	3,57	0,12	0,00	0,00	0,76	0,00
Pedestrian area L	5	22,73	2,00	0,36	18,25	0,66	1,22	0,23	11,30	0,80
Street left	7	31,82	1,29	0,31	12,44	0,33	0,49	0,22	4,99	0,22
Street right	17	77,27	1,06	0,31	12,90	0,33	0,24	0,17	8,59	0,18
Junction/vehicle left	10	45,45	1,38	0,33	17,07	0,39	0,51	0,28	15,19	0,39
Junction/vehicle right	8	36,36	1,33	0,25	12,52	0,30	0,71	0,13	11,60	0,28
Crossing II										
Close lane	2	9,09	1,00	0,92	39,17	0,92	0,00	1,07	43,61	1,07
Middle lane	8	36,36	1,00	0,52	37,16	0,52	0,00	0,25	26,86	0,25
Far lane	4	18,18	1,00	0,28	16,63	0,28	0,00	0,10	7,73	0,10
2nd pedestrian crossing	4	18,18	1,33	0,25	23,22	0,27	0,52	0,05	14,80	0,09
Pedestrian area K	13	61,90	1,00	0,34	23,10	0,34	0,00	0,08	6,62	0,08
Pedestrian area L	14	66,67	1,57	0,31	25,32	0,38	0,53	0,17	12,84	0,19
Street left	1	4,55	1,00	0,40	19,23	0,40	0,00	0,00	0,00	0,00
Junction/vehicle left	4	18,18	1,00	0,21	14,41	0,21	0,00	0,09	11,20	0,09
Exit										
Close lane	6	27,27	1,33	0,41	15,47	0,51	0,82	0,21	15,37	0,33
Middle lane	11	50,00	1,45	0,35	12,22	0,37	0,69	0,21	9,03	0,22
Far lane	9	40,91	1,22	0,47	18,07	0,49	0,44	0,32	14,37	0,31
Oncoming lane	6	27,27	1,67	0,21	12,07	0,25	0,52	0,08	10,62	0,10

	Mean						STDEV			
Scenario 5 (Baseline)	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion (%)	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	8	38,10	2,13	0,76	28,18	1,07	1,13	0,61	27,69	1,02
Middle lane	12	57,14	2,25	0,45	16,92	0,65	0,97	0,32	14,18	0,56
Far lane	16	76,19	2,31	0,45	16,80	0,66	1,40	0,21	10,34	0,36
Traffic sign	13	61,90	1,77	0,28	8,86	0,33	0,93	0,10	5,35	0,09
Street + junction left	3	14,29	1,00	0,31	4,39	0,31	0,00	0,20	2,59	0,20
Street + junction right	11	52,38	1,36	0,44	9,59	0,51	0,67	0,25	6,86	0,32
Pedestrian crossing	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrain I	3	14,29	1,67	0,50	11,40	0,55	0,58	0,30	2,77	0,25
Pedestrian J	4	19,05	1,25	0,27	5,47	0,29	0,50	0,21	2,60	0,19
Deceleration										
Close lane	12	57,14	1,58	0,40	13,71	0,46	0,90	0,44	14,89	0,45
Middle lane	10	47,62	1,20	0,33	8,06	0,34	0,42	0,21	5,77	0,23
Far lane	7	33,33	1,43	0,54	11,71	0,61	1,13	0,41	12,45	0,42
Traffic sign	1	4,76	1,00	0,20	6,67	0,20	0,00	0,00	0,00	0,00
1st Pedestrian crossing	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area I	6	28,57								
Pedestrian area J	14	66,67								
Street left	2	9,52	2,00	0,42	10,28	0,66	0,00	0,14	3,49	0,20
Street right	3	14,29	1,33	0,41	11,23	0,59	0,58	0,15	8,57	0,46
Junction left	15	71,43	1,93	0,97	26,61	1,18	0,96	0,77	16,49	0,72
Junction right	14	66,67	1,57	0,36	9,28	0,39	0,85	0,27	7,21	0,27
Oncoming vehicle/direction	14	66,67	1,88	0,38	10,92	0,53	1,22	0,26	9,85	0,50
Vehicle from left	8	38,10	1,36	0,24	5,95	0,25	0,67	0,08	4,19	0,09
Vehicle from right	10	47,62	1,00	0,20	3,48	0,20	0,00	0,10	1,59	0,10
2nd pedestrian crossing + areas K and L	5	23,81	1,60	0,45	16,84	0,55	0,89	0,23	13,11	0,33
Turning										
Close lane	5	25,00	1,20	0,37	13,49	0,38	0,45	0,23	11,97	0,23
Middle lane	4	20,00	1,50	0,38	16,64	0,44	0,58	0,13	6,72	0,11
Far lane	1	5,00	1,00	0,24	10,91	0,24	0,00	0,00	0,00	0,00
Pedestrian from left/ area L	14	65,00	1,15	0,46	18,20	0,46	0,38	0,22	10,89	0,22
Pedestrian from right area J	7	33,33	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Junction/vehicle left	12	55,00	1,35	0,42	12,50	0,44	0,61	0,47	12,06	0,48
Oncoming vehicle	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exit										
Close lane	6	28,57	1,17	0,97	15,43	1,03	0,41	1,00	11,37	0,99
Middle lane	13	61,90	1,46	0,47	14,31	0,53	0,78	0,25	13,78	0,28
Far lane	6	28,57	1,33	0,37	17,54	0,38	0,52	0,19	17,59	0,18
Opposite lane	10	47,62	1,70	0,29	10,73	0,33	1,06	0,14	10,36	0,15

Scenario 5 (Time pressure)	Mean						STDEV			
	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion (%)	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	8	38,10	1,25	0,96	43,15	1,04	0,82	0,95	36,39	0,96
Middle lane	9	42,86	1,33	0,43	16,32	0,59	0,71	0,32	15,59	0,54
Far lane	10	47,62	2,20	0,32	15,36	0,39	1,23	0,23	8,39	0,24
Traffic sign	8	38,10	1,88	0,25	15,02	0,36	0,83	0,14	12,35	0,29
Street + junction left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street + junction right	6	28,57	1,67	0,45	15,16	0,51	0,82	0,40	11,46	0,40
Pedestrian crossing	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrain I	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian J	2	9,52	1,00	0,38	9,77	0,38	0,00	0,14	6,15	0,14
Deceleration										
Close lane	7	33,33	1,57	0,48	21,59	0,54	0,79	0,73	35,05	0,71
Middle lane	10	47,62	1,20	0,42	14,13	0,46	0,42	0,17	5,83	0,21
Far lane	10	47,62	1,50	0,43	15,95	0,46	0,85	0,26	9,53	0,27
Traffic sign	1	4,76	1,00	0,52	17,33	0,52	0,00	0,00	0,00	0,00
1st Pedestrian crossing	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area I	5	23,81	1,00	0,51	17,07	0,51	0,00	0,29	9,68	0,29
Pedestrian area J	9	42,86	1,00	0,16	5,33	0,16	0,00	0,00	0,00	0,00
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	3	14,29	1,00	0,33	11,11	0,33	0,00	0,23	7,70	0,23
Junction left	11	52,38	1,45	0,49	17,30	0,64	0,69	0,29	11,81	0,47
Junction right	17	80,95	1,71	0,29	14,59	0,36	0,77	0,14	12,37	0,22
Oncoming vehicle/direction	15	71,43	1,44	0,43	15,23	0,50	0,70	0,54	13,33	0,56
Vehicle from left	2	9,52	1,00	0,62	12,55	0,62	0,00	0,03	0,07	0,03
Vehicle from right	4	19,05	1,00	0,24	4,46	0,24	0,48	0,20	6,89	0,21
2nd pedestrian crossing + areas K and L	7	33,33	1,29	0,28	8,89	0,30	0,49	0,16	5,26	0,15
Turning										
Close lane	5	22,73	1,40	0,81	31,95	1,10	0,55	0,79	15,13	1,30
Middle lane	4	18,18	1,50	0,42	17,49	0,46	1,00	0,18	10,76	0,18
Far lane	2	9,09	1,00	0,18	7,41	0,18	0,00	0,08	2,00	0,08
Pedestrian from left/ area L	11	50,00	1,27	0,33	17,78	0,35	0,65	0,19	10,76	0,19
Pedestrian from right area J	6	27,27	1,17	0,48	25,15	0,50	0,41	0,39	19,40	0,38
Junction/vehicle left	9	40,91	1,22	0,54	25,17	0,56	0,44	0,39	17,25	0,40
Oncoming vehicle	2	9,09	1,00	0,18	5,91	0,18	0,00	0,03	1,46	0,03
Exit										
Close lane	7	33,33	1,14	0,55	35,00	0,59	0,38	0,19	27,56	0,18
Middle lane	9	42,86	1,00	0,78	26,77	0,78	0,00	0,87	27,90	0,87
Far lane	4	19,05	1,00	0,70	55,89	0,70	0,00	0,50	48,87	0,50
Opposite lane	6	28,57	1,00	0,27	14,47	0,27	0,00	0,14	12,23	0,14

	Mean						STDEV			
Scenario 6 (Baseline)	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Perceteged glance proporotion	Max glance duration [s]	Average number of glances	Mean glance duration	Perceteged glance proporotion	Max glance duration
Approach										
Close lane	1	5,26	1,00	3,08	77,78	3,08	0,00	0,00	0,00	0,00
Middle lane	8	42,11	1,25	0,36	10,15	0,40	0,46	0,26	6,30	0,26
Far lane	14	73,68	2,29	0,45	22,28	0,76	1,07	0,33	17,13	0,66
Traffic sign	10	52,63	1,32	0,33	10,23	0,37	0,48	0,28	10,83	0,36
Street + junction left	6	31,58	1,14	0,29	5,80	0,30	0,38	0,15	3,02	0,14
Street + junction right	7	36,84	1,14	0,47	12,97	0,51	0,38	0,21	6,17	0,19
Pedestrian crossing	4	21,05	1,00	0,22	5,06	0,22	0,00	0,07	2,27	0,07
Pedestrain I	7	36,84	1,00	0,43	12,72	0,43	0,00	0,12	10,28	0,12
Pedestrian J	5	26,32	1,14	0,31	6,42	0,32	0,38	0,16	3,16	0,16
Deceleration										
Close lane	4	21,05	2,50	0,46	22,50	0,80	2,38	0,33	24,70	0,77
Middle lane	7	36,84	1,14	0,51	17,13	0,57	0,38	0,19	9,47	0,25
Far lane	6	31,58	1,50	1,05	42,21	1,11	0,55	0,86	32,00	0,87
Traffic sign	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1st Pedestrian crossing	1	5,26	4,00	0,57	12,08	1,04	0,00	0,00	0,00	0,00
Pedestrian area I	7	36,84	1,43	0,38	8,30	0,46	0,79	0,16	3,30	0,31
Pedestrian area J	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	11	57,89	1,55	0,49	17,00	0,55	0,82	0,35	12,31	0,35
Junction left	6	31,58	1,00	0,24	5,01	0,24	0,00	0,09	3,46	0,09
Junction right	9	47,37	1,11	0,21	6,46	0,23	0,33	0,10	3,74	0,10
Oncoming vehicle/direction	8	42,11	1,50	0,44	13,35	0,52	1,27	0,37	13,66	0,43
Vehicle from left	7	36,84	1,36	0,28	8,05	0,35	0,67	0,14	6,92	0,21
Vehicle from right	8	42,11	1,30	0,29	6,54	0,30	0,67	0,28	8,05	0,27
2nd pedestrian crossing + areas K and L	5	26,32	1,20	0,34	13,25	0,34	0,45	0,22	16,55	0,22
Crossing I										
Close lane	6	31,58	1,00	0,76	16,07	0,76	0,00	0,58	15,78	0,58
Middle lane	5	26,32	1,20	0,73	17,10	0,74	0,45	0,87	20,81	0,87
Far lane	3	15,79	1,00	0,13	1,13	0,13	0,00	0,02	0,15	0,02
2nd pedestrian crossing	4	21,05	1,25	0,65	11,45	0,66	0,50	0,34	7,58	0,33
Pedestrian area K	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area L	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street left	5	26,32	1,20	0,29	6,38	0,34	0,45	0,14	2,97	0,23
Street right	15	78,95	1,73	0,31	9,47	0,36	0,70	0,21	7,04	0,25
Junction/vehicle left	16	84,21	1,41	0,35	11,02	0,40	0,67	0,40	20,28	0,41
Junction/vehicle right	9	47,37	1,33	0,29	5,36	0,32	0,49	0,17	3,24	0,17
Turn										
Close lane	4	21,05	1,50	0,32	12,87	0,36	0,58	0,08	2,53	0,09
Middle lane	5	26,32	1,00	0,31	10,68	0,31	0,00	0,17	9,81	0,17
Far lane	1	5,26	1,00	0,12	3,45	0,12	0,00	0,00	0,00	0,00
Pedestrian/ area J	8	38,10								
Pedestrian/area K	6	28,57								
Pedestrian crossing	13	68,42	1,20	0,33	12,62	0,34	0,41	0,19	7,65	0,19
Oncoming vehicle	4	21,05	1,75	0,34	11,74	0,39	0,50	0,13	7,31	0,14
Vehicle from left (if visible)	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exit										
Close lane	6	31,58	1,00	1,03	22,44	1,03	0,00	0,96	19,77	0,96
Middle lane	4	21,05	1,00	0,27	7,69	0,27	0,00	0,19	3,94	0,19
Far lane	8	42,11	1,25	0,57	21,60	0,63	0,46	0,72	23,47	0,76
Opposite lane	5	26,32	1,20	0,28	14,38	0,31	0,45	0,10	8,70	0,14

	Mean						STDEV			
Scenario 6 (Time pressure)	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion (%)	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	3	13,64	1,33	0,61	42,70	0,68	0,58	0,66	43,55	0,63
Middle lane	5	22,73	1,40	0,42	20,38	0,63	0,55	0,25	16,65	0,57
Far lane	13	59,09	1,38	0,49	23,04	0,59	0,51	0,35	18,84	0,48
Traffic sign	10	45,45	1,32	0,28	9,53	0,30	0,48	0,22	6,73	0,22
Street + junction left	2	9,09	1,00	0,36	9,07	0,36	0,00	0,17	6,68	0,17
Street + junction right	8	36,36	1,33	0,39	13,95	0,48	0,50	0,17	6,66	0,29
Pedestrian crossing	3	13,64	1,00	0,32	12,47	0,32	0,00	0,07	8,15	0,07
Pedestrain I	6	27,27	1,00	0,37	11,13	0,37	0,00	0,24	5,31	0,24
Pedestrian J	12	54,55	1,25	0,41	23,31	0,43	0,45	0,23	26,20	0,24
Deceleration										
Close lane	5	22,73	1,80	0,40	21,41	0,44	0,84	0,28	13,22	0,27
Middle lane	10	45,45	1,10	0,69	22,20	0,69	0,32	0,80	26,92	0,80
Far lane	6	27,27	1,50	0,33	17,62	0,35	0,84	0,21	17,95	0,21
Traffic sign	1	4,55	1,00	0,12	4,00	0,12	1,00	0,12	4,00	0,12
1st Pedestrian crossing	5	22,73	1,20	0,60	23,20	0,66	0,45	0,55	18,54	0,54
Pedestrian area I	5	22,73	1,00	0,39	13,07	0,39	0,00	0,21	7,14	0,21
Pedestrian area J	3	13,64	1,00	0,23	6,35	0,23	0,00	0,06	4,06	0,06
Street left	2	9,09	1,00	0,16	5,33	0,16	0,00	0,06	1,89	0,06
Street right	10	45,45	1,20	0,51	18,73	0,58	0,42	0,20	11,66	0,26
Junction left	6	27,27	1,00	0,33	7,41	0,33	0,00	0,25	2,66	0,25
Junction right	9	40,91	1,11	0,30	9,17	0,31	0,33	0,15	4,69	0,15
Oncoming vehicle/direction	6	27,27	1,29	0,49	19,11	0,57	0,49	0,24	9,83	0,29
Vehicle from left	3	13,64	1,00	0,32	6,91	0,32	0,00	0,21	2,98	0,21
Vehicle from right	7	31,82	1,45	0,40	13,82	0,45	0,52	0,30	9,96	0,29
2nd pedestrian crossing + areas K and L	6	27,27	1,18	0,48	19,66	0,53	0,40	0,38	20,64	0,42
Crossing I										
Close lane	7	31,82	1,29	0,25	10,60	0,26	0,49	0,16	11,42	0,17
Middle lane	5	22,73	1,20	0,45	17,86	0,46	0,45	0,32	16,21	0,31
Far lane	5	22,73	1,80	0,43	19,70	0,46	0,84	0,30	15,86	0,29
2nd pedestrian crossing	8	36,36	1,11	0,58	14,45	0,60	0,33	0,32	8,10	0,30
Pedestrian area K	3	13,64	1,33	0,21	3,76	0,21	0,58	0,10	2,03	0,10
Pedestrian area L	2	9,09	1,00	0,26	6,85	0,26	0,00	0,14	3,04	0,14
Street left	2	9,09	1,50	0,25	11,89	0,34	0,71	0,04	2,87	0,08
Street right	10	45,45	1,20	0,30	11,38	0,32	0,42	0,22	12,41	0,22
Junction/vehicle left	16	72,73	1,38	0,48	13,74	0,51	0,92	0,42	11,76	0,42
Junction/vehicle right	14	63,64	1,29	0,28	8,10	0,32	0,47	0,16	4,76	0,19
Turn										
Close lane	4	18,18	1,25	0,44	12,07	0,46	0,50	0,15	4,27	0,12
Middle lane	5	22,73	1,00	0,62	16,33	0,62	0,00	0,46	22,01	0,46
Far lane	1	4,55	1,00	0,28	8,24	0,28	0,00	0,00	0,00	0,00
Pedestrian/ area J	6	28,57								
Pedestrian/area K	5	23,81								
Pedestrian crossing	9	40,91	1,50	0,50	25,28	0,55	0,71	0,42	19,71	0,41
Oncoming vehicle	8	36,36	1,75	0,41	17,29	0,51	0,89	0,31	12,78	0,39
Vehicle from left (if visible)	4	18,18	1,60	0,92	20,10	0,94	0,89	1,63	28,25	1,62
Exit										
Close lane	9	40,91	1,22	0,77	25,22	0,84	0,67	0,51	15,01	0,50
Middle lane	7	31,82	1,00	0,54	14,55	0,54	0,00	0,30	9,30	0,30
Far lane	8	36,36	1,25	0,49	19,64	0,55	0,46	0,54	20,33	0,58
Opposite lane	7	31,82	1,00	0,28	8,66	0,28	0,00	0,13	5,20	0,13

Scenario 7 (Baseline)	Mean						STDEV			
	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Middle lane	5	26,32	1,20	0,68	33,28	0,75	0,45	0,35	26,14	0,33
Far lane	9	47,37	1,33	0,30	17,52	0,41	0,50	0,21	18,62	0,39
Traffic sign	2	10,53	1,00	0,36	9,29	0,36	0,00	0,28	7,06	0,28
Street + junction left	2	10,53	1,00	0,16	6,10	0,16	0,00	0,06	4,47	0,06
Street + junction right	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian crossing + area I, J	9	47,37	1,27	0,52	12,64	0,60	0,47	0,33	6,32	0,39
Oncoming vehicle/direction	8	42,11	1,44	0,34	10,57	0,39	0,73	0,14	4,90	0,18
Leading vehicle	17	89,47	2,12	0,65	31,59	0,80	1,27	0,70	20,20	0,72
Deceleration										
Close lane	1	5,26	2,00	0,54	36,00	0,96	0,00	0,00	0,00	0,00
Middle lane	7	36,84	1,43	0,35	6,81	0,38	0,79	0,17	5,51	0,21
Far lane	4	21,05	1,25	0,24	3,11	0,24	0,50	0,14	2,01	0,14
Traffic sign	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1st Pedestrian crossing	15	78,95	1,50	0,51	7,31	0,57	0,86	0,44	8,40	0,44
Pedestrian area I	5	26,32	1,67	0,38	7,67	0,49	1,21	0,09	6,70	0,33
Pedestrian area J	7	36,84	1,86	0,50	7,73	0,57	0,69	0,23	5,05	0,27
Street left	2	10,53	1,00	0,34	2,97	0,34	0,00	0,08	0,54	0,08
Street right	2	10,53	1,50	0,26	3,69	0,32	0,71	0,14	3,68	0,23
Junction left	3	15,79	1,00	0,28	2,45	0,28	0,00	0,11	0,85	0,11
Junction right	7	36,84	1,43	0,42	4,15	0,46	0,53	0,27	2,58	0,29
Oncoming vehicle/direction	10	52,63	1,58	0,28	3,82	0,32	0,90	0,14	2,50	0,19
Vehicle from left	9	47,37	1,67	0,51	6,22	0,67	0,87	0,26	3,42	0,44
Vehicle from right	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2nd pedestrian crossing + K, L	7	36,84	1,33	0,30	3,65	0,31	0,65	0,22	3,14	0,22
Leading vehicle	18	94,74	4,22	1,02	45,82	1,80	2,46	0,61	23,71	0,73
Crossing I										
Close lane	1	5,26	4,00	1,03	27,84	2,44	0,00	0,00	0,00	0,00
Middle lane	7	36,84	1,29	0,33	7,18	0,38	0,76	0,13	7,47	0,23
Far lane	4	21,05	1,00	0,25	2,59	0,25	0,00	0,11	0,86	0,11
2nd pedestrian crossing	7	36,84	1,20	0,26	4,10	0,30	0,42	0,12	3,43	0,18
Pedestrian area K	2	10,53	1,50	0,31	9,43	0,40	0,71	0,04	6,47	0,17
Pedestrian area L	3	15,79	1,00	0,59	20,90	0,59	0,00	0,18	16,67	0,18
Street left	4	21,05	1,75	0,20	10,57	0,26	0,96	0,03	7,07	0,08
Street right	10	52,63	1,30	0,55	27,92	0,58	0,48	0,34	17,99	0,32
Junction/vehicle left	13	68,42	1,38	0,39	11,19	0,42	0,50	0,22	9,25	0,24
Junction/vehicle right	3	15,79	1,75	0,27	9,93	0,34	0,96	0,11	8,57	0,11
Leading vehicle	7	36,84	4,43	0,52	26,27	1,23	2,51	0,32	17,81	1,02
Turn										
Close lane	6	31,58	1,00	0,53	25,59	0,53	0,00	0,38	23,29	0,38
Middle lane	3	15,79	1,00	0,48	17,28	0,48	0,00	0,24	12,80	0,24
Far lane	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area I	6	31,58								
Pedestrian area K	9	47,37								
Pedestrian crossing	15	78,95	1,50	0,44	19,75	0,51	1,10	0,37	14,69	0,42
Oncoming vehicle	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Vehicle from left (if visible)	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Leading vehicle	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exit										
Close lane	10	52,63	1,20	0,55	21,05	0,63	0,42	0,32	15,43	0,43
Middle lane	11	57,89	1,27	0,53	30,42	0,57	0,47	0,39	27,73	0,39
Far lane	6	31,58	1,50	0,41	14,80	0,53	0,55	0,43	13,11	0,67
Oncoming lane	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

	Mean						STDEV			
Scenario 7 (Time pressure)	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	3	13,64	2,33	0,66	10,04	1,21	2,31	0,48	9,08	1,19
Middle lane	7	31,82	2,71	0,53	20,45	0,86	4,11	0,46	10,17	1,12
Far lane	10	45,45	2,90	0,42	21,85	0,69	5,32	0,22	14,45	0,72
Traffic sign	3	13,64	1,00	0,31	12,95	0,31	0,00	0,08	10,56	0,08
Street + junction left	2	9,09	2,50	0,46	5,04	0,72	2,12	0,25	5,41	0,62
Street + junction right	2	9,09	3,50	0,23	2,32	0,30	3,54	0,16	1,89	0,25
Pedestrian crossing + area I, J	9	40,91	1,30	0,34	9,07	0,38	0,95	0,16	7,60	0,19
Oncoming vehicle/direction	4	18,18	5,00	0,38	11,39	0,74	5,34	0,14	9,38	0,49
Leading vehicle	17	77,27	1,82	0,49	43,70	0,66	0,81	0,24	24,31	0,58
Deceleration										
Close lane	1	4,55	2,00	0,12	1,50	0,12	0,00	0,00	0,00	0,00
Middle lane	5	22,73	1,40	0,45	8,02	0,50	0,89	0,19	8,96	0,16
Far lane	7	31,82	1,29	0,29	4,10	0,31	0,49	0,13	3,10	0,16
Traffic sign	4	18,18	1,25	0,29	2,55	0,32	0,50	0,05	0,99	0,07
1st Pedestrian crossing	15	68,18	1,81	0,36	5,62	0,46	1,10	0,21	4,54	0,37
Pedestrian area I	6	27,27	1,17	0,37	5,00	0,37	0,41	0,40	3,43	0,40
Pedestrian area J	9	40,91	1,86	0,35	6,41	0,46	1,23	0,14	4,02	0,26
Street left	2	9,09	1,50	0,22	3,59	0,28	0,71	0,14	3,66	0,23
Street right	3	13,64	1,67	0,27	2,94	0,36	0,58	0,15	2,21	0,29
Junction left	2	9,09	1,00	0,34	5,55	0,34	0,00	0,14	3,47	0,14
Junction right	5	22,73	1,60	0,46	7,37	0,58	0,89	0,17	3,60	0,31
Oncoming vehicle/direction	14	63,64	1,40	0,30	3,84	0,36	0,58	0,13	4,48	0,14
Vehicle from left	5	22,73	1,00	0,38	2,83	0,38	0,00	0,30	2,11	0,30
Vehicle from right	2	9,09	1,00	0,26	4,88	0,26	0,00	0,08	2,53	0,08
2nd pedestrian crossing + K, L	9	40,91	1,44	0,22	2,24	0,25	0,70	0,09	1,03	0,10
Leading vehicle	19	86,36	5,11	0,99	56,44	1,84	3,23	0,56	16,18	0,85
Crossing I										
Close lane	6	27,27	1,17	0,29	4,22	0,29	0,41	0,15	2,01	0,14
Middle lane	3	13,64	1,33	0,40	8,33	0,40	0,58	0,11	5,41	0,11
Far lane	6	27,27	1,17	0,22	5,35	0,23	0,41	0,06	5,37	0,07
2nd pedestrian crossing	5	22,73	1,30	0,29	2,99	0,30	0,48	0,27	2,34	0,27
Pedestrian area K	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area L	5	22,73	1,00	0,26	9,36	0,26	0,00	0,09	6,53	0,09
Street left	6	27,27	1,00	0,33	11,98	0,33	0,00	0,17	11,52	0,17
Street right	3	13,64	1,00	0,40	12,07	0,40	0,00	0,17	11,28	0,17
Junction/vehicle left	13	59,09	1,50	0,37	13,28	0,41	0,73	0,23	15,26	0,25
Junction/vehicle right	4	18,18	1,50	0,29	5,35	0,30	0,58	0,15	3,85	0,15
Leading vehicle	14	63,64	4,21	1,00	40,29	1,59	2,97	1,70	21,56	1,76
Turn										
Close lane	6	27,27	1,17	0,87	32,73	0,97	0,41	0,77	25,61	0,81
Middle lane	2	9,09	1,00	0,64	23,06	0,64	0,00	0,17	8,10	0,17
Far lane	1	4,55	2,00	0,28	22,95	0,48	0,00	0,00	0,00	0,00
Pedestrian area I	10	52,63	1,00	0,27	17,90	0,27	0,00	0,13	3,41	0,13
Pedestrian area K	7	36,84								
Pedestrian crossing	9	40,91	1,00	0,34	17,98	0,34	0,00	0,22	11,74	0,22
Oncoming vehicle	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Vehicle from left (if visible)	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Leading vehicle	5	22,73	1,40	0,30	18,51	0,45	0,55	0,27	13,68	0,54
Exit										
Close lane	11	50,00	1,45	0,51	27,57	0,60	0,69	0,20	16,15	0,25
Middle lane	13	59,09	1,38	0,85	32,30	0,96	0,87	0,94	26,43	0,98
Far lane	4	18,18	1,25	0,61	24,15	0,76	0,50	0,38	5,28	0,51
Oncoming lane	2	9,09	1,00	0,64	38,39	0,64	0,00	0,34	19,79	0,34
Leading vehicle	3	13,64	1,33	0,43	27,47	0,44	0,58	0,41	33,80	0,42

Scenario 8 (Baseline)	Mean						STDEV			
	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percentege d glance proporotion	Max glance duration [s]	Average number of glances	Mean glance duration	Percentege d glance proporotion	Max glance duration
Approach										
Close lane	4	19,05	1,75	0,82	18,37	1,19	0,96	0,39	9,32	0,80
Middle lane	4	19,05	1,00	0,65	15,66	0,65	0,00	0,45	9,88	0,45
Far lane	10	47,62	1,30	0,42	8,47	0,48	0,71	0,16	3,34	0,26
Traffic sign	10	47,62	1,13	0,39	7,53	0,41	0,35	0,31	5,83	0,31
Street + junction left	4	19,05	1,00	0,25	4,40	0,25	0,00	0,05	1,42	0,05
Street + junction right	5	23,81	1,00	0,58	10,68	0,58	0,00	0,25	7,05	0,25
Pedestrian crossing	5	23,81	1,17	0,46	6,50	0,49	0,41	0,18	2,75	0,16
Pedestrain I	6	28,57	1,33	0,40	8,23	0,42	0,52	0,18	6,00	0,19
Pedestrian J	6	28,57	1,50	0,22	6,41	0,28	0,55	0,11	6,46	0,19
Leading vehicle	18	85,71	3,11	0,75	36,19	1,20	1,60	0,63	21,24	0,74
Deceleration										
Close lane	2	9,52	3,00	0,49	13,80	0,78	1,41	0,07	12,17	0,48
Middle lane	5	23,81	1,20	0,28	10,59	0,36	0,45	0,19	17,44	0,36
Far lane	6	28,57	1,00	0,32	3,95	0,32	0,00	0,27	3,70	0,27
Traffic sign	6	28,57	1,38	0,30	3,38	0,45	0,74	0,20	3,86	0,57
1st Pedestrian crossing	15	71,43	2,35	0,41	7,71	0,58	1,73	0,22	4,54	0,40
Pedestrian area I	13	61,90	1,69	0,47	5,98	0,60	0,79	0,36	3,31	0,53
Pedestrian area J	5	23,81	1,00	0,18	1,94	0,18	0,00	0,07	1,22	0,07
Street left	2	9,52	1,00	0,42	2,52	0,42	0,00	0,25	1,44	0,25
Street right	4	19,05	1,25	0,43	6,33	0,50	0,00	0,11	7,21	0,11
Junction left	9	42,86	1,56	0,32	8,94	0,34	0,88	0,14	7,10	0,16
Junction right	9	42,86	1,33	0,18	3,87	0,20	0,50	0,11	4,90	0,10
Oncoming vehicle/direction	10	47,62	1,67	0,29	6,63	0,38	0,89	0,08	6,34	0,24
Vehicle from left	6	28,57	1,00	0,30	2,73	0,30	0,00	0,15	2,08	0,15
Vehicle from right	4	19,05	2,25	0,44	6,31	0,68	0,96	0,23	4,64	0,49
2nd pedestrian crossing + K, L	13	61,90	1,40	0,26	4,77	0,31	0,60	0,17	5,74	0,19
Leading vehicle	16	76,19	5,50	1,05	52,71	2,45	3,20	0,63	19,89	1,43
Crossing I										
Close lane	6	28,57	1,17	0,52	9,64	0,55	0,41	0,21	5,58	0,25
Middle lane	5	23,81	1,20	0,28	5,11	0,29	0,45	0,18	4,69	0,18
Far lane	7	33,33	1,29	0,39	11,11	0,47	0,49	0,23	13,36	0,35
2nd pedestrian crossing	7	33,33	1,25	0,26	6,23	0,27	0,46	0,14	7,52	0,14
Pedestrian area K	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area L	4	19,05	1,50	0,23	6,68	0,26	1,00	0,06	5,28	0,11
Street left	2	9,52	1,00	0,26	13,00	0,26	0,00	0,14	7,07	0,14
Street right	12	57,14	1,17	0,35	11,32	0,36	0,39	0,15	9,61	0,14
Junction/vehicle left	16	76,19	1,38	0,30	9,33	0,33	0,92	0,16	9,90	0,22
Junction/vehicle right	10	47,62	2,00	0,22	8,84	0,36	1,81	0,13	11,38	0,50
Leading vehicle	10	47,62	3,70	0,76	32,87	1,95	2,58	0,44	19,73	1,93
Turn										
Close lane	4	27,27	1,50	0,39	10,44	0,40	0,84	0,39	11,16	0,38
Middle lane	3	13,64	1,00	0,27	5,18	0,27	0,00	0,22	0,33	0,22
Far lane	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian/ area J	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian/area K	3	13,64	1,00	0,21	3,38	0,21	0,00	0,06	1,66	0,06
Pedestrian crossing	13	57,14	1,22	0,37	11,21	0,40	0,43	0,22	7,57	0,28
Oncoming vehicle	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Vehicle from left (if visible)	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Leading vehicle	4	18,18	1,75	0,34	16,57	0,46	0,96	0,16	9,10	0,37
Exit										
Close lane	5	21,05	1,25	0,31	16,70	0,33	0,50	0,18	10,14	0,18
Middle lane	7	31,58	1,00	0,61	21,66	0,61	0,00	0,37	24,14	0,37
Far lane	6	26,32	1,20	0,29	16,97	0,30	0,45	0,11	5,71	0,11
Oncoming lane	3	15,79	1,00	0,25	6,28	0,25	0,00	0,12	2,10	0,12

Scenario 8 (Time pressure)	Mean						STDEV			
	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	5	22,73	2,20	0,46	22,42	0,62	1,34	0,26	20,71	0,39
Middle lane	4	18,18	3,50	0,56	41,89	0,86	2,89	0,35	46,57	0,66
Far lane	8	36,36	1,63	0,31	6,14	0,35	1,41	0,20	2,62	0,25
Traffic sign	3	13,64	1,00	0,31	4,35	0,31	0,00	0,18	3,46	0,18
Street + junction left	4	18,18	1,40	0,37	5,86	0,48	0,55	0,11	3,49	0,27
Street + junction right	3	13,64	1,67	0,30	5,60	0,39	0,58	0,10	6,80	0,18
Pedestrian crossing	4	18,18	1,00	0,44	3,11	0,44	0,00	0,53	1,64	0,53
Pedestrain I	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian J	4	18,18	1,00	0,58	25,47	0,58	0,00	0,32	21,23	0,32
Leading vehicle	16	72,73	3,06	0,61	42,49	1,11	1,34	0,41	20,71	0,86
Deceleration										
Close lane	5	22,73	1,80	0,44	11,37	0,50	0,45	0,44	16,65	0,43
Middle lane	6	27,27	1,50	0,15	4,97	0,19	0,84	0,05	4,27	0,11
Far lane	5	22,73	1,60	0,62	23,04	0,73	0,89	0,38	15,80	0,36
Traffic sign	7	31,82	1,11	0,24	3,95	0,24	0,33	0,19	4,83	0,19
1st Pedestrian crossing	12	54,55	2,13	0,46	6,21	0,58	1,27	0,19	3,33	0,30
Pedestrian area I	11	50,00	1,69	0,58	8,91	0,72	0,75	0,21	4,54	0,36
Pedestrian area J	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street left	1	4,55	2,00	0,26	3,02	0,28	0,00	0,00	0,00	0,00
Street right	3	13,64	1,67	0,39	6,13	0,41	0,58	0,29	3,95	0,30
Junction left	8	36,36	1,50	0,27	4,66	0,31	0,76	0,12	5,46	0,14
Junction right	4	18,18	1,50	0,28	8,05	0,37	0,58	0,18	9,52	0,29
Oncoming vehicle/direction	12	54,55	1,60	0,27	5,62	0,29	0,83	0,16	4,59	0,16
Vehicle from left	5	22,73	1,33	0,28	2,77	0,30	0,52	0,15	1,25	0,15
Vehicle from right	5	22,73	1,20	0,20	3,16	0,22	0,45	0,05	3,31	0,05
2nd pedestrian crossing + K, L	7	31,82	1,38	0,30	3,50	0,32	0,52	0,09	2,61	0,10
Leading vehicle	17	77,27	4,29	1,20	48,52	2,27	3,10	0,78	24,69	1,41
Crossing I										
Close lane	7	33,33	1,29	0,43	20,24	0,44	0,49	0,40	21,14	0,40
Middle lane	5	23,81	1,40	0,33	17,46	0,36	0,55	0,16	7,90	0,14
Far lane	3	14,29	1,67	0,32	17,08	0,35	0,58	0,11	3,47	0,14
2nd pedestrian crossing	3	13,64	1,00	0,19	5,26	0,19	0,00	0,05	3,75	0,05
Pedestrian area K	3	14,29	2,00	0,21	9,57	0,23	0,00	0,10	5,03	0,08
Pedestrian area L	2	9,09	1,50	0,19	9,54	0,20	0,71	0,01	11,96	0,00
Street left	2	9,52	1,00	0,30	4,67	0,30	0,00	0,25	5,69	0,25
Street right	1	4,76	1,00	0,76	38,00	0,76	0,00	0,00	0,00	0,00
Junction/vehicle left	16	76,19	1,47	0,35	16,18	0,42	0,62	0,20	12,49	0,29
Junction/vehicle right	6	28,57	1,00	0,48	5,29	0,48	0,00	0,36	2,21	0,36
Leading vehicle	8	38,10	2,25	0,46	20,38	1,07	2,19	0,38	14,31	1,54
Turn										
Close lane	6	28,57	1,67	0,36	11,67	0,65	1,21	0,24	15,80	0,90
Middle lane	3	14,29	3,67	0,90	27,88	1,16	4,62	0,51	21,44	0,55
Far lane	3	14,29	2,67	0,40	4,45	0,47	2,89	0,24	1,77	0,34
Pedestrian/ area J	1	4,76	3,00	0,36	0,93	0,64	0,00	0,00	0,00	0,00
Pedestrian/area K	3	14,29	1,33	0,21	6,34	0,23	0,58	0,05	3,64	0,06
Pedestrian crossing	9	42,86	1,50	0,36	12,78	0,38	1,45	0,23	14,73	0,23
Oncoming vehicle	2	9,52	3,50	0,38	5,60	0,80	2,12	0,15	4,94	0,57
Vehicle from left (if visible)	2	9,52	1,67	0,13	3,22	0,16	0,58	0,06	0,61	0,04
Leading vehicle	9	42,86	1,89	0,56	34,06	0,60	1,62	0,41	27,12	0,42
Exit										
Close lane	8	36,36	1,63	0,73	37,86	1,00	1,06	0,37	30,14	0,69
Middle lane	8	36,36	2,13	0,45	17,56	0,56	2,71	0,22	12,71	0,42
Far lane	4	18,18	2,50	0,37	17,20	0,42	2,38	0,20	16,77	0,29
Oncoming lane	6	27,27	1,67	0,29	11,24	0,31	1,63	0,13	11,23	0,14
Leading vehicle	10	45,45	1,60	1,12	64,55	1,51	0,53	0,70	36,06	0,91

Scenario 9 (Baseline)	Mean						STDEV			
	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion (%)	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	4	20	1,75	0,46	20,79	0,62	1,50	0,33	25,07	0,63
Middle lane	9	45	1,44	0,45	19,59	0,55	0,73	0,17	12,23	0,23
Far lane	8	40	1,50	0,46	14,53	0,52	0,76	0,22	8,45	0,27
Traffic sign	11	55	1,44	0,53	16,15	0,60	0,63	0,38	11,45	0,38
Street + junction left	2	10	1,00	0,28	8,36	0,28	0,00	0,23	8,65	0,23
Street + junction right	11	55	1,36	0,51	20,74	0,57	0,50	0,43	24,53	0,44
Pedestrain I	3	15	1,33	0,44	10,05	0,56	0,58	0,30	3,81	0,35
Pedestrian J	7	35	1,14	0,40	10,14	0,40	0,38	0,28	4,95	0,28
Deceleration										
Close lane	6	30	1,33	0,87	22,83	1,15	0,52	0,62	20,70	0,86
Middle lane	8	40	1,50	0,36	10,75	0,42	0,76	0,23	5,64	0,38
Far lane	4	20	1,25	0,31	12,09	0,31	0,50	0,13	7,47	0,13
Traffic sign	6	30	1,00	0,43	13,33	0,43	0,00	0,52	18,02	0,52
1st Pedestrian crossing	9	45	1,42	0,31	12,05	0,33	0,79	0,14	9,23	0,15
Pedestrian area I	5	25	1,20	0,33	8,31	0,34	0,45	0,10	3,71	0,08
Pedestrian area J	1	5	1,00	0,44	14,67	0,44	0,00	0,00	0,00	0,00
Street left	0	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	10	50	1,30	0,56	17,87	0,66	0,48	0,51	18,63	0,55
Junction left	4	20	1,25	0,49	6,18	0,50	0,50	0,64	6,54	0,63
Junction right	16	80	1,56	0,30	11,54	0,34	1,03	0,19	8,18	0,20
Oncoming vehicle/direction	11	55	1,50	0,32	10,35	0,40	0,85	0,23	7,34	0,32
Vehicle from left	3	15	1,33	0,29	5,23	0,31	0,58	0,20	3,53	0,18
Vehicle from right	8	40	1,33	0,32	7,86	0,33	0,49	0,21	3,80	0,21
2nd pedestrian crossing + K, L	9	45	1,27	0,28	9,50	0,29	0,65	0,14	4,63	0,15
Crossing I										
Close lane	6	30	2,00	0,38	17,67	0,69	2,00	0,28	23,30	0,98
Middle lane	6	30	1,17	0,37	7,88	0,47	0,41	0,29	8,70	0,54
Far lane	2	10	1,00	0,22	3,62	0,22	0,00	0,03	0,89	0,03
2nd pedestrian crossing	10	50	1,40	0,28	7,51	0,34	0,70	0,10	3,95	0,18
Pedestrian area K	3	15	1,33	0,13	3,64	0,13	0,58	0,06	1,32	0,05
Pedestrian area L	5	25	1,20	0,49	18,71	0,50	0,45	0,29	17,78	0,27
Street left	1	5	1,00	0,20	10,00	0,20	0,00	0,00	0,00	0,00
Street right	16	80	1,50	0,42	16,71	0,50	0,63	0,40	21,98	0,41
Junction/vehicle left	4	20	2,00	0,27	13,22	0,33	1,15	0,08	9,45	0,14
Junction/vehicle right	4	20	1,75	0,24	8,38	0,26	0,50	0,20	11,98	0,19
Crossing II										
Close lane	7	35	1,00	0,51	43,54	0,51	0,00	0,22	24,76	0,22
Middle lane	5	25	1,00	0,37	21,49	0,37	0,00	0,16	15,16	0,16
Far lane	1	5	1,00	0,28	28,00	0,28	0,00	0,00	0,00	0,00
2nd pedestrian crossing	12	60	1,43	0,39	29,94	0,43	0,65	0,21	16,56	0,21
Pedestrian area K	2	10	1,50	0,35	30,35	0,58	0,71	0,21	37,44	0,54
Pedestrian area L	8	40	1,30	0,26	16,85	0,30	0,67	0,12	9,59	0,19
Street left	0	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Junction/vehicle left	3	15	1,00	0,28	13,22	0,28	0,00	0,21	4,47	0,21
Exit										
Close lane	6	30,00	1,17	0,60	27,54	0,60	0,41	0,60	29,45	0,60
Middle lane	8	40,00	1,50	0,32	14,52	0,39	0,76	0,13	8,09	0,22
Far lane	4	20,00	1,25	0,33	14,34	0,34	0,50	0,22	12,06	0,24
Oncoming lane	5	25,00	1,20	0,35	9,69	0,36	0,45	0,26	5,42	0,25

	Mean						STDEV			
Scenario 9 (Time pressure)	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proportion (%)	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	6	27,27	1,33	0,32	29,77	0,42	0,52	0,19	18,07	0,40
Middle lane	3	13,64	1,33	0,39	30,37	0,47	0,58	0,11	25,07	0,13
Far lane	6	27,27	1,50	0,32	24,34	0,36	0,55	0,25	19,06	0,27
Traffic sign	2	9,09	1,00	0,40	13,31	0,40	0,00	0,28	1,58	0,28
Street + junction left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street + junction right	10	45,45	1,09	0,60	27,18	0,60	0,30	0,38	15,88	0,37
Pedestrain I	2	9,09	1,00	0,30	45,02	0,30	0,00	0,14	14,90	0,14
Pedestrian J	6	27,27	1,00	0,26	15,48	0,26	0,00	0,13	6,90	0,13
Deceleration										
Close lane	7	31,82	1,57	0,33	17,14	0,43	0,53	0,14	8,59	0,21
Middle lane	7	31,82	1,86	0,39	23,81	0,57	0,90	0,26	17,10	0,50
Far lane	4	18,18	1,00	0,55	18,33	0,55	0,00	0,39	13,08	0,39
Traffic sign	8	36,36	1,00	0,32	10,50	0,32	0,00	0,16	5,49	0,16
1st Pedestrian crossing	7	31,82	1,27	0,33	13,45	0,36	0,47	0,14	7,09	0,14
Pedestrian area I	5	22,73	1,00	0,22	7,47	0,22	0,00	0,11	3,60	0,11
Pedestrian area J	10	45,45	1,09	0,33	12,10	0,33	0,30	0,22	7,95	0,22
Street left	2	9,09	1,00	0,68	22,67	0,68	0,00	0,62	20,74	0,62
Street right	6	27,27	1,17	0,61	22,67	0,67	0,41	0,45	16,49	0,48
Junction left	3	13,64	1,00	0,19	6,22	0,19	0,00	0,06	2,04	0,06
Junction right	9	40,91	1,78	0,22	12,91	0,27	0,97	0,15	8,92	0,20
Oncoming vehicle/direction	7	31,82	1,57	0,49	27,06	0,62	0,79	0,18	16,66	0,34
Vehicle from left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Vehicle from right	5	22,73	1,20	0,26	10,07	0,28	0,45	0,04	4,32	0,06
2nd pedestrian crossing + K, L	9	40,91	1,27	0,23	10,06	0,25	0,47	0,09	7,04	0,14
Crossing I										
Close lane	12	54,55	1,75	0,49	19,12	0,55	0,87	0,45	11,28	0,42
Middle lane	5	22,73	1,00	0,50	10,48	0,50	0,00	0,50	4,70	0,50
Far lane	1	4,55	1,00	0,28	7,61	0,28	0,00	0,00	0,00	0,00
2nd pedestrian crossing	5	22,73	1,17	0,30	5,00	0,31	0,41	0,11	2,96	0,10
Pedestrian area K	1	4,55	1,00	0,44	22,00	0,44	0,00	0,00	0,00	0,00
Pedestrian area L	6	27,27	1,14	0,38	15,15	0,41	0,38	0,21	11,22	0,24
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	14	63,64	1,43	0,40	13,54	0,44	0,65	0,36	12,36	0,35
Junction/vehicle left	7	31,82	1,00	0,38	10,49	0,38	0,00	0,21	9,35	0,21
Junction/vehicle right	3	13,64	1,00	0,23	5,80	0,23	0,00	0,08	3,20	0,08
Crossing II										
Close lane	8	36,36	1,13	0,33	28,20	0,33	0,35	0,20	29,52	0,20
Middle lane	4	18,18	1,25	0,40	22,72	0,40	0,50	0,47	17,23	0,46
Far lane	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2nd pedestrian crossing	13	59,09	1,26	0,37	26,82	0,44	0,45	0,31	14,22	0,45
Pedestrian area K	1	4,55	1,00	0,12	7,50	0,12	0,00	0,00	0,00	0,00
Pedestrian area L	11	50,00	1,00	0,27	21,21	0,27	0,00	0,10	15,23	0,10
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Junction/vehicle left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exit										
Close lane	6	27,27	1,33	0,81	42,12	1,04	0,82	0,63	34,77	0,85
Middle lane	9	40,91	1,11	0,45	17,55	0,46	0,33	0,24	11,07	0,25
Far lane	3	13,64	1,00	0,31	15,55	0,31	0,00	0,06	2,96	0,06
Oncoming lane	2	9,09	1,00	0,48	15,99	0,48	0,00	0,23	3,10	0,23

	Mean						STDEV			
Scenario 10 (Baseline)	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	2	9,524	2,5	0,75	42,51	1,48	0,707	0,41	40,16	1,2445
Middle lane	9	42,86	1,889	0,722	27,2	0,88	0,928	0,75	17,67	0,7655
Far lane	13	61,9	2,154	0,433	23,09	0,603	0,987	0,192	12,55	0,362
Traffic sign	12	57,14	1,333	0,669	22,55	0,72	0,617	0,793	23,03	0,7911
Street + junction left	0	0	0	0	0	0	0	0	0	0
Street + junction right	4	19,05	1,25	0,735	20,98	0,82	0,5	0,345	11,64	0,398
Pedestrain I	0	0	0	0	0	0	0	0	0	0
Pedestrian J	5	23,81	1	0,712	17,67	0,712	0	0,449	7,428	0,4494
Deceleration										
Close lane	8	38,1	1	0,655	19,37	0,655	0	0,484	16,8	0,4842
Middle lane	8	38,1	1,25	0,63	22,6	0,685	0,463	0,314	19,56	0,3444
Far lane	9	42,86	1,556	0,661	26,76	0,76	1,014	0,48	18,42	0,5158
Traffic sign	11	52,38	1,071	0,283	8,924	0,283	0,267	0,081	3,122	0,0807
1st Pedestrian crossing	0	0	0	0	0	0	0	0	0	0
Pedestrian area I	2	9,524	1	0,48	10,39	0,48	0	0,17	2,979	0,1697
Pedestrian area J	0	0	0	0	0	0	0	0	0	0
Street left	2	9,524	1	0,16	3,99	0,16	0	0	2,215	0
Street right	5	23,81	1,4	0,464	12,25	0,496	0,548	0,23	8,854	0,222
Junction left	3	14,29	1,333	0,253	5,217	0,28	0,577	0,14	2,417	0,1058
Junction right	8	38,1	1,125	0,278	7,334	0,28	0,354	0,175	3,954	0,1724
Oncoming vehicle/direction	15	71,43	1,25	0,383	13,34	0,433	0,447	0,195	10,86	0,2745
Vehicle from left	0	0	0	0	0	0	0	0	0	0
Vehicle from right	0	0	0	0	0	0	0	0	0	0
2nd pedestrian crossing + K, L	14	66,67	1,217	0,373	11,42	0,423	0,518	0,287	10,21	0,3678
Crossing I										
Close lane	7	33,33	1,571	0,275	6,32	0,36	0,787	0,062	1,804	0,1697
Middle lane	5	23,81	2	0,363	8,918	0,552	1,414	0,069	4,492	0,2356
Far lane	5	23,81	1,4	0,336	12,63	0,432	0,894	0,131	8,966	0,2972
2nd pedestrian crossing	8	38,1	1,727	0,302	5,915	0,367	1,009	0,155	2,124	0,1875
Pedestrian area K	11	52,38	2	0,317	12,38	0,382	1,183	0,188	7,885	0,2089
Pedestrian area L	4	19,05	1	0,36	4,579	0,36	0	0,327	2,202	0,3266
Street left	10	47,62	1,2	0,452	12,34	0,464	0,422	0,206	8,006	0,2015
Street right	18	85,71	1,222	0,35	8,335	0,391	0,428	0,22	4,204	0,3222
Junction/vehicle left	10	47,62	1,4	0,291	8,906	0,328	0,699	0,155	11,43	0,2055
Junction/vehicle right	3	14,29	1	0,24	4,285	0,24	0	0,106	4,686	0,1058
Crossing II										
Close lane	5	23,81	1,2	0,26	16,46	0,264	0,447	0,092	8,674	0,0829
Middle lane	5	23,81	1,6	0,305	26,38	0,336	0,894	0,146	14,49	0,1152
Far lane	6	28,57	1	0,333	21,04	0,333	0	0,118	7,975	0,1178
2nd pedestrian crossing	10	47,62	1,667	0,401	23,93	0,516	1,029	0,251	25	0,4081
Pedestrian/ area J	13	61,9	1,231	0,276	16,11	0,302	0,599	0,177	10,93	0,2278
Pedestrian/area K	7	33,33	1,143	0,389	30,23	0,394	0,378	0,246	22,79	0,2416
Street left	0	0	0	0	0	0	0	0	0	0
Junction left	3	14,29	1,333	0,38	9,064	0,507	0,577	0,381	7,349	0,6004
Exit										
Close lane	6	28,57	1,167	0,283	11,75	0,287	0,408	0,123	7,419	0,125
Middle lane	11	52,38	1,455	0,54	34,7	0,625	0,522	0,333	24,57	0,3724
Far lane	11	52,38	1,273	0,65	37,97	0,705	0,647	0,481	33,85	0,4757
Oncoming lane	4	19,05	1,25	0,35	15,18	0,35	0,5	0,089	16,5	0,0887

Scenario 10 (Time pressure)	Mean						STDEV			
	Number of test persons	Percentage of test persons [%]	Average number of glances	Mean glance duration (s)	Percenteged glance proporotion	Max glance duration [s]	Average number of glances	Mean glance duration	Percenteged glance proporotion	Max glance duration
Approach										
Close lane	4	18,18	2,00	0,92	63,71	1,13	2,31	0,57	54,70	0,22
Middle lane	8	36,36	2,50	0,86	29,43	1,07	3,12	0,95	20,80	0,95
Far lane	11	50,00	2,18	0,43	27,86	0,57	2,36	0,24	18,69	0,35
Traffic sign	10	45,45	1,17	0,41	21,18	0,44	0,39	0,30	18,71	0,30
Street + junction left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street + junction right	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian crossing	1	4,55	1,50	0,28	0,23	0,34	0,71	0,06	0,06	0,03
Pedestrain I	6	27,27	1,57	0,37	19,39	0,45	1,13	0,15	15,62	0,26
Pedestrian J	0									
Deceleration										
Close lane	5	22,73	1,20	1,06	40,53	1,06	0,45	0,69	23,52	0,68
Middle lane	10	45,45	1,30	0,58	20,92	0,60	0,48	0,51	16,03	0,49
Far lane	13	59,09	1,31	0,51	20,31	0,62	0,48	0,29	16,13	0,50
Traffic sign	10	45,45	1,13	0,36	13,48	0,39	0,35	0,32	11,06	0,33
1st Pedestrian crossing	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pedestrian area I	1	4,55	1,00	0,28	13,46	0,28	0,00	0,00	0,00	0,00
Pedestrian area J	1	4,55	1,00	0,52	17,33	0,52	0,00	0,00	0,00	0,00
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Street right	3	13,64	1,33	0,23	6,55	0,23	0,58	0,10	2,22	0,10
Junction left	6	27,27	1,00	0,46	14,48	0,46	0,00	0,35	12,62	0,35
Junction right	4	18,18	1,75	0,34	15,44	0,39	0,96	0,11	11,30	0,16
Oncoming vehicle/direction	9	40,91	1,44	0,39	15,44	0,44	0,73	0,21	6,15	0,19
Vehicle from left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Vehicle from right	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2nd pedestrian crossing + K, L	10	45,45	1,20	0,40	13,54	0,42	0,77	0,22	7,77	0,23
Crossing I										
Close lane	8	36,36	1,63	0,33	16,96	0,40	0,74	0,19	8,55	0,23
Middle lane	7	31,82	1,57	0,30	12,14	0,45	0,79	0,19	7,95	0,40
Far lane	5	22,73	1,40	0,32	13,22	0,48	0,55	0,23	11,48	0,49
2nd pedestrian crossing	6	27,27	1,00	0,35	7,70	0,35	0,00	0,30	4,50	0,30
Pedestrian area K	5	22,73	1,00	0,26	7,32	0,26	0,00	0,15	4,20	0,15
Pedestrian area L	5	22,73	2,00	0,25	11,44	0,28	0,71	0,09	2,79	0,10
Street left	5	22,73	1,20	0,24	11,23	0,25	0,45	0,08	4,24	0,08
Street right	16	72,73	1,06	0,23	7,47	0,24	0,25	0,08	2,82	0,08
Junction/vehicle left	11	50,00	1,27	0,35	15,48	0,37	0,47	0,28	15,25	0,30
Junction/vehicle right	6	27,27	1,00	0,34	9,71	0,34	0,00	0,18	5,01	0,18
Crossing II										
Close lane	5	22,73	1,20	0,60	28,47	0,60	0,45	0,99	39,99	0,99
Middle lane	7	31,82	1,29	0,26	21,78	0,26	0,49	0,17	15,36	0,16
Far lane	4	18,18	1,25	0,37	26,87	0,38	0,50	0,32	20,33	0,31
2nd pedestrian crossing	7	31,82	1,10	0,31	16,88	0,31	0,32	0,22	9,75	0,22
Pedestrian/ area J	8	36,36	1,13	0,37	22,85	0,39	0,35	0,37	22,42	0,37
Pedestrian/area K	11	50,00	1,18	0,51	40,84	0,56	0,40	0,37	30,30	0,39
Street left	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Junction left	1	4,55	1,00	0,20	18,52	0,20	0,00	0,00	0,00	0,00
Exit										
Close lane	7	31,82	1,00	0,38	19,83	0,38	0,00	0,25	12,74	0,25
Middle lane	9	40,91	1,44	0,51	31,32	0,62	0,53	0,34	23,68	0,47
Far lane	10	45,45	1,20	0,83	49,75	0,87	0,42	0,47	27,96	0,46
Oncoming lane	4	18,18	1,25	0,37	18,95	0,37	0,50	0,37	12,99	0,37

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