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Final DVE model structure

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Glossary of Abbreviations

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
AIDE	Adaptive Integrated Driver-vehicle InterfacE
DIL	Driver Impairment Level
DS	Driver State
DVE	Driver-vehicle-environment
FCW	Frontal Collision Warning
FP6	Sixth Framework Programme
HMI	Human-machine Interaction
ICA	Interaction and Communication Assistant
IP	Integrated Project
ISO	International Standardization Organization
IVIS	In-vehicle Information Systems
JAB	Journey A-B
LDW	Lane Departure Warning
PDA	Personal Digital Assistant
PDT	Peripheral Detection Task
RTD	Research and Technological Development
SA	Situation Awareness
SP	Sub-project
TD	Task Demand
TLC	Time to Line Crossing
TTC	Time to collision
UCD	User-Centred Design
VDM	Visual Demand Measurement
WP	Workpackage

Executive Summary

The main goal of this deliverable is to present the “final formulation” of driver-vehicle-environment model, as it will be implemented in the SP1 simulation tool.

In modern systems, modelling of human behaviour entails the consideration both of cognitive processes and system dynamic evolution (such as the mental activities, resulting from the time dependent interaction of humans and machines). Thereby, a model of human behaviour has to be developed that takes into account and is coupled to a model of plant/system performance. In other words, the simulation develops a "joint" human machine system, the so-called "Joint Cognitive System" (JCS).

A simulation of JCS enables to predict behaviour and interaction process that are useful for design and implementation of new system. In particular, in modern vehicles, it is necessary to consider that several functions and applications are implemented. They are the Advanced Driver Support Systems (ADAS) and In-Vehicle Information Systems (IVIS). These add another level of complexity.

It has to be recognised that it is not possible to identify an architecture or a structure that is best in absolute to represent JCS, unless the generality of the approach is so wide that it loses sight of its potential applications. On the contrary, it is very important that the users of models have a clear picture of the goals and objectives of applications, in order to select the paradigm that best suits their aims among the available ones.

This deliverable is focused on the development of a “model” and associated “simulation” of a JCS, with the main objective of being a predictive tool, in order to study (all) possible Driver-Vehicle-Environment (DVE) interactions with a specific attention to design and safety analysis. In particular, in this Deliverable, the final formulation of the models that will be applied to generate a simulation of the JCS is discussed in details. Moreover, the most relevant part of the document is dedicated to the Driver model. The selected paradigm for modelling Driver behaviour is the so-called “Information Processing System” (IPS), which has been applied in almost all technological fields to describe human interaction with control systems, at different levels of automation. It consists in four steps, in which cover cognitive and behavioural aspects:

- Perception and interpretation of information from Vehicle and Environment;
- Formulation of goals and intentions and selection of tasks to be carried out;
- Performance of actions on the control panel and vehicle commands.

The important characteristic of this approach is that it allows to consider behavioural as well as the cognitive aspects of human behaviour.

In the first part of the Deliverable the basic characteristics of the Driver model are briefly recalled, as the main modelling architecture have already been the object of detailed analysis in previous Deliverables. The description of Driver model focuses on the actual “task” and “activities” that are the major building blocks of the whole model. These are described in detail, including the way in which a dynamic interaction should logically occur.

Two major types of behaviour are then highlighted: normative and descriptive behaviour. Their correlation and dependence on different “parameters” and observable “variables” is then described, which take the form of numerical or logical expressions. In the numerical simulation, the choice has been to utilise *Fuzzy* descriptions. Consequently, each variable associated to a parameter is evaluated during the simulation by means of correlations that define fuzzy values and membership functions, reached during the DVE interaction. Subsequently, the estimation of the (fuzzy) value of each parameter requires the application of typical fuzzy rules. The complete set of fuzzy correlations, membership functions and fuzzy rules that control the simulation is quite complex and requires a considerable effort of data input and data definition. In the present document, these topics are deeply investigated and discussed.

As the focus of the model and simulation is mainly on the Diver model, and given that the models of Vehicle and Environment have already extensively been discussed in previous Deliverables (D1.1.2 and D1.1.3), this Deliverable contain only short descriptions of the other two components of the DVE system.

The concluding section gives a rapid overview of the input-output system of the simulation. This part will be better developed in the specific documents associated with the technical description of the simulation tool and relative how-to-use, that will be developed in the following stage of the work of Sub-Project 1 of AIDE.

1. Introduction

The ability to model and predict Human-Machine Interaction (HMI) with consistent approaches is a crucial aspect of modern technological systems where the presence of humans is necessary at production or implementation processes. A reliable and realistic approach that enables to anticipate what will be “done” at different levels of cognition and behaviour by a human being, enables the prevention of erroneous or risky behaviour, as well the implementation of means of intervention exploiting the power of modern technologies and the decision making skill of humans. The literature of the last decades is rich of approaches and methods that focus on this subject.

In modern systems, modelling human behaviour entails considering primarily cognitive processes and system dynamic evolution, i.e., mental activities, resulting from the time dependent interaction of humans and machines. In this sense, a model of human behaviour can not be developed in total isolation and abstraction, but it must be coupled and linked to a model of plant performance in order to develop the simulation of a "joint" human machine system, also called "Joint Cognitive System". Therefore any model of human behaviour comes necessarily framed in a clear interaction context with the associated technological system.

The formulation of models of HMI is an evolutionary process whose origin lies in the cybernetic paradigm of Wiener (1948) that developed the analogy between the human operator and the servomechanism and in the similarities between computers and brains pointed out by von Neumann (1958). These analogies have increased awareness of the closed-loop nature of human-machine interaction, with the specific goal-oriented behaviour of the human controller. The progress of technology towards supervisory control and automation required the formulation of much more complex models of human reasoning and decision making processes, able to account primarily for cognitive rather than manual activities. The need of simulating the man-plus-the-controlled-element was then enunciated in the 60s by McRuer and colleagues (1965). Other pioneering research in this area, combined with the development of computer technologies, inspired the first formulations of theoretical models of cognition (Neisser, 1967) and, in the early 70s, the metaphor of the operator as *Information Processing System (IPS)* (Newell and Simon, 1972).

Since then, a variety of paradigms of human behaviour have been developed (Rouse, 1980; Rasmussen, 1983; Stassen, et al., 1990; Sheridan, 1992; Wickens, 1984 & 2002) which aim to cover different levels of complexity and depth in representing mental processes, cognitive functions as well as behavioural performances. These models vary quite substantially for many reasons. Certain models focus on a specific domain of application. Other models pay attention primarily to cognitive functions, such as decision making or diagnostic processes. Certain models concentrate on the role of operators and their interactions, such as supervisory control process and teamwork.

This variety of models offers the analysts and designers of joint cognitive systems the possibility to choose the most suitable approach and paradigm to apply for specific applications. However, in order to make the best selection in relation to the problem at hand, the scope of application of the available methods and models must be recognized. The existence of conceptual frameworks that enable to identify boundaries and areas of consideration for modelling human behaviour is discussed in detail in previous Deliverables

of this AIDE Project where several modelling architectures have been reviewed and compared (AIDE Deliverables 1.1.1a and 1.1.1b).

This overall picture is further complicated by the massive presence in modern vehicles of Advanced Driver Support Systems (ADAS) and In-Vehicle Information Systems (IVIS), which add another level of complexity. For all these reasons, the development of a model of driver behaviour is a very complex and difficult endeavour. However, the implementation of a model and associated simulation is a necessary step forward for the improvement of the effectiveness of all new means and systems that are designed and implemented in modern vehicles.

The models of drivers and operators in general can be utilised for many different purposes. The goals of the users of models are the means for selecting amongst the variety of proposed paradigms that can be found in the literature. The key for choosing is therefore a set of criteria on which to compare the different paradigms and approaches. One way to compare is to consider models ability to describe performance or to evaluate motivational aspects. Another assessment perspective is the capability to account for actual performances vs. risk taking and perception. A very important way to compare models is to consider their ability to describe the dynamic interaction and predictive power vs. their capability to describe real time behaviour in a realistic a coherent way.

In general, it is not possible to identify an architecture or a structure that is the best in absolute, unless the generality of the approach is so wide that it loses sight of potential applications. What is instead very important is that the users of models have a clear picture of the goals and objectives of the applications, so as to select in the range of paradigms the one that best suits their aims (AIDE Deliverables D 1.1.2; D 1.1.3; Carsten, 2005).

In this Deliverable, we focus on the development of a model and associated simulation with the primary objective to be a predictive tool for studying possible Driver-Vehicle-Environment (DVE) interactions dedicated to design and safety analyses. Such type of tool is normally associated and compared with real time applications that can be utilised on board of vehicles, as they are usually integrated and streamlined version of the former model. This is considered an evolutionary process that firstly realises a tool that is able to reproduce reasonable and verified behaviours for design studies. These simulations are very useful for predicting behaviour and DVE interactions that enable the designer and safety analysts to evaluate potential applications, drawbacks and advantages of new systems and design solutions, without spending too much time and effort in performing field tests on expensive prototypes and lengthy experiments. With a valuable model and simulation, it is possible to assess potential errors and mishaps derived from various aspects of a new tool, such as type of interface, location on board, effects on driver attitudes and behaviour with respect to other systems, etc. Once such a simulation is tested and validated, it is then very possible that a simplified or streamlined version is developed that can be utilised on board of vehicles for anticipating behaviour and avoiding errors or improving information management by on-board communication tools.

The simulation described in this paper concentrates on the first part of such a development. It aims therefore at predicting DVE interactions in a sufficiently accurate fashion to be utilised by designers and safety analysts for studies and preliminary evaluations of human-machine interactions. The evolution of this approach into a real time tool is a natural follow up of the development, but is not discussed here.

In this Deliverable we will primarily describe the modelling architecture from the simulation perspective. We will concentrate on the algorithms that have been selected to represent the Driver behaviour in a form that can be implemented in a computerised expression. Secondly, we will describe the different numerical formalisms and the mathematical expressions utilised for simulating the dynamic interactions with the Vehicle and Environment. We will then present a series of sample cases of predictive interactions between drivers, vehicles and environments that can be used for design and safety assessment purposes. Finally, we will conclude with some speculative consideration of the possible extension of this simulation in a streamlined version that may be considered for real time representation of driver behaviour for implementation in-vehicle systems.

1.1 Paradigm of reference of Driver Behaviour

The development of a model/simulation of DVE system is driven by the model of the Driver, which is the most complex element of the system. In previous AIDE Deliverables (D1.1.1a, D1.1.1b, D1.1.2 and D1.1.3) the general criteria for developing a generic paradigm of reference have been discussed in detail.

In this Deliverable the final formulation of the model that will be applied to generate a computerised simulation is discussed in detail. The criteria for selection of the paradigm of reference for the development of this simulation of driver behaviour have been the following:

1. The model must make possible the performance of a variety of rapid assessments of DVE interactions with different configurations, so as to evaluate prototypes of different conceptual nature.
2. The dynamic interactions between driver, vehicle and environment needs to be included in the simulation. The vehicle and environment should offer dynamic changing situations and interactivity with driver actions.
3. Cognitive aspects of behaviour and “joint modelling” between humans and vehicle-environment must be considered.
4. The model needs to account for behavioural adaptation to different types of Advanced Driver Assistance Systems and possible emotional/attitudinal aspects.
5. The model should enable to consider possible driver errors, in addition to normative behaviour, in different traffic conditions. Error generation mechanism needs to be included in the model.
6. The overall model and simulation should be developed in such a configuration to facilitate the evolution towards a “real-time” simulation approach of the DVE system.

The first two requirements concentrate on the specific objective of generating a simulation tool for design and safety assessment, which is able to predict driver behaviour and interactions with the vehicle and environment in dynamic conditions.

The following three requirements focus on the model of the driver and, in particular, concentrate on the need to consider cognitive aspects of behaviour, in addition to manifestations and performances, when modelling the integrated DVE system. In addition, adaptive behaviour and emotional and attitudinal aspects are also identified as necessary peculiarities that need to be included in the simulation, as they are essential components of

behaviour. Modelling human error is deemed essential for evaluating mishaps and inadequate performance.

The last requirement is specific to the perspective application of the simulation. Indeed, even if the primary objective lies in the ability to support designers in predictive assessments, it is equally relevant to identify how to adapt a predictive model and simulation of this nature to more direct implementation in vehicles for real time application.

According to these requirements, the simulation should not necessarily “run” faster than real time. However, the ability to perform predictive studies of DVE for safety purposes demands that many simulations are performed with different behavioural characteristics and traffic/vehicle conditions. A balance between these two requirements is therefore needed. Moreover, the consideration for errors and dynamic aspects enhance quite considerably the need to enable the performance of several simulation runs, even for single traffic configurations. Therefore, the overall simulation has to present the basic characteristic of being *predictive, simple and fast running*, accounting for *dynamic interactions, human errors, and adaptive behaviour*.

Amongst the variety of paradigms that enable to describe the DVE interactions, those described in Deliverables D 1.1.1a and b of the AIDE Project cover the vast majority of architectures that have been proposed and are sufficiently developed to represent driver’s interaction in modern automotive systems and traffic contexts. The specific requirements of the simulation discussed here favour the selection of the paradigm described by Carsten (2005) as it offers the possibility to represent a simple DVE interaction, based on a quite normative type of approach to describe “normative” and task oriented behaviour. At the same time it depicts the framework to consider cognitive and adaptive behaviour by means of a limited number of *parameters*, and it offers the possibility to account for *human error* on the basis of these same parameters. The specificity of dynamic interaction is also permitted, even if these aspects are not actually discussed at modelling level. Also the characteristics of real time and fast running are not reviewed, even if they are very relevant features when transforming a paradigm into a running tool, at simulation level.

The simulation that has been developed on the basis of this paradigm has been called “*Simple Simulation of Driver Performance*” (*SSDRIVE*). The specific characteristics of the SSDRIVE will now be briefly described by discussing primarily the way to represent normative behaviour, followed by the description of the algorithm by which to consider cognitive aspects, behavioural adaptation and errors, and finally by considering the dynamic interaction of the SSDRIVE within the overall DVE simulation.

2. DVE modelling

2.1 *Driver Model*

2.1.1 Basic Theoretical formulation

The basic assumption made for the development of the driver model is that the driver is essentially performing a set of actions on the vehicle commands and controls that are known and, in many cases, familiar, according to experience. As the driving process is very dynamic, these actions are continuously selected or developed from the knowledge base of the driver. However, prior to this activity a process of information management and formulation of goals and tasks is necessary.

Consequently, independently of the specific model selected for describing the driver behaviour, the following four steps of cognitive and behavioural interactions must be considered:

- Perception and interpretation of information from Vehicle and Environment;
- Formulation of goals and intentions and selection of tasks to be carried out;
- Performance of actions on control panel and on vehicle commands.

This is a typical formulation of a model based on the paradigm called “Information Processing System” (IPS), which has been applied in almost all fields to account for human interaction with technology at different levels of automation. The important characteristic of this approach is that it allows considering the behavioural as well as the cognitive aspects of human behaviour. This paradigm is the stand of the SS-DRIVE (Simple Simulation of Driver Performance).

The way in which the various cognitive functions of the model are implemented in the simulation is quite simple and straightforward, and depends on two possible types of modelling architecture: the simple and linear *normative driver behaviour* or the complex and more realistic *descriptive driver behaviour*. These two types of simulation are described in detail.

The most suitable model for representing driver behaviour during the performance of normative activities, both at primary and secondary levels, is to apply a simple “Task Analysis” approach. The detail of accuracy of the analysis and description of the tasks that are performed by the driver defines also the *granularity* of the simulation (Michon, 1985).

By carrying out a driving Task Analysis, the performance of a driver can be formalised and structured in a sequence of actions and goals that are carried out during the interaction with the vehicle and environment. Commonly used task analysis techniques such as Hierarchical Task Analysis (HTA) or Time Line Analysis (Kirwan and Ainsworth, 1992) are best suited to tasks that are associated with procedures or routines in industrial environments. Driving is on the other hand not suitable to a description following the principles of a traditional task analysis, but rather requires a method that can cope with the irregularity of the driving situation. Driving can be easily be seen as a set of interconnected and dynamically link set of

goals, where the top goal is getting to the destination, while several series of lower or simpler tasks are associated with local traffic situations. From this, a set of sub-goals and corresponding means can be derived. Consequently, instead of proposing a hierarchical structure of goals and sub-goals, the functional dependencies among goals are analysed and described. From this basis, a goals-means structure can be instantiated for any given situation and set of conditions. Whereas a HTA tend to generate a single, typical task, a Goals-Means analysis produces a description of a set of possible tasks. Therefore, the approach selected for the SS-DRIVE simulation to describe “normative” driver behaviour is based on the rationale that identifies the Goals-Means Task Analysis (GMTA) approach (Hollnagel, 1993).

In order to represent the set of Tasks that are carried during driving a certain differentiation has been defined according to the complexity associated with the actual activity described by a task. Three basic elements have been identified, namely:

- **Elementary Functions**, which represent the basic activity that can not be further subdivided into simpler components;
- **Elementary Task**, which is a Task made of Elementary functions only; and
- **Complex Task**, which is a Task made of a combination of Elementary Tasks and Elementary Functions

The first step to perform is to define the correlations between what has been called “Task” and individual Elementary Functions. Table 1 contains some possible sets of *Elementary Functions* that can be accounted for in order to describe the basic actions of a driver. These *Elementary Functions* have been grouped according to their type and the area of activity involved. As an example, all *Elementary Functions* associated with perception, either visual, aural or haptic, are grouped under the ”type”: Receive Perceptual Input. The only detailed process that remains to be performed is the association of each Tasks and Elementary Functions with a detailed Task Analysis, which will results in the definition of the exact actions and results of each task.

ELEMENTARY FUNCTIONS	
Receive Perceptual Input	<ul style="list-style-type: none"> • <i>Perceive phone ringing</i> • <i>Perceive warnings</i> • <i>Perceive indicators</i> • <i>Perceive traffic</i> • <i>Perceive incoming traffic</i> • <i>Perceive congestion</i> • ..
Elementary checking actions (primary task - vehicle controls)	<ul style="list-style-type: none"> • <i>Check mirrors</i> • <i>Check speedometer</i> • <i>Check road signals</i> • <i>Check traffic light</i> • <i>Check signals for direction</i> • <i>Scan road side</i> • <i>Scan road forward</i> • <i>Scan road backwards</i> •
Elementary control actions (primary task - vehicle controls)	<ul style="list-style-type: none"> • <i>Accelerate</i> • <i>Brake</i> • <i>Steer</i> • <i>Change gear</i> • <i>Set indicator (right/left)</i> •
Elementary control actions (primary task - vehicle ADAS)	<ul style="list-style-type: none"> • <i>ACC:</i> <ul style="list-style-type: none"> ✓ <i>Headway</i> ✓ <i>Check distance to lead vehicle</i> ✓ <i>Check ACC is enabled</i> ✓ <i>Select speed</i> • <i>FCW:</i> <ul style="list-style-type: none"> ✓ <i>ON/OFF</i> ✓ <i>Check FCW is enabled</i> ✓ <i>Check distance and relative speed to lead vehicle</i> ✓ <i>Select information to provide</i> ✓ • <i>LDW:</i> <ul style="list-style-type: none"> ✓ <i>ON/OFF</i> ✓ <i>Check LDW is enabled</i> ✓ <i>Check distance to the lane and compute Time to Lane Crossing (TLC)</i> ✓ <i>Select information to provide</i> ✓

<p>ELEMENTARY FUNCTIONS</p>	
<p>Elementary actions (secondary task - IVIS controls)</p>	<ul style="list-style-type: none"> • <i>Make Phone Call:</i> <ul style="list-style-type: none"> ✓ <i>Select phone</i> ✓ <i>Enter phone numb.</i> ✓ <i>Check number</i> ✓ <i>Perform conversation</i> ✓ <i>Hang up</i> • <i>Receive phone call:</i> <ul style="list-style-type: none"> ✓ <i>Select phone</i> ✓ <i>Perform conversation</i> ✓ <i>Hang up</i> • <i>Make Selection on Navigator</i> • <i>Adjust Navigator data</i> • <i>Radio:</i> <ul style="list-style-type: none"> ✓ <i>Select radio</i> ✓ <i>Change volume</i> ✓ <i>Select programme</i>

Table 1- Elementary functions

At present all the following Tasks are contained in the simulation: *Attain higher speed, Attain lower speed, Stop vehicle, Reverse vehicle, Turn left, Turn right, Change lane, Pass Vehicle, Overtake, Keep lateral safety margins, Keep longitudinal safety margins, Maintain speed, Give way at intersection, Emergency manoeuvre*. In the SS-DRIVE all these tasks are described in detail and fully simulated according to the logic and dynamic sequence described below (Table 2).

Goal/Task ^{1,2}	Task/Elementary Functions involved	Pre-conditions
Attain higher speed <i>(Complex Task)</i> <u>Goal/Post-condition:</u> Reach the selected speed	<ol style="list-style-type: none"> 1. <i>Accelerate</i> 2. <i>Check speedometer</i> 3. Maintain speed 	<u>Pre-conditions:</u> <ol style="list-style-type: none"> 1. Check all Preconditions of <i>Elementary Tasks</i> 2. No ahead vehicle with lower speed Maintain Longitudinal Safety margin
Attain lower speed <i>(Complex Task)</i> <u>Goal/Post-condition:</u> Reach the selected speed	<ol style="list-style-type: none"> 1. <i>Brake or slow down</i> 2. <i>(Change gear)</i> 3. <i>Check speedometer</i> 4. Maintain speed 	<u>Pre-conditions:</u> <ol style="list-style-type: none"> 1. Check all Preconditions of <i>Elementary Tasks</i> 2. Ahead vehicle with lower speed 3. Presence of give way signals
Stop vehicle <i>(Elementary Task)</i> <u>Goal/Post-condition:</u> Vehicle speed equal to zero	<ol style="list-style-type: none"> 1. <i>Brake</i> 2. <i>Change gear</i> 	<ol style="list-style-type: none"> 1. Presence of Red traffic light or 2. Presence of an obstacle on the carriageway 3. Car incoming from the main road
Reverse vehicle <i>(Complex Task)</i> <u>Goal/Post-condition:</u> Vehicle turned 180	<ol style="list-style-type: none"> 1. <i>Check mirror</i> 2. <i>Scan road backward</i> 3. <i>Change gear (reverse)</i> 4. <i>(Steer)</i> 5. <i>Accelerate</i> 6. Stop Vehicle 	<u>Pre-conditions:</u> <ol style="list-style-type: none"> 1. Check all Preconditions of <i>Elementary Tasks</i> 2. Reverse vehicle allowed
Turn left <i>(Complex Task)</i> <u>Goal/Post-condition:</u> Being on the Left Road	<ol style="list-style-type: none"> 1. <i>Set indicator left</i> 2. Attain lower/higher speed 3. (Stop vehicle) 4. (Give way at intersection) 5. <i>Scan road forward</i> 6. <i>Check mirror</i> 7. <i>Steer</i> 8. <i>Attain Higher speed</i> 	<u>Pre-conditions:</u> <ol style="list-style-type: none"> 1. Check all Preconditions of <i>Elementary Tasks</i> 2. Turn left allowed 3. No incoming vehicle on the other land

¹ Formalism:
Italic = Elementary Function
Bold = Task

Parenthesis = Conditional activity (function/task)

² Definitions:

Elementary Task = Task made of Elementary functions only

Complex Task = Task made of a combination of Elementary Tasks and Elementary Functions

Goal/Task ^{3,4}	Task/Elementary Functions involved	Pre-conditions
<p>Turn right (Complex Task)</p> <p><u>Goal/Post-condition:</u> Being on the right road</p>	<ol style="list-style-type: none"> 1. <i>Set indicator right</i> 2. Attain lower/higher speed 3. <i>Check mirror</i> 4. <i>Scan road side</i> 5. <i>Steer</i> 6. <i>Attain Higher speed</i> 	<p><u>Pre-conditions:</u></p> <ol style="list-style-type: none"> 1. Check all Preconditions of <i>Elementary Tasks</i> 2. Being on the right side of the road 3. Turn right allowed
<p>Change lane: (Elementary Task)</p> <p><u>Goal/Post-condition:</u> Being on other lane</p>	<ol style="list-style-type: none"> 1. <i>Check road signal</i> 2. <i>Check mirror</i> 3. <i>Scan road side</i> 4. <i>Scan road forward/backwards</i> 5. <i>Set indicator (right/left)</i> 6. <i>Steer</i> 	<p><u>Pre-conditions:</u></p> <ol style="list-style-type: none"> 1. Lane free 2. No incoming vehicle with higher speed 3. Change lane allowed 4. Visibility
<p>Pass Vehicle (Complex Task)</p> <p><u>Goal/Post-condition:</u> Being head of vehicle in front</p>	<ol style="list-style-type: none"> 1. <i>Verify Speed difference (speedometer, relative speed with other vehicle., side mirror)</i> 2. (Attain Higher Speed) 3. Keep lateral safety margins 	<p><u>Pre-conditions:</u></p> <ol style="list-style-type: none"> 4. Check all Preconditions of <i>Elementary Tasks</i> 5. Δv sufficient 6. Lane free
<p>Overtake: (Complex Task)</p> <p><u>Goal/Post-condition:</u> Being head of vehicle in front and (being) in the same lane</p>	<ol style="list-style-type: none"> 1. Change lane 2. Pass vehicle 3. Change lane 	<p><u>Pre-conditions:</u></p> <ol style="list-style-type: none"> 1. Check all Preconditions of <i>Elementary Tasks</i> 2. <i>Ahead presence of a vehicle with lower speed</i>

³ Formalism:
Italic = Elementary Function
Bold = Task
Parenthesis = Conditional activity (function/task)

⁴ Definitions:
Elementary Task = Task made of Elementary functions only
Complex Task = Task made of a combination of Elementary Tasks and Elementary Functions

Goal/Task ^{5,6}	Task/Elementary Functions involved	Pre-conditions
Keep lateral safety margins <i>(Elementary Task)</i> <u>Goal/Post-condition:</u> Maintain safe distance from left and right side of the road	<ol style="list-style-type: none"> 1. <i>Scan road side</i> 2. <i>(Steer)</i> 	AUTOMATIC task
Keep longitudinal safety margins <i>(Complex Task)</i> <u>Goal/Post-condition:</u> Maintain safe distance from leading vehicle	<ol style="list-style-type: none"> 1. <i>Scan road forward</i> 2. <i>Check speedometer</i> 3. (Attain lower speed - brake) 	AUTOMATIC task
Maintain speed <i>(Elementary Task)</i> <u>Goal/Post-condition:</u> Have the previous time-step speed	<ol style="list-style-type: none"> 1. <i>(Accelerate/ Brake)</i> 	<ol style="list-style-type: none"> 1. No ahead vehicle with lower speed or obstacle on road 2. No red/yellow traffic light 3. No speed limitations signals 4. No give way at intersection
Give way at intersection <i>(Complex Task)</i> <u>Goal/Post-condition:</u> Let the incoming car pass	<ol style="list-style-type: none"> 1. Attain lower speed 2. <i>Check road signals</i> 3. <i>Set indicator</i> 4. <i>Scan road side/Scan road forward</i> 5. (Stop – Attain higher speed) 	<u>Pre-conditions:</u> <ol style="list-style-type: none"> 1. <i>Check all Preconditions of Elementary Tasks</i> 2. Being on a intersection with the “give way” signal
Emergency manoeuvre <i>(Elementary Task)</i> <u>Goal/Post-condition:</u> Avoid obstacle	<ol style="list-style-type: none"> 1. <i>(Brake / Steer)</i> 	<ol style="list-style-type: none"> 1. Obstacle on road ahead 2. Incoming vehicle

Table 2- Goals and Tasks of SSDRIVE

⁵ Formalism:
Italic = Elementary Function
Bold = Task
Parenthesis = Conditional activity (function/task)

⁶ Definitions:
Elementary Task = Task made of Elementary functions only
Complex Task = Task made of a combination of Elementary Tasks and Elementary Functions

2.1.2 Dynamic Logical Simulation of Tasks

Each Task is represented in the simulation as a “Frame” (Minsky, 1975), which is associated with attributes or *pre-condition*, that enable the frame to be initiated, and *post-conditions*, that are applied for “closing” the frame.

The Tasks, or Frames, are simulated implementing the associated procedure and sequence of elementary tasks/functions by means of sequences of rules and actions described through Object Oriented Programming (OOP) (D1.3.1), or similar programming languages. Attributes (pre and post conditions) are correlated according to rules and entity-attribute matrices.

The logical dynamic sequence of tasks is defined according to a hierarchy between frames derived from the satisfaction of the pre-conditions, and a simple model of cost associated to the maximum speed allowed on the specific road and traffic conditions.

Another fundamental characteristic of the SS-DRIVE simulation is the consideration for the permanent or *automatic tasks*. These tasks are identified by the fact that they are permanently carried out during a DVE interaction and do not require specific pre-conditions to be launched. These are stereotypes of what may be called “skill-based behaviour” in a very “classical” modelling architecture based on a Skill-Rule-Knowledge type behaviour that has been the most known implementation of the Information Processing Paradigm proposed in the early 80s for describing human behaviour (Rasmussen, 1983). Two tasks are considered permanent in the present simulation approach, namely: *Keep lateral safety margins*, *Keep longitudinal safety margins*.

The concept of permanent tasks is quite straightforward, as it is associated with the fact that drivers “normally” keep with no specific effort and cognitive demand the vehicle within lane margins and do not hit vehicles or obstacles in front. Consequently, these two tasks are permanently active in the DVE loop and are always performed every time the driver simulation is activated. This simulation requirement, associated with the fact that there is no cognitive load in performing these “simple vehicle control” tasks, in normal conditions, has generated the choice of a classical (optimal) control modelling approach (Weir and Chao, 2005) for their simulation in the DVE loop.

In practice every time the driver simulation is activated in the DVE loop, the permanent tasks are performed first, unless an accident or human error is underway. They aim at keeping the vehicle under control with respect to longitudinal and lateral coordinated of the driving environment (road and traffic) (Figure 1).

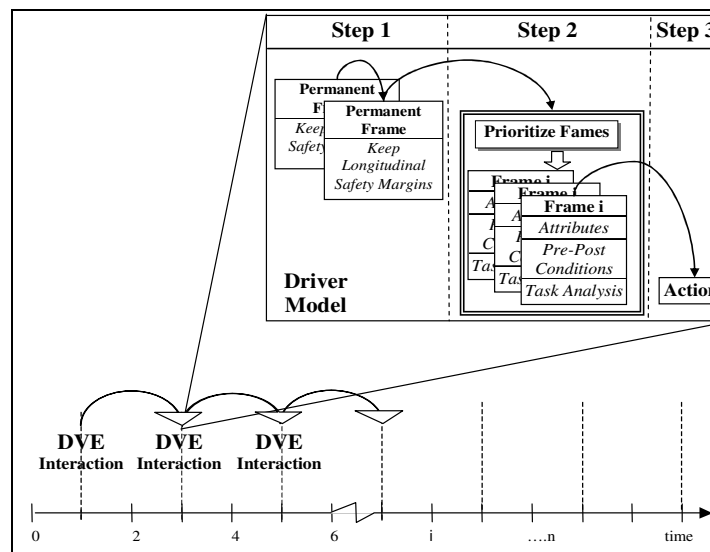


Figure 1-Dynamic-Logical Task sequence

2.1.3 Normative driver behaviour

In *normal conditions*, i.e., when the driver has a very low or zero level of impairment and no behavioural adaptation occur, the simulation covers what may be called *normative driver behaviour*. This is a merely theoretical condition which is not reflected in realistic behaviours. However, from the simulation point of view it is necessary that these formal aspects of driver behaviour are represented and stored in the overall simulation tool.

The following sequence of steps is performed (Figure 2):

1. All signals and signs that are produced inside and outside the vehicle are perceived.
2. Interpretation is conform with the meaning associated with signs and signals.
3. Intentions are formulated in relation to the ongoing task and the information perceived and interpreted. A task is then either continued or newly started.
4. Actions are carried out according to the “active” task.

The key step in normative behaviour is the process of formulation of intentions. In the simulation a very simple approach has been selected that is based on cost/benefit rule for prioritizing tasks. The rule implies that the driver minimizes cognitive efforts and time for reaching indented location by applying the following principles:

1. Assess whether *permanent tasks* require a change of task or function (conditional activity).
 - a. In the case of conditional activity, then adapt to demands of permanent task.
 - b. Otherwise continue the process.
2. The ongoing task is terminated before starting a new task.
3. Tasks are started only when and if all pre-conditions are satisfied.
4. Speed is kept at maximum allowed by road signals and traffic.

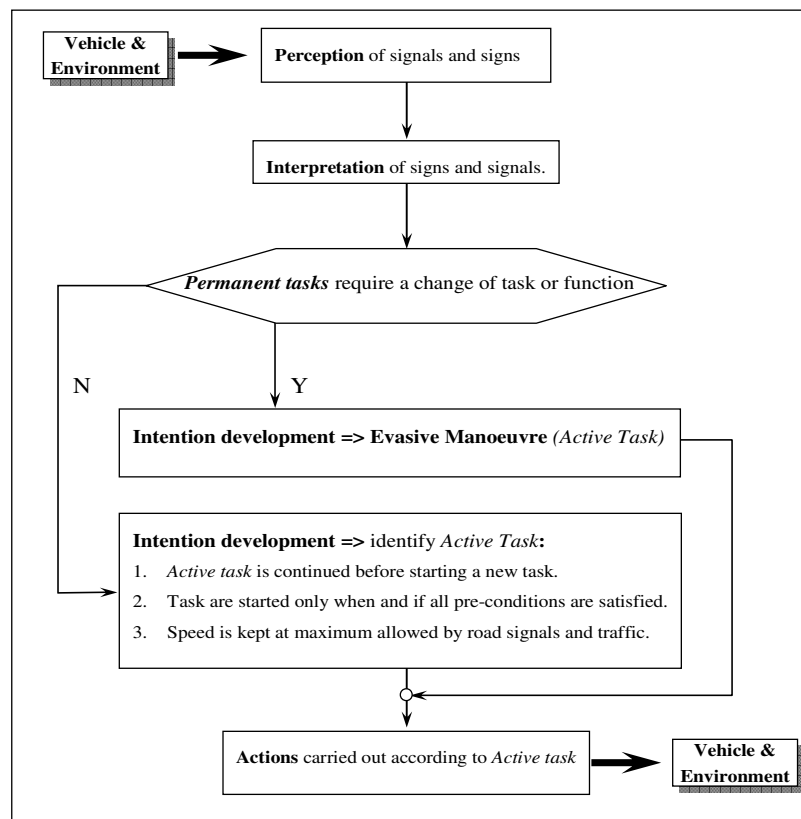


Figure 2-Flowchart of the simulation of *Normative driver behaviour*.

2.1.4 Descriptive driver behaviour - Main Parameters and Variables

In *non-normal conditions*, i.e., when the level of impairment is such that an “error” may occur, or when behavioural adaptation becomes a relevant factor, then the simulation covers what is called *descriptive driver behaviour*. In this case, the sequence of steps remains unchanged as far as the information processing is concerned. However, before entering the IPS loop, the *parameters* governing adaptation and error must be evaluated. This may lead to modifying any of the cognitive functions and possibly to error making. Task selection and performance is also affected by behavioural adaptation. This type of simulation is much more realistic with respect to actual driver behaviour. However, the level of complexity from the simulation viewpoint is much higher and requires some degree of simplification and linearization.

Descriptive driver behaviour is identified by a number of *parameters* that enable to modify and adapt the way in which cognitive functions are selected, during the phases of perception, interpretation and intention development, and are performed during the execution of actions.

The parameters and variables that affect behaviour are the crucial factors and goals of research of SP 1 WP2 (D1.2.3). Their definition and correlation with the V and E variables will be the object of the field studies and discussion that will continue for the whole project.

After several discussions and iterations between partners of SP 1, the best list of parameters that accounts for previous selections (Deliverable 1.1.1/b), as well as ongoing discussion within SP 3 partners, has been identified as follows (Carsten, 2005):

- *Attitudes/personality*: static parameters associated with each driver.
- *Experience/competence*: static parameters associated with each driver.
- *Task Demand (TD)*: objective dynamic parameter resulting from DVE interaction. When Task Demand is focused only on driving, then *Task Demand = Driving Demand*.
- *Driver State (DS)*: subjective dynamic parameter resulting from DVE interaction.
- *Situation Awareness/Alertness (SA)*: subjective dynamic parameter resulting from DVE interaction.
- *Intentions/goals*: dynamic variables and parameters that are evaluated during the evolution of the Driver model. This parameter will not be further discussed as *Intentions/goals* are essentially derived (or result) from the Driver Model/Task Analysis and thus can not be correlated to other independent variable.

It is important to note here that the parameter *Task Demand* is in most cases equivalent to *Driving Demand*. However, as the objective of the correlations between parameters and behaviour covers all potential aspects affecting driver performance, it is preferable to retain in this parameter also the factors associated with secondary task performance, as well as social and personal characteristics of the driving context.

The definitions of these parameters and other quantities are being integrated throughout the whole AIDE activity by means of the “Glossary” that is being developed as integrating action.

However, it is primarily noticeable that the two static parameters of Attitude/personality and Experience/competence enable the definition of some initial characteristics of behaviour that affect all decision making processes and performances throughout the simulation. On the other side, the dynamic parameters enable to account for the variability of conditions and environmental changes that are encountered during a typical journey. In this sense, both types of parameters are very important and may play a crucial role in the simulation of DVE interactions. Naturally, this implies that the model and associated simulation are sufficiently powerful to incorporate all these types of effects.

The set of variables that govern the dynamic Driver model is directly correlated with the ability of the model to account for the above functions at different levels of depth. The crucial open issues that remain to be resolved with respect to the DVE parameters are of three types:

1. *Correlation of parameters with respect to measurable variables*. This involves two aspects:
 - Which are the actual measurable variables that affect the *parameters*; and
 - How these variables influence the change of value of the *parameters*.
2. *Intentions/goals*: The dynamic process of decision making and interaction with the Vehicle-Environment is regulated by the development of intentions, such as for example “intention to overtake a vehicle in front”, “increase speed” etc.

3. *Correlation of parameters with respect to driver behaviour.* How the parameters combine in affecting driver behaviour and/or performance.

The forms that these functions may take are numerical or logical expressions. In the SSDRIVE approach the choice of utilising *Fuzzy* descriptions has been made. Consequently, each variable associated to a parameter is evaluated during the simulation by means of correlations that define fuzzy values reached during the DVE interaction. Subsequently, the estimation of the (fuzzy) value of the parameter requires the application of typical fuzzy rules.

The complete set of fuzzy correlations and fuzzy rules that govern the SSDRIVE simulation is quite complex and requires a considerable effort of data input and data definition. This is not surprising as the actual combinations of variables, parameters and effects are distributed and can not be oversimplified with the risk of undermining the overall effort of modelling carried out at theoretical level.

The actual formulation of the parameters that govern the model of the driver is obviously critical for the overall DVE modelling. For this reason, the implementation of the correlations linking all static and dynamic *parameters*, i.e., *EXP*, *ATT*, *DS*, *TD*, and *SA*, and *measurable variables* is kept wide open in the simulation approach of SSDRIVE. This means that the users have two main options:

1. To utilise the set of *default correlations*, i.e., those that are described in this paper, and adapt simply their boundary conditions and limits by input data. This alternative is obviously quiet easy and simple.
2. To apply a set of *specific correlations*, by developing appropriate programming routines that will then be interfaced with the main SSDRIVE simulation. This makes the input process more complicated and time consuming. However, in this way, the flexibility of the overall simulation is widely improved and makes possible to test different formulations and combinations of (fuzzy) functions and rules that combine parameters and variables.

In practice, the five *parameters* that govern the SSDRIVE are fixed. A set of default correlations between parameters and measurable variables is available. These require in input only the limits for each independent measurable variable to structure the fuzzy correlations. On the other side, if the user of the simulations intends to study and apply new functions and rules, then the input requires the definition of new independent variables, to be selected amongst those calculated by the three modules of the DVE simulation, and the formulation and programming new correlations that replace the default ones. This is a very flexible aspect of the simulation that requires however programming ability and knowledge of the simulation software details.

2.1.5 Parameters and measurable variables

The identification of the way in which the parameters that affect driver behaviour can be measured is the next issue that needs to be resolved in order to progress with the development of a simulation. This issue involves two aspects, as stated above: the definition of which variables are associated to each parameter and how such variables affect parameters.

The problem of interest in the case of the development of a simulation is instead the numerical or analytical expressions that are applied for the evaluation of the parameters on the

basis of the calculated variables from the dynamic simulations of the vehicle of the environment and also from the driver itself. For this reason, the initial values associated to the *Attitude/personality* and *Experience/competence* are not discuss any further as they do not change over time and intervene, together with the dynamic parameters, on the definition of driver decision making and behavioural aspects, as it will be discussed in next section.

Parameters	Definition	Measurable Variables
EXPERIENCE	The accumulation of knowledge or skills that result from direct participation in the driving activity.	<ol style="list-style-type: none"> 1. No of Km per year. 2. Number of years with driving license
ATTITUDES	A complex mental state involving beliefs and feelings and values and dispositions to act in certain ways. <i>Sensation Seeking</i> and <i>Locus of Control</i> have been identified as personality based predictors of accident involvement.	<ol style="list-style-type: none"> 1. Speed 2. Lane keeping 3. Overtaking 4. Headway
TASK DEMAND	The demands of the process of achieving a specific and measurable goal using a prescribed method. When Task Demand is focused only on driving, then <i>Task Demand = Driving Demand</i>	<ol style="list-style-type: none"> 1. Traffic complexity 2. Weather 3. Light 4. Speed 5. Driving direction
DRIVER STATE	Driver physical and mental ability to drive (fatigue, sleepiness...). A set of dynamic parameters representing aspects of the driver relevant for the human-machine interaction.	<ol style="list-style-type: none"> 1. Lane keeping; Headway control 2. Duration of driving; time-on-task 3. Weather, Road conditions 4. Traffic complexity 5. Speed
SITUATION AWARENESS	Perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.	<ol style="list-style-type: none"> 1. Distraction 2. Driver State 3. Task Demand

Table 3-Identified correlations between parameters and measurable or observable variables of the DVE evolution

Focusing on the possible forms of correlations between parameters and variables, the most generic representation that can be formulated according to the quantities identified in Table 3 are:

Sit. Awareness $SA = f_1(\text{Driver State, Distraction, Task Demand etc.})$

Driver State $DS = f_2(\text{Lane Keeping, Duration of Drive, Weather, Road Conditions, etc.})$

Task Demand: $TD = f_3(\text{Traffic Complexity, Weather, etc.})$

Task Demand

A simple example of these types of correlations is shown in Figure 3, with respect to the evaluation of *Task Demand*:

1. *Task Demand (TD)* is assumed to be a fuzzy function with values *High*, *Acceptable*, and *Low*, and is correlated only to visible level of traffic and environment (*Visibility*), and to the number of vehicles present on the road (*Complexity of traffic, CoT*):
 - $TD = f(\text{Visibility}, \text{CoT})$
2. *Visibility* is measured in terms of distance and is considered:
 - *Good* when the driver can see at a distance of more than 100 meters;
 - *Acceptable* for distances of clear vision between 70 and 100 meters; and
 - *Bad* for less than 70 meters of clear vision.
3. *Complexity of traffic (CoT)*, is measured in terms of vehicles per kilometre on the road:
 - *Good* when the density of vehicles is less than 100 per kilometre;
 - *Acceptable* when the density of vehicles is between 100 and 250 per kilometer; and
 - *Bad* when the density of vehicles is greater than 250 per kilometre.
4. The fuzzy rule applied to calculate the fuzzy value of *Task Demand* is:
 - $TD = \text{High}$ if $\min(\text{Visibility}, \text{CoT}) = \text{Bad}$
 - $TD = \text{Medium}$ if $\min(\text{Visibility}, \text{CoT}) = \text{Acceptable}$
 - $TD = \text{Low}$ if $\min(\text{Visibility}, \text{CoT}) = \text{Good}$

This means that the less favorable value is associated with TD between the two fuzzy values of *Visibility* and *Complexity of traffic*.

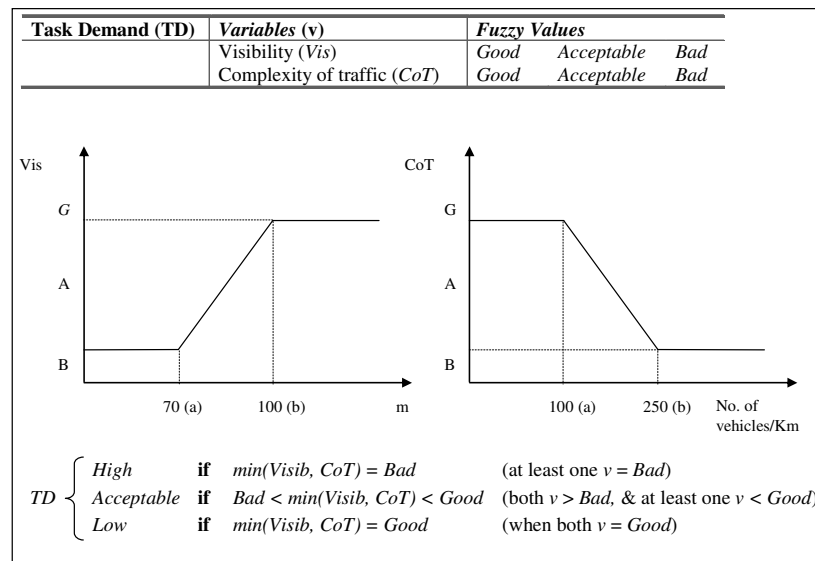


Figure 3-Example of fuzzy correlations and fuzzy rule between Task Demand vs Complexity of traffic and Weather Conditions (Visibility).

Driver State

The default fuzzy correlations and rule for the evaluation of *Driver State* are shown in Figure 4.

- Driver State (DS)* is assumed to be a fuzzy function with values *Bad*, *Acceptable*, and *Good*, and is correlated simply to the time dedicated to driving (*Duration of Driving, DoD*), and to the *Speed change* ($|\Delta \text{Speed}|$) and *Steering* ($|\Delta \varphi|$), over a period of driving of 10 minutes:
 - $DS = f(\text{DoD}, |\Delta \text{Speed}|, |\Delta \varphi|)$
- Duration of Driving (DoD)* is measured in terms of overall driving time, and is considered:
 - Low*, when the driver has been driving for less than 60 minutes;
 - Acceptable*, for a driving time between 60 and 180 minutes; and
 - High*, for more than 180 minutes of driving time.
- Variation of steering ($|\Delta \varphi|$) is associated to the road geometry, and not to the yaw disturbance. Variation of speed ($|\Delta \text{Speed}|$) is associated to the traffic conditions and road type/geometry. Therefore, it is assumed that in the case of roads with constant geometry (straight roads or small bends and curves, e.g., highways) very little change of steering and speed occurs. These are causes of possible drowsiness in drivers. Changing either of them, over a period of 10 minutes, is considered sufficient to retain an acceptable level of vigilance. They are therefore combined in defining a fuzzy measure of Driver State. The fuzzy correlations for the variation of speed and steering (for a period of driving $\Delta t = 10 \text{ minutes}$) are as follows:
 - Low*, when $|\Delta \text{Speed}| < 10 \text{ Km/h}$; or $|\Delta \varphi| < 5^\circ$;
 - Medium/Acceptable*, when $10 \leq |\Delta \text{Speed}| \leq 30 \text{ Km/h}$; or $5^\circ \leq |\Delta \varphi| \leq 30^\circ$;
 - High*, when $|\Delta \text{Speed}| > 30 \text{ Km/h}$; or $|\Delta \varphi| > 30^\circ$.

4. The fuzzy rule applied to calculate the fuzzy value of *Driver State* is:

$$\begin{cases}
 \bullet DS = \textit{Bad} \\
 \bullet DS = \textit{Acceptable} \\
 \bullet DS = \textit{Good}
 \end{cases}
 \left. \begin{array}{l}
 \text{if} \\
 \text{if} \\
 \text{if}
 \end{array} \right\}
 \text{Min} [\text{Max} (| \Delta \textit{Speed} | , | \Delta \varphi |), \overline{\textit{DoD}}]
 \begin{array}{l}
 = \textit{Low} \\
 = \textit{Acceptable} \\
 = \textit{High}
 \end{array}$$

This means that the less favourable value is associated with DS between the fuzzy values of *Duration of Driving* and the combination of *Speed change* and *Steering*.

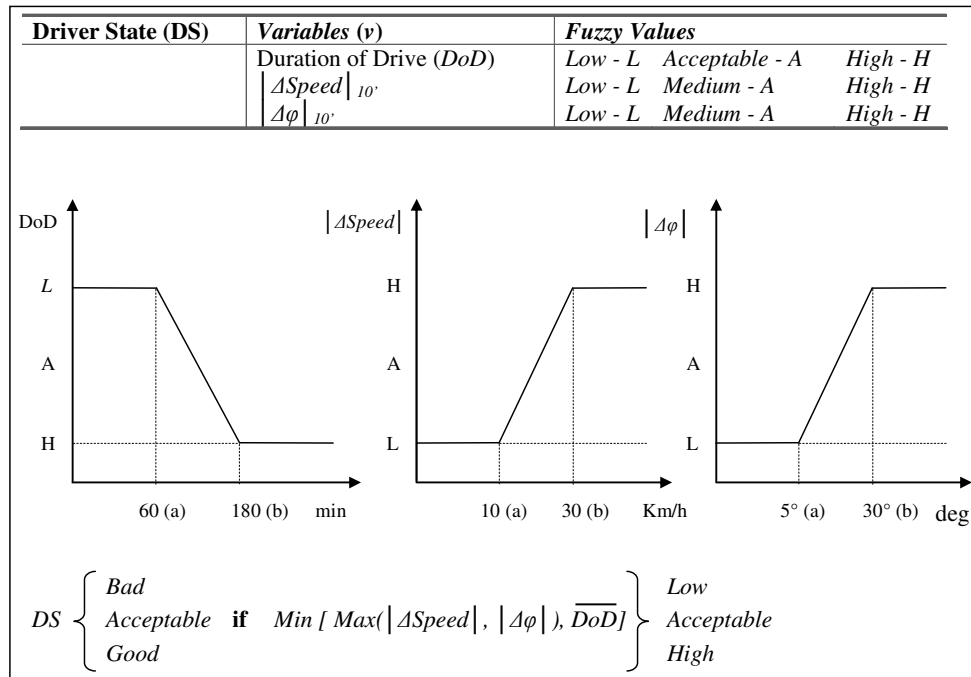


Figure 4-Example of fuzzy correlations and fuzzy rule between *Driver State* vs. *Duration of Drive*, *Speed change* and *Steering*.

Situation Awareness

Finally, an example of correlations is shown in Figure 5 for the evaluation of *Situation Awareness*:

1. *Situation Awareness (SA)* is assumed to be a fuzzy function with values *Bad*, *Acceptable*, and *Good*, and is correlated to *Task Demand (TD)*, *Driver State (DS)*, and to driver *Distraction (Dis)*:
 - $SA = f(TD, DS, Dis)$
2. *Task Demand (TD)* and, *Driver State (DS)* are measured according to the two fuzzy rules and functions described above.
3. *Distraction (Dis)* is a fuzzy rule, associated to two fuzzy functions, i.e., number of vehicles per kilometer on the road (v_1) and number of active indicators and IVIS (v_2), where:

- $Dis(v_1)$: *High* when $v_1 < 50$, or $v_1 > 250$;
Medium, when $50 \leq v_1 \leq 100$, and $200 \leq v_1 \leq 250$; and
Low, when $100 < v_1 < 250$.
- $Dis(v_2)$: *High* when $v_2 > 5$;
Medium, when $3 \leq v_2 \leq 5$; and
Low, when $3 < v_2$.

Then the fuzzy rules imposes that the less favourable value is associated with Distraction between the two fuzzy values of number of vehicles per kilometer on the road (v_1) and number of active indicators and IVIS (v_2).

4. The fuzzy rules that combine SA the each variable TD , DS and Dis are:

- $f_1(TD) = SA(TD)$
 $SA(TD) = Bad$ if $TD = Low$
 $SA(TD) = Good$ if $TD = Medium$
 $SA(TD) = Bad$ if $TD = High$
- $f_2(DS) = SA(DS)$
 $SA(DS) = Bad$ if $DS = Bad$
 $SA(DS) = Acceptable$ if $DS = Acceptable$
 $SA(DS) = Good$ if $DS = Good$.
- $f_3(Dis) = SA(Dis)$
 $SA(Dis) = Bad$ if $Dis = High$
 $SA(Dis) = Acceptable$ if $Dis = Medium$
 $SA(Dis) = Good$ if $Dis = Low$

5. Finally, SA is evaluated according to the following fuzzy rule:

- $SA = Bad$ if $\min [f_1(TD), f_2(DS), f_3(Dis)] = Bad$
- $SA = Acceptable$ if $\min [f_1(TD), f_2(DS), f_3(Dis)] = Acceptable$
- $SA = Good$ if $\min [f_1(TD), f_2(DS), f_3(Dis)] = Good$

This means that the less favourable value is associated with DS between the three fuzzy values of *Task Demand*, *Driver State*, and *Distraction*.

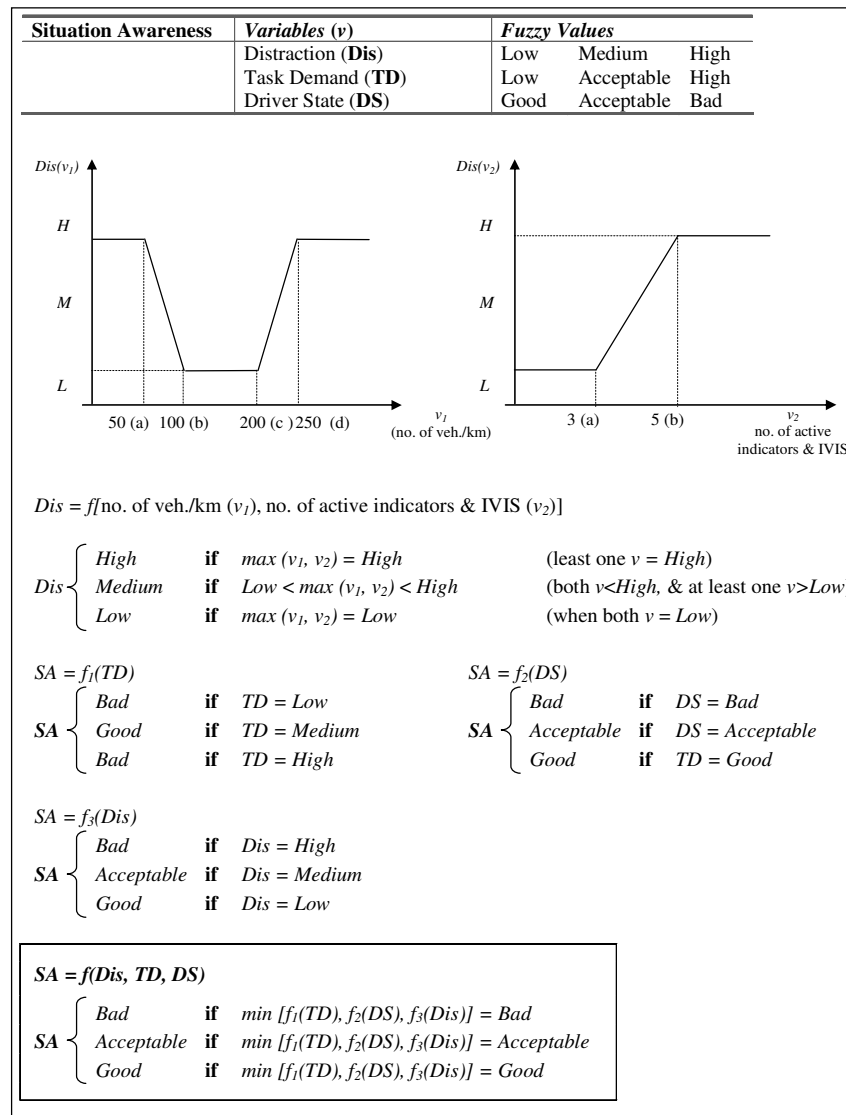


Figure 5-Example of fuzzy correlations and fuzzy rule between Situation Awareness vs. Driver State, Task Demand, and Distraction.

2.1.6 Decision Making and Human Error

The overall simulation dynamics is governed by the time unfolding and generation of intentions and decisions of the driver model. This is another crucial aspect of the model, from the theoretical viewpoint, as it impacts on the validity of the overall approach and is correlated to an enormous amount of research that has been performed and is still developed, in association with humans attitudes, characteristics, personality, individual and social aspects, etc.

The literature on this matter dates many decades and is rich of many different theoretical stands and formulations.

From a simulation perspective, the choice that has been made in the development of SSDRIVE is to keep the maximum flexibility for this part of the simulation, as it has been done in the case of the definition of the *parameters* and *measurable variables*. The user will

retain the possibility to develop sets of programming parts of the SSDRIVE, so as to modify the default settings. These are kept as simple as possible in order to make the development of standard cases relatively easy and fast. As in the case of parameters and measurable variables the development and implementation in the simulation of new algorithms will require a more complex definition of the input and deeper knowledge of the simulation architecture and programming languages.

The set of defaults conditions existing in the simulation are now discussed. These are simple correlations that govern primarily development of *intentions and decision making*, and *error generation*.

Intentions and decision making

The generation of intentions is simulated by means of a very simple correlation that enables the dynamic simulation of tasks and elementary functions and new intentions and goals, as the overall DVE interaction progresses and new traffic conditions are met.

At default level, the correlation that has been chosen is very simple and it is based on the driver assessment of the cost-benefit of the minimum time to reach the objective, i.e., **going from the starting point of the journey to its destination in the minimum allowable time**. In other words, the vehicle is driven at the highest “intended” speed, depending on driver characteristics, traffic and maximum allowed speed. The static parameters of experience and attitude will affect the highest intended speed in a very simple manner. The decision making process based on the two parameters *EXP* and *ATT* would give a constant and thus static value of highest intended speed with respect to the maximum allowed speed.

There is not a direct decision making process concerning the steering angle. In fact, steering angle ($\Delta\phi$) is a direct consequence of the meta-goal that rules all the simulation architecture (Task Analysis and Parameters calculation). In order to satisfy the objective of reaching a destination in the minimum allowable time, the simulator will have to calculate the position of the vehicle and the steering angle in order to avoid any obstacle on the carriageway and, if necessary, to overtake any slower leading car.

In order to introduce a dynamic contribution to this decision making process, two other parameters are introduced in the correlation, namely, *Task Demand (TD)* and *Road condition / geometry*. The overall correlation that is set as default for the intended speed (*Speed_{intended}*) is:

$$Speed_{intended} = \{1 + 0.2 [f(EXP, ATT) + g(TD)] + 0.2 \psi(Road_{cond.})\} * Speed_{max-allowed}$$

The following data and functions apply:

ATT has three possible fuzzy input values: *EXP* has also three possible input data:

- | | |
|---|---|
| 1. <i>ATT</i> = 0, for Low-Risk-Taker, | 1. <i>EXP</i> = 0, for Low-Experience, |
| 2. <i>ATT</i> = 1, for Moderate-Risk-Taker; | 2. <i>EXP</i> = 1, for Moderate-Experience; |
| and | and |
| 3. <i>ATT</i> = 2, for High-Risk-Taker. | 3. <i>EXP</i> = 2, for High-Experience. |

$$f(EXP, ATT) = (ATT - EXP + 1) \quad -1 \leq f \leq 3$$

and

- if $TD = High$ → $g(TD) = -1$
- if $TD = Medium$ → $g(TD) = 0$
- if $TD = Low$ → $g(TD) = 1$

and

- if $Road_{cond} = Bad$ → $\psi(Road_{cond.}) = -1$
- if $Road_{cond} = Acceptable$ → $\psi(Road_{cond.}) = 0$
- if $Road_{cond} = Good$ → $\psi(Road_{cond.}) = 1$

In this way, the intended speed may vary between the two following maximum and minimum values:

$$Max\ Speed_{intended} = 2 * Speed_{max-allowed}$$

and

$$Min\ Speed_{intended} = 0.4 * Speed_{max-allowed}$$

The consequent dynamic unfolding of tasks, such as overtaking of slower vehicles and avoiding obstacles, depends on this simple process of decision making associated with the intention of the driver to select and maintain the intended speed ($Speed_{intended}$), as the limits change along the road.

As discussed earlier, also in this case, the possibility for the user to utilise different and more complex correlations is granted by the specific type of simulation.

Error generation

The last open issue concerns the correlation of the five basic *parameters* with driver behaviour and performance with respect to error generation. As in the previous cases, the user will have the possibility to apply different and complex correlations by exploiting the flexibility of the simulation tool.

At default level, very simple assumptions are made, associated with the dynamic evolution of the DVE interaction. The mechanism that has been devised to describe Driver error and behaviour in relation to the basic parameters has been called Model of Basic Indicators of Driver Operational Navigation (BIDON). To provide a first attempt of evaluation of dynamic change of DVE conditions, it is assumed that the variables affecting the driver behaviour, i.e., the subjective dynamic parameters DS and SA and the objective dynamic parameter TD are represented by “containers” with thresholds/levels, that change from a driver to another and enable to define the overall state/performance-ability of the driver, as the DVE interaction evolves. The static parameters *Experience/competence*, and *Attitudes/personality* are evaluated at the beginning of a simulation and remain constant. They also contribute to the initial “filling” of the “containers” and can therefore be associated to the starting levels of *Situation Awareness* (SA_0), *Driver State* (DS_0) and *Task Demand* (TD_0).

Every time a relevant event happens, the level of both subjective and objective conditions will change, affecting the efficiency and performance of the driver behaviour. This will contribute

to the dynamic process of progressive “filling” or “draining” of the “containers” of the BIDON model.

The error generation mechanism that is implemented in the SSDRIVE is as simple as the other correlations that have been discussed above. The same rule of flexibility applies, whereby the user of the simulation tool is able to make use of more complex error making functions by means of more complicated formulations from input data setting and definition of specific programs that may be interfaced with the main simulation. At default level, the error generation process is essentially associated to a single parameter called, Driver Impairment Level (DIL). The DIL depends essentially on the static and dynamic parameters.

The values of *Experience/competence*, *Attitudes/personality*, *Situation Awareness (SA₀)*, *Driver State (DS₀)* and *Task Demand (TD₀)* are user input. The DIL or error generation mechanism is associated to the following correlations:

$$DIL_t = f(SA_t, DS_t, TD_t, EXP, ATT) \quad 0 \leq DIL \leq 1$$

The following logics and fuzzy correlations are implemented as default:

- An error occurs when $DIL = 1$;
- $DIL = 1$ if
 - ✓ All three dynamic parameters reach their most negative conditions at the same time, i.e., $SA_t = Bad$, $TD_t = High$, $DS_t = Bad$; or
 - ✓ Anyone of the three dynamic parameters reaches and remains at its most negative condition for at least N consecutive minutes (Δt_{DIL}). Δt_{DIL} depends on *age* of the driver and on the parameters *EXP* and *ATT*. The following fuzzy rule applies:

$$\Delta t_{DIL} = N + f(EXP, ATT) + g(AGE)$$

where:

$$N = 4 \quad (\text{default value})$$

$$f \begin{cases} -2 & \text{if } \min(\overline{EXP}, \overline{ATT}) = High \\ 0 & \text{if } Moderate < \min(\overline{EXP}, \overline{ATT}) < High \\ 1 & \text{if } \min(\overline{EXP}, \overline{ATT}) = Low \end{cases}$$

and

$$g \begin{cases} -1 & \text{if } AGE \geq 50 \\ 0.5 & \text{if } 35 < AGE < 50 \\ 0 & \text{if } AGE \leq 35 \end{cases}$$

- In this way, the maximum and minimum time intervals for error making when one of the critical parameters is at its most negative condition are:

$$Max \Delta t_{DIL} = 5 \text{ minutes}$$

$$Min \Delta t_{DIL} = 1 \text{ minute}$$

When an error occurs, then the types and modes of errors are associated with the ongoing activity being carried out by the driver at the time of the error. The types and modes of errors are also defined through the input data system. However, the simulation is able to combine different errors, situations and solutions.

Moreover, the whole variety of potential errors (types and modes) that may occur when the $DIL = 1$ needs to be studied in order to enable the evaluation of the largest variety of DVE dynamic interactions. This concept is described in the example shown in Figure 6, where the first error occurs in step 6 ($SA_{t=6} = Bad$, $DS_{t=6} = Bad$, and $TD_{t=6} = High$). In this case, two possible types/modes of errors have been identified by input data and consequently, three sequences are generated: one with no error; one with the first type/mode of error; and the third one with the second type/mode of error. This generates a very complex spectrum of possible sequences and requires a very accurate analysis tool for screening, the selection of relevant results, and outcome of the simulation.

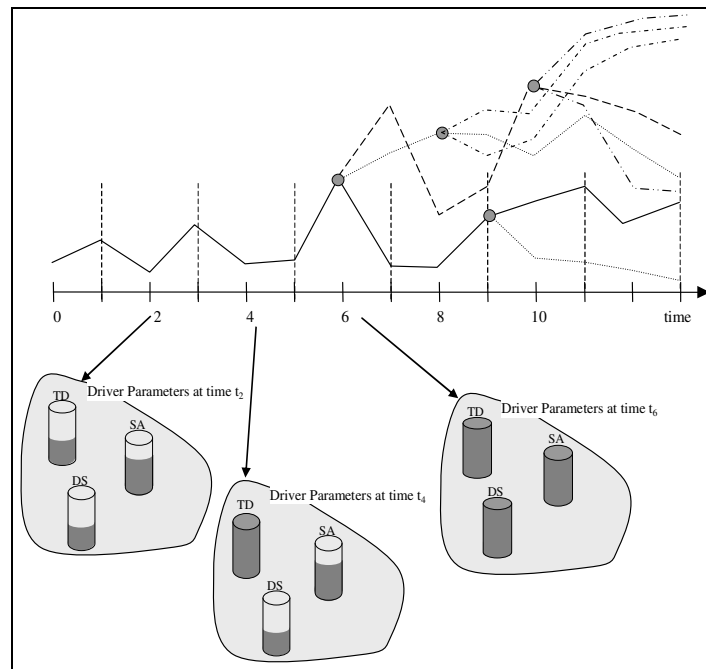


Figure 6-Error Mechanism and dynamic sequences generation

2.2 Vehicle Model

As stated in the previous AIDE Deliverables (D1.1.2 and D1.1.3), a simplified model of vehicle is described, taking into account separately the longitudinal and the lateral task. Hereafter, only the most important details are provided, since already described in the previous deliverables, highlighting also the main parameters and variables used.

2.2.1 Basic Theoretical formulation

The two main sub-models, the longitudinal and lateral ones, are briefly presented hereafter.

The **longitudinal vehicle model** is described by the following equation, derived by the *Newton's Second Law*:

$$m \cdot a_x = F_x - R_x - D_A - F_{brake} - W \cdot \sin \vartheta \quad (1)$$

where, the meaning of variables and parameters is illustrated in the next paragraph.

The Figure 7 below shows the most significant forces acting on a vehicle:

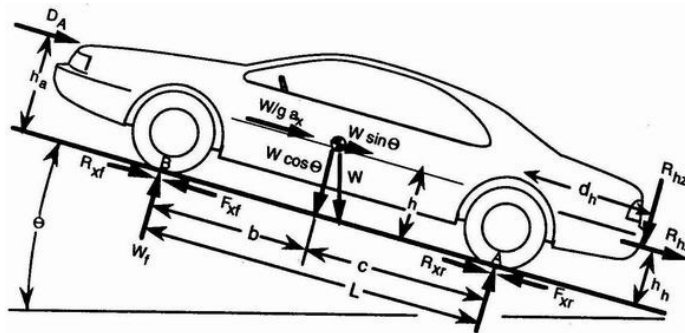


Figure 7-Arbitrary forces acting on a vehicle

The longitudinal motion is given by the contribution of several forces:

- tractive
- rolling resistance
- aerodynamic drag
- braking
- gravity due to slope

Deliverable D1.1.2 describes all terms in equation (1) in details. In the context of this document, only the final equation is presented, putting together the different terms describing each one a type of force; the resulting equation is:

$$\left(m + \frac{(J_m + J_t) \cdot \tau_{pc}^2}{R^2} \right) \cdot a_x = \frac{T_e \cdot \tau_{pc} \cdot \eta_t}{R} - (F_0 + F_2) \cdot v^2 - m \cdot (a_{brake} + g \cdot \sin \vartheta) \quad (2)$$

All in all, equation 2 describes the longitudinal motion of a vehicle of mass m . Again, the meaning of variables and parameters is illustrated in the next paragraph.

Concerning the **lateral vehicle model**, the design of steering control algorithms is based on *two-wheels model*, also named *bicycle model*, which considers the *lateral* and *yaw* dynamics. The motion equation, obtained by equilibrating lateral forces and torque acting on vehicle, are described by the following formula:

$$\begin{bmatrix} \dot{v}_y \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} -\frac{C_f + C_r}{m V} & -\left(\frac{C_f l_f + C_r l_r}{m V} + V\right) \\ \frac{C_f l_f - C_r l_r}{J_z V} & -\frac{C_f l_f^2 + C_r l_r^2}{J_z V} \end{bmatrix} \begin{bmatrix} v_y \\ \psi \end{bmatrix} + \begin{bmatrix} \frac{C_f}{m} \\ \frac{C_f l_f}{J_z} \end{bmatrix} \cdot \frac{\delta_{sw}}{N} \quad (3)$$

Next paragraph details the meaning of each term appearing in the equation.

As detailed in D1.1.2, there is the necessity to a linear model, in order to design linear control algorithms and this has led to get a linear formulation for the vehicle position, based on small yaw angle supposition. The difference, with respect to truth model, has been taken into account as uncertainty model and in order to face up to this discrepancy, a robust control algorithm can be implemented. Combining the vehicle lateral equations and the vehicle position equations, after a linearization process, a single dynamical system has been obtained:

$$\begin{aligned} \dot{x} &= \begin{bmatrix} a_{11} & a_{12} & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & a_{43} & 0 \end{bmatrix} x + \begin{bmatrix} b_{11} \\ b_{21} \\ 0 \\ 0 \end{bmatrix} \cdot \frac{\delta_{sw}}{N} \\ y &= [0 \ 0 \ 0 \ 0 \ 1]x \end{aligned} \quad (4)$$

where:

$$a_{11} = -\frac{C_f + C_r}{m \cdot V} \quad a_{12} = -\frac{C_f \cdot a - C_r \cdot b}{m \cdot V} - V \quad (5)$$

$$a_{21} = -\frac{C_f \cdot a - C_r \cdot b}{J_z \cdot V} \quad a_{22} = -\frac{C_f \cdot a^2 + C_r \cdot b^2}{J_z \cdot V} \quad (6)$$

$$a_{43} = -V \quad b_{11} = \frac{C_f}{m} \quad b_{21} = \frac{C_f \cdot a}{J_z} \quad (7)$$

with the state vector $x = \begin{bmatrix} v_y & \dot{\psi} & \psi & y_G \end{bmatrix}^T$ and output $y = y_G$.

2.2.2 Main Parameters and Variables

In this paragraph all the values of each parameter and constant, presented in the previous section, are summarized and illustrated.

With reference to equations 1, the following parameters and variables are present:

- m = Vehicle Mass
- a_x = Longitudinal acceleration
- F_x = Tractive Force at the ground
- R_x = Rolling resistance forces
- D_A = Aerodynamic drag force
- F_{brake} = Braking force
- W = Vehicle weight ($W = mg$)
- θ = Road slope

Note that the *tractive force* F_x includes engine torque and rotational inertia terms.

About equation 2, the meaning of variables and parameters (not already illustrated) is the following:

- v = vehicle speed
- T_e = engine torque
- τ_{pc} = ratio of transmission
- η_t = efficiency of transmission
- R = tires rolling radius
- J_m = engine moment of inertia
- J_t = transmission moment of inertia
- g = gravity acceleration
- F_0 = coefficient for rolling resistance
- F_2 = coefficient for aerodynamics drag forces

These two last coefficients, F_0 and F_2 , are defined experimentally.

Eventually, for equations (4) ÷ (7), these are the variables and parameters:

- δ_{sw} = Steering wheel angle
- N = Steering gear ratio

- J_z = Moment of inertia of vehicle yaw
- l_f/l_r = Distance from front/rear wheels to center of gravity
- C_f/C_r = Cornering power
- $\dot{\psi}$ = Yaw rate

and where a linear characterization for the tires has been assumed.

In the next two paragraphs the main signal and parameters ordinarily used inside a vehicle are presented; they concern both the primary task and the secondary one.

2.2.3 Main Vehicle Signals on Primary Task

In details, it is important to distinguish between primary and secondary task, namely the tasks more concerning driving activity (that is, leading the vehicle to its mission) and the ones involving other activities performed typically inside the cockpit of the vehicle (such as: managing the car-stereo; using the navigation system and so on).

Here the first type of variables and parameters are illustrated. The nature of this content is usually the set of sensitive car parameter, involved with its dynamics and controlled by the driver in order to lead the vehicle to a certain mission.

The main signals are:

1. speed,
2. steering angle,
3. yaw-rate,
4. number of brakes,
5. brakes status,
6. accelerator pedal position (or throttle information),
7. clutch,
8. Indicators status,
9. light status,
10. windshield wipers status,
11. diagnosis of main vehicle sub-system (such as: ABS / ASR / ESP fault; engine failure; and so on).

These ones are available on the high-speed vehicle network, that is CAN-C.

The last point (point 11) concerns the failure status of the vehicle sub-systems which can possibly affect its dynamic. How it can affect driver's behavior and how it copes with the DVE model is still to be clarified with the experimental phase; probably only a rough estimation can be provided now leaving the room for further investigation.

All these signals can be used (and needed) by the DVE model and they will be defined after that a full version of this model is completed.

In this context, for example, points 9 and 10 are used in the computation of “*Driver State*” parameter (see again previous section), which is linked to weather conditions and the signals 9 and 10 just provide information about. Again, points 4, 5 and 6 are connected with task demand, since they give an idea about the driving direction, average speed and traffic complexity, which are variables influencing the parameter “*Task Demand*”, used in the driver’s model evaluation (Table 3).

Other type of parameters can be considered as well, for instance, the ones related to enhanced information coming from “external sensors”; above all:

- Lateral position and number of Line Crossing (from a camera).
- Headway, Time-To-Collision, obstacle data (from a Radar).

About the first item, lateral position is the position of the vehicle inside the lane, expressed as the distance from the right / left boarders or from the middle of the lane; the number of line crossing gives numerically the idea of how many times driver is passing from one lane to another and thus information about his/her driving style.

For the second item, headway (H_d) is the distance between the two vehicles, divided by the host vehicle speed⁷; Time-To-Collision (*TTC*) is very similar to the Headway concept, because it is defined as the distance between the two vehicles, divided by their relative speed.

These parameters are more related to detection of the external environment and thus they can affect (and to be used for) the evaluation of “*Situation Awareness*”, where ADAS-like⁸ information are taken into account to assess how much the drivers are aware of surrounding scenario.

In order to have more precise information about the main features of aforementioned sensors, please read appendixes A and B in deliverable D1.1.2.

2.2.4 Main Vehicle Signals on Secondary Task

The signals concerning the secondary task driving⁹ are related basically to the presence of IVIS. The main ones are the following (Table 4):

⁷ “Host-vehicle” or “Ego-vehicle” means the vehicle on which the ADAS sensor or application is installed

⁸ With ADAS-like information it is meant the information related to warnings for specific situations, such as obstacle ahead, lane crossing, dangerous curve, etc. In particular, the simulator of AIDE-SP1 will deals with two applications: FCW and LDW.

⁹ With activities concerning the secondary task, it is basically meant the use of a on-board device or any system or part of cabin object of evaluation.

Source	Topics
GSM Module	SMS
	Telephone
	E-mail
	Info-traffic
Vocal Module	Vocal Commands
Navigation System	Navigation Commands
Car Stereo System	Radio commands
	CD / MC / MP3 Player
	Tuning
	DVD Player
	Other Entertainment devices ¹⁰

Table 4-Secondary Driving Task signals

These signals are on CAN-B bus (that is the low-speed CAN network in the vehicle architecture). Usually they are considered in an ON / OFF mode, namely it is taken into account if the device has been turn on or switched off (see COMUNICAR project), in order to monitor the driver's activities on secondary task.

This can be useful to modify some strategies, to cope with driver's distraction, or to take into account the workload associated with driving task, as well.

For example, the number of IVIS On can affect (again) the "Situational Awareness" parameters, as stated in Table 3 of paragraph 2.1.5. However, a complete description of all signals used in the driver's model could be done only after the first simulation results.

In Chapter 3 of this deliverable the table of the variables of INPUT-OUTPUT concerning the Vehicle Model is reported. This table addresses the final user of the DVE simulator.

¹⁰ Not properly dedicated to driver, but to passengers and often to rear passengers (i.e.: children).

2.3 *Environment Model*

The model of the environment is described by considering road, traffic and weather conditions, from the summary of previous work done in this activity.

2.3.1 Introduction

Driving a vehicle may be described as a dynamic control task in which the driver has to select relevant information from a vast array of mainly visual inputs to make decisions and execute appropriate control responses. Although there are occasions when the driver has to react to some unexpected event, in the main, drivers execute planned actions which are shaped by their expectations of the unfolding road, pedestrian and traffic scenario in front of them and the reality that they actually observe.

The road infrastructure conveys a **wealth of information** that guides drivers' activity and their interactions with others in situ (explicitly through devices such as road signs and road markings, and implicitly by means of environmental context and road layout, for example).

In the broadest sense, the **road environment** comprises the vehicle, the road infrastructure and other road users. It also includes the rules of the highway code governing the use of the road infrastructure and interactions with other road users. For this specific context of DVE modelling, the concept of the environment makes reference to any external conditions and surroundings to the vehicle, that is to say, road, traffic and weather conditions.

The **environment model** will be built by considering driving behaviour from the point of view of how drivers **perceive, attend, memorise**, etc. environmental conditions to make choices and respond to those conditions. The aim is to model how these conditions are related to risk factors. Particular attention will be paid to the identification of the most risky and critical scenarios. Therefore, the DVE model should include those parameters from the environment which drivers indicate as the most attention demanding. The environment model will be synthesised into a preliminary joint DVE model.

2.3.2 Basic Theoretical formulation

2.3.2.1 Approach: driving environment determines driving task demands

The roadway, traffic, and weather conditions present a wide array of stimuli that attract a driver's visual attention. As depicted in Figure 8, in most driving situations the driver's attentional capacity is adequate to handle the demands of the driving task. However, as the attentional demands increase due to a change in roadway, traffic, or environment, the driver's attentional capacity may become inadequate, which could increase the likelihood of a distraction-related crash.

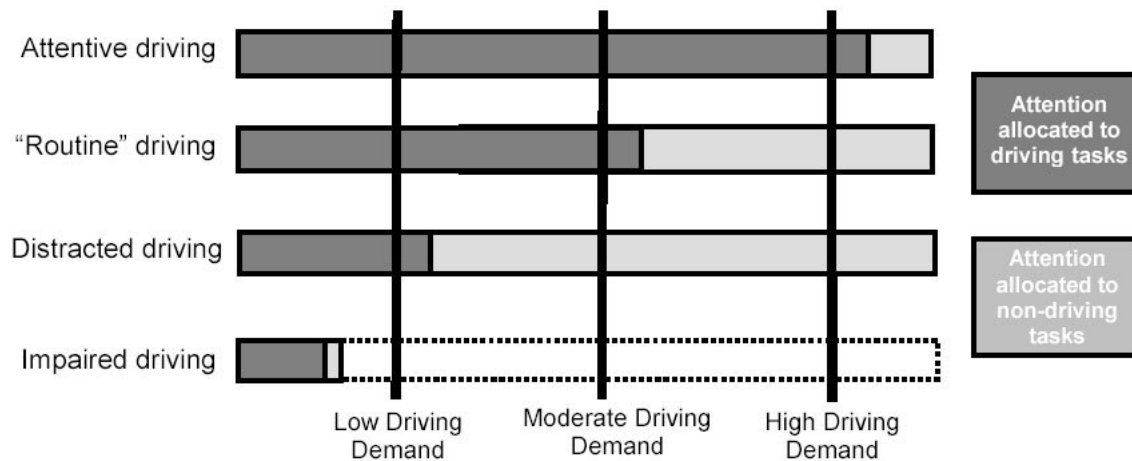


Figure 8-Attention allocation to driving and non-driving tasks

Because of this increased potential for a crash, it is important to determine the visual attention demands of various characteristics of the roadway, traffic conditions, and weather conditions.

Environmental stimuli must be attended to be processed, and the **level of attention** that is required for safe driving is likely to be correlated with the level of demand (**driving task demand**) imposed on the driver by the driving environment. As the demand on driving increases, fewer attentional resources are available for non-driving tasks leading to a greater likelihood of accident.

Under most circumstances, drivers are very good at allocating an appropriate amount of attention to the appropriate elements of the road environment in order to meet situational demands (Shinar, 1978).

In his Presidential Address to the Division of Traffic and Transportation Psychology at the 2002 International Congress of Applied Psychology, John Groeger (2002) claimed that the gibsonian approach to traffic psychology is wrong. According to Gibson’s Ecological Theory (Gibson and Crooks, 1983) there is invariant information in the environment that determines human behaviour. The environment specifies much of the information required to initiate and control action (Gibson, 1979). Therefore, in this approach what seemed to be important is to discover that invariant information (traffic characteristics, road type, etc.) which would explain driver’s behaviour by itself.

However, Groeger claimed that thirty years of research have shown that driving could not be described as a perceptual response to invariant information in the environment, but a complex feedback dependent skilled behaviour. He cited the influential book of Fitts and Posner (1967) as the starting point of what we might call the cognitive approach to driving behaviour. In Fitts and Posner’s words “In driving an automobile one does not randomly respond to stimuli on the road. Instead, one makes responses in accordance with some internal model which involves reaching a destination at a certain time while obeying various traffic regulations, accommodating oneself to the other traffic on the road and adapting one’s driving in numerous other ways to the immediate environmental situation” (Fitts and Posner, 1967, p.3).

In the cognitive approach to driving behaviour what is important is how drivers perceive, attend, memorise, etc. environmental conditions to make choices and respond to those conditions.

There are two factors that interact to determine the level of **driving task demands** (Figure 9):

- the **characteristics of driving environment**, including:
 - road characteristics
 - traffic conditions
 - weather conditions
- **driver's scanning strategies**

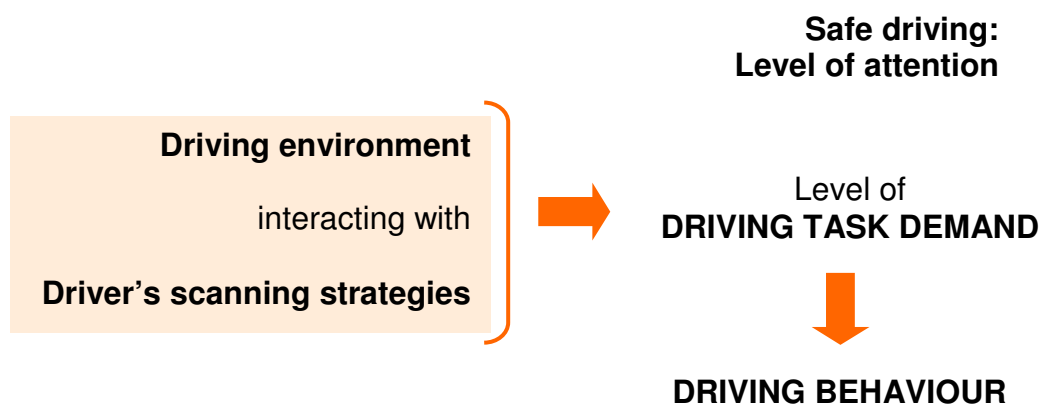


Figure 9- Factors determining driving task demand

In the following sections, a few human factors studies of visual driving task demand are reviewed, distinguishing three general categories of visual demand: roadway, traffic, and weather, all of them considered as characteristics of driving environment. There is also a section dedicated to the analysis of driver's scanning strategies.

2.3.2.2 Characteristics of driving environment

Road characteristics

We could draw conclusions from studies of **subjective** categorization of road types and characteristics.

For example, Kaptein, Janssen and Cleassens (2002) asked 48 drivers to perform a sorting task of computer-generated images of four existing road categories (Motorway, Motorroad, 80 km/h road for monitorized traffic, and 80 km/h road for monitorized plus slow traffic). They asked each participant to imagine themselves driving on the road and how they would behave and what behaviour they would expect from other drivers on the same road. The pictures were sorted in such a way that the behaviour on the roads in a pile was the same and different from the other piles. Therefore, the results from the sorting task reflected road categories as a function of drivers behaviour. The results showed that participants categorized road images in four groups very similar to the existing roads. The characteristics that were identified in both the existing road categories and the categories sorted by the participants were:

1. Width of carriageway;
2. Width of lanes;
3. Edge lines;
4. Recovery lane;
5. Width of emergency lane;
6. Guard rail;
7. Number of carriageways;
8. Centerline markings; spaces in between centreline markings;
9. Width of bicycle lanes.

In a second phase of the study the authors asked 48 drivers to drive in a simulator. After the driving, they had to fill out a questionnaire. The questions addressed the selection of an appropriate speed for each environment, the influence of the road environment on driving speed, the ease with which road categories could be distinguished, the extent that road category determine driving speed, and the experienced realism of the simulation.

The results showed that driving speed followed this order from faster to slower: Motorway, Motorroad, 80 km/h road for monitorized traffic, and 80 km/h road for monitorized plus slow traffic. The following table (Table 5) shows the number of characteristics that the participants claimed to determine their driving speeds.

Road characteristics	Numbers
Lights	9
Bicycle paths	4
Houses	7
Trees	11
Lateral clearance	9
Curves	5
No other traffic	4
Number of carriageways	9
Width of carriageway	6
Emergency lanes	4
Bicycle lanes	5
Guard rail	7
Road markings	6

Table 5-Road characteristics determining driving speeds

Other existing studies have found similar results (Saad and Schnetzler, 1994). From these results we could make conclusions about what characteristics could affect driver's behaviour (speed). These characteristics would be the parameters to include in the DVE model.

As first described by Versace (1960), crashes seem to be more likely at certain roadway characteristics. This implies that the visual characteristics of certain road features may create higher demand than other features. While there are many roadway features that could be investigated in a human factors study, only two features have been researched: curves and lane widths.

Curves

The visual demand of driving horizontal curves has been studied extensively with the visual occlusion method (Courage, Milgram, and Smiley, 2000; Godthelp, 1986; Mourant and Ge, 1997; Senders, et al., 1967; Shafer, Brackett, and Krammes, 1995; Tsimhoni and Green, 1999; Tsimhoni, Yoo, and Green, 1999; Wooldridge, Bauer, Green, and Fitzpatrick, 1999; Wooldridge, Fitzpatrick, Koppa, and Bauer, 2000).

Generally, these studies show that drivers need more visual input for curves than for straight sections of roadway, indicating that curves require greater visual demand. Those studies that have systematically varied the features of curves (e.g., Shafer, Brackett, and Krammes, 1995; Tsimhoni and Green, 1999; Tsimhoni, Yoo, and Green, 1999; Wooldridge, Fitzpatrick, Koppa, and Bauer, 2000) have found that visual demand:

- 1) is inversely related to the radius of curvature;
- 2) does not vary much with deflection angle;
- 3) begins to rise at the end of the approach tangent and peaks at the beginning of the curve followed by a decline throughout the curve;
- 4) was higher for s-curves than for broken-back curves (a broken-back curve has two curves in the same direction whereas an s-curve has two curves in opposite directions) but the effect was weakened with a large separation between the curves; and
- 5) these findings held for both on-the road and simulator studies.

Another potentially demanding curve-type is vertical curves (hill and valleys). Perhaps because driving simulators do not simulate vertical curves adequately and test-courses are usually flat, the effect of this roadway characteristic has not been studied. Future work should address the visual demand of various horizontal curves.

Lane Width

Another frequently studied roadway characteristic is lane width. Crash analyses on Highway Safety Information System data show that crash-rates are elevated for narrow lane widths (Zeeger, Huang, Stewart, and Williams, 1998), suggesting that visual demand might also be related to lane width. Indeed, studies utilizing the visual occlusion method have found that the percent of time not occluded increased with decreasing lane width; that is, visual demand increased with decreasing lane width (Courage, Milgram, and Smiley, 2000; Senders et al., 1967; Van der Horst and Godthelp, 1989). For example, Courage, Milgram, and Smiley

(2000) varied lane width in a medium-fidelity driving simulator. They found that as width varied from 3.7 to 2.7 m (12 to 9 feet), visual demand increased by 6 percent. Thus, the effect of lane width is significant but not strong.

Other Characteristics

Several other roadway characteristics undoubtedly affect visual demand. These characteristics include: shoulder width, sight distance, pavement markings, and roadway surface. Theoretically, each of these features can increase the uncertainty of the driving task leading to increased visual demand. However, we could find no human factors studies that have investigated these variables in an attentional demand context.

Traffic Conditions

As the density of vehicles increase for a given driving situation, the likelihood of a vehicle doing something unexpected increases. As such, increases in traffic density should increase visual demand. Using a medium-fidelity simulator and the visual occlusion method, Mourant and Ge (1997) presented two levels of on-coming traffic density (no traffic and “moderate density”) to subjects while they drove both curved and straight roadway sections. Results showed that the percent of non-occluded vision increased with increasing traffic density; that is, visual demand was 8 percent higher for moderate traffic than for no traffic. This effect, however, was found only for driving curves. Whether or not visual demand was affected by high density traffic on straight sections of roadway is unknown, but would undoubtedly increase demand on curved sections of roadway.

Weather conditions

The weather conditions during a particular driving situation should influence visual demand, especially if conditions degrade visual perception (such as rain or fog) or increase the difficulty of maintaining lane position (such as with a strong cross-wind or an icy road). Probably because these conditions are difficult to simulate in the laboratory and even more difficult to create artificially on a closed driving-course, an extensive search of the literature revealed no studies that have investigated visual demand of driving in inclement weather.

Data from questionnaire studies has shown that drivers acknowledge the need to modify their behaviour to adapt to weather conditions (Quimby and Downing, 1991). However, a recent study by Edwards (1999) shows that in practice drivers only marginally alter their driving habits to adapt to bad weather conditions. The author observed driving speed in the following conditions: (1) Sunny, clear spells; (2) dull, overcast, cloudy; (3) steady/heavy rain; (4) drizzle, road surface spray; and (5) misty, fog. The results showed that drivers only make a token gesture of slowing down by a few miles per hour during rain, but as the author claimed such minor reduction in speed would have little bearing on their ability to stop suddenly in the event of an incident ahead.

As a consequence, we could state that weather conditions affect driver performance whereas they hardly affect driver behaviour. Therefore, these weather conditions should be included as environment parameters in the DVE model, bearing in mind the fact that these parameters mainly have an effect on driving performance.

2.3.2.3 Driver's scanning strategies

The role of the visual road environment is presented below.

Perception is an active construction process: it is the result of an interaction between sensory input, expectations and other information processing characteristics of the driver. In general, it has been estimated that over 90% of the information that a driver has to process is visual (Hills, 1980). Since the visual system is limited and the driving environment is relatively complex, in many circumstances perception of the road environment will rely on top-down expectations. In other words, drivers will perceive those events that are in line with their expectations and will overlook events that are not in line with their expectations.

According to this idea, perceiving road environmental objects and events is the result of the interaction between sensory information, task demands and expectations of the road user. In line with the cognitive approach, it is important to note that sensory information is not what determines perception, but the interaction of it with the driver cognitive processes (task demands and expectations). Drivers rely on their experience with the driving task and perceiving the road environment rely on top-down expectations (Theeuwes, 2002). For example, Theeuwes and Hagenzieker (1993) had shown that drivers expect that objects that are likely to appear in a given scene should occupy specific positions in that scene. Results from their study showed that errors in perceiving objects occurred when road users had wrong expectations regarding the location of particular target objects. Therefore, the authors claimed that extremely dangerous situations may occur when the design of the traffic environment induces incorrect expectations regarding the spatial arrangement of the object in that scene.

As a result, drivers should be informed about objects and events appearing in unexpected places of the road scene (**unexpected locations**).

It has often been suggested that the road environment itself can modulate the **perception of self-motion** (for instance, we will have more of a sensation of increased speed while driving along a small road bounded by trees, than on an empty highway). From the results of several studies, it is suggested that the actual road environment might play a direct role in the way **visual motion information** is processed. It is obvious that the road environment structure plays a role in the perception of a car's trajectory. In this sense, it is proposed that the "objects" along the road, including road signs, might also play a role. This approach suggests that every road element has to be taken into account in a "dynamic visual approach" to driving. A singular object might capture attention, and induce an eye fixation on it.

Drivers react to traffic conditions by rapidly fixating in the direction of the most demanding events in the environment. Therefore, studies that explore **eye fixations** as a function of road characteristics and conditions are relevant for detecting attentional demands. The increase in fixation duration reflects the increase workload as the driver decides upon a course of action, or it may indicate increased sampling of data from the environment.

There is empirical data to detect the level of demand as a function of the part of the driving scene monitored by the driver.

Data collected by Underwood, Chapman, Berger and Crundall (2003), and Underwood, Chapman, Brocklehurst, Underwood and Crundall (2003) (Figure 10) suggest that:

- Simple fixations: In all road (urban, dual-carriageway, and rural roads)

1. The road far ahead and mid ahead attracted more fixations than any other part of the scene.
 2. The road near left and road near right attracted fewer fixations than any other part of the scene.
- In two-fixation transitions:
 1. Having looked in the mirror, then looked at road far ahead.
 2. Fixation of other objects such as other road users also terminated with fixation of the road far ahead on many occasions.
 3. Wherever drivers looked away from the road it is then invariably refixated at the point that delivers maximum preview.
 4. There were invariant transitions from the road far left to the road far ahead, reflecting the importance of maximum preview of the road way ahead and the objects that may require further attention.

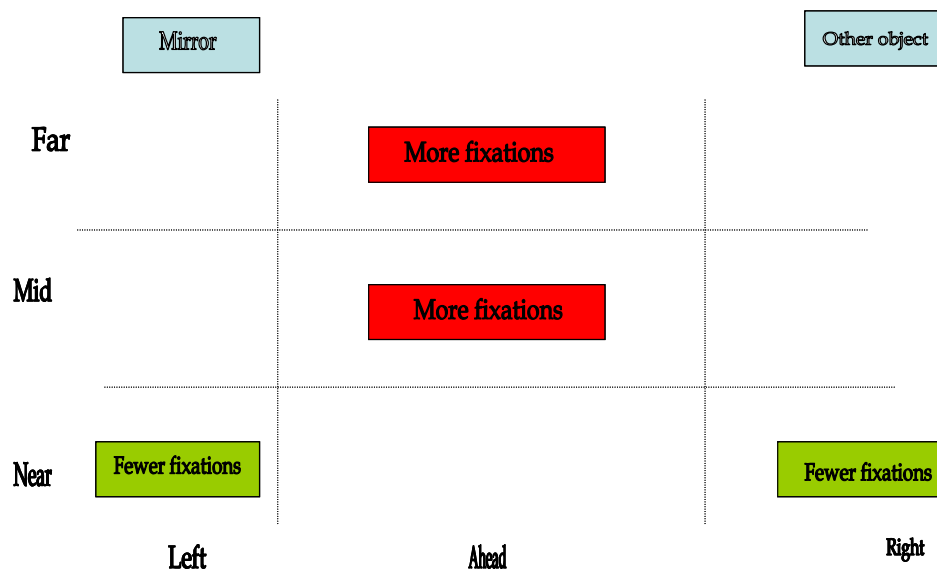


Figure 10-Eye fixations to parts of the driving scene

- In the three-fixation transitions:
 1. The road far ahead again appears as a destination location, but also as a starting location.
 2. The road mid ahead- the section of the road that the driver would encounter one or two seconds later- was the starting and finishing point for a number of transitions that might be characterized as a scanning strategy. This strategy tended to be used less in urban roads.
 3. After inspections of the rear view mirror drivers looked at the road far ahead, the returned to the mirror.
 4. Returning to the mirror is more frequent in dual-carriageway.

From these results, it can be concluded that the most important road characteristics are the ones that give information to the driver about the road preview, that is to say, that anticipate what is going to happen subsequently in the road environment. Thus, these characteristics should be included in the DVE model.

2.3.3 Main parameters and variables

After this review of existing studies relating environment features with driver behaviour, it becomes necessary to establish a criterion for the selection of the environment parameters to include in the Environment Model. We have taken as a reference the concept of complexity of a certain route section, which is expressed below.

To identify if a specific section or turn has a certain complexity the **taxonomy by Fastenmeier** is used (1995). A complex route section would imply having high demands on information processing and high demands on vehicle handling.

This taxonomic approach to describe **information processing demands of traffic situations** was proposed by Fastenmeier (1995) who performed a detailed analysis of the classification scheme for traffic situations developed by Benda et al. by using parts of the German version of the "Position Analysis Questionnaire – PAQ" (Benda, Hoyos, & Graf & Schaible-Rapp, 1983). Summarising his results, Fastenmeier highlights the following characteristics of traffic situations as crucial for their complexity, i.e. the demands they put on drivers' information processing and/or vehicle handling capabilities:

- presence of intersections;
- the kind of priority rules;
- "duration" of a situation;
- visibility conditions resulting from daytime and weather conditions;
- traffic density.

According to this approach, traffic situations from a drivers' perspective can be subsumed under one of the following four groups:

1. *High demands on information processing and high demands on vehicle handling*: Typical examples of this group of situations are "driving within city centres", complex intersections with road signs where the driver has to give right of way. Here, route section with these characteristics are referred as having "high-high complexity" or are simply referred as "complex".
2. *High demands on information processing and low demands on vehicle handling*: Typical examples of this group of situations occur at those intersections which are regulated by road signs and where the driver has the right of way. Other examples are entering or leaving a highway/motorway.
3. *Low demands on information processing and high demands on vehicle handling*: Typical examples of this group of situations occur on older, curvy rural roads or at intersections which are regulated by traffic lights. Groups two and three are referred as having "medium complexity".
4. *Low demands on information processing and low demands on vehicle handling*: Low demands result from all those situations in urban and rural areas and on motorway where "free driving", i.e. without interactions with other traffic participants is possible. In this report, route sections with these characteristics are referred as having "low-low complexity" or are referred as "simple".

An **intersection** can be regarded as a zone of transition along the road where the driver may have to adjust her or his speed so as to comply with the regulatory and/or functional

requirements resulting in a change from the previous driving situation. More precisely, we will define it as a zone of potential interaction with one or several other road users.

In accordance with the objective previously stated, we should be able to identify the most risky and critical scenarios. Following the classification by Fastenmeier, groups 1, 2 and 3 refer to traffic situations with high or medium complexity. Specifically, they include complex intersections with road signs (e.g. give way signs), curves, interactions with traffic participants, etc.

In Chapter 3 of this deliverable the table of the variables of INPUT-OUTPUT concerning the Environment Model is reported. The table addresses the final user of the DVE model.

3. DVE Input – Output

The following tables contain the list of variables that will form the Input-Output system of the simulation software that will derive from the implementation of the equations described in the previous Chapters and the algorithms adopted for their numerical solution. These will therefore be utilised by the WP 1.3.

3.1 *Driver Model*

INPUT	From
EXP	Input data
ATT	Input data
CoT	Model Environment
VIS	Model Environment
Distraction (V1)	Model Environment
Distraction (V2)	Model Vehicle
DoD	Simulation Time
$ \Delta Speed $	Model Vehicle
$ \Delta\varphi $	Model Vehicle
OUTPUT	To
Intended Speed	Model Vehicle
Position/ $\Delta\varphi$	Model Vehicle

3.2 *Vehicle Model Input*

INPUT	From
Vehicle mass	Input data
Maximum acceleration braking	Input data
Engine moment of Inertia	Input data
Transmission moment of Inertia	Input data
Efficiency of transmission	Input data
Coefficient for rolling resistance (F_0)	Input data
Coefficient for aerodynamic drag forces (F_2)	Input data
Gravity acceleration	Input data
OUTPUT	To
$ \Delta Speed $	Model Driver
$ \Delta \varphi $	Model Driver
Distraction (V2)	Model Driver

3.3 *Environment Input*

INPUT	From
Complexity of Traffic	Input data
Weather conditions	Input data
Light conditions	Input data
Road conditions	Input data
Visibility	Input data
OUTPUT	To
CoT	Model Driver
VIS	Model Driver
Distraction (V1)	Model Driver

4. Conclusions

This deliverable has presented the formulations of the three models of DVE framework, namely the driver's, the vehicle and the environment model. In particular, the main focus has been on the first item: the Driver model. A deep discussion and problem investigation have been illustrated, in particular, describing the basic paradigm: the Information Processing System (IPS). In this context, many variables and parameters, describing the human behaviour during driving have been selected and chosen. In order to find a relationship to link and associate the relative parameters and variables, a fuzzy approach has been followed and the relative expressions have been detailed in the text. The actual formulation of the parameters governing the driver's model is critical for the overall DVE modelling. For this reason, the implementation of the correlations linking all static and dynamic *parameters* (i.e., *EXP*, *ATT*, *DS*, *TD*, and *SA*) and *measurable variables* is kept wide open in the simulation. A set of default correlations (illustrated in the document) between parameters and measurable variables is available: as inputs, only the limits for each independent measurable variable are required, in order to structure the fuzzy correlations.

On the other side, if the user of the simulations intends to study and apply new functions and rules, then the input requires the definition of new independent variables, to be selected amongst those calculated by the three modules of the DVE simulation. In this case, there are the formulation and computations of new correlations that replace the default ones. This is a very flexible aspect of the simulation that requires however programming ability and knowledge of the simulation software details.

Eventually, concerning the other two aspects of DVE modelling, the environment has been already presented in the previous deliverables (D1.1.2 and D1.1.3) and therefore only a summary has been reported here. About the vehicle model, most of the part has been detailed in D1.1.2: here the main input / output signals have been highlighted, leaving the description of ADAS models to be used inside the simulator for the next deliverable (D1.1.5).

Using these characteristics to determine as static parameter the level of experience of the driver will help modelling driver behaviour. However, the professional drivers are not considered here as their driving activity represents something quite different than standard drivers: additive stakes make professional drivers drive differently with global long-term goals that are not shared by standard drivers. Experience level of professional drivers would be categorized on the basis of less quantitative indicators, even if years of driving is a major parameter.

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