SIMULATION-BASED TESTING AND EVALUATION OF AUTOMATED VEHICLE MOTION PLANNING AND CONTROL ALGORITHMS

OTONOM ARAÇLARIN HAREKET PLANLAMA VE KONTROL ALGORİTMALARININ SİMÜLASYON ORTAMINDA TESTİ VE DEĞERLENDİRİLMESİ

KEMAL FURKAN BEK

PROF. DR. SELAHATTIN ÇAĞLAR BAŞLAMIŞLI
Supervisor

Submitted to
Graduate School of Science and Engineering of Hacettepe University
as a Partial Fulfilment to the Requirement

for the Award of the Degree of Master of Science

in Mechanical Engineering

May 2022

ABSTRACT

SIMULATION-BASED TESTING AND EVALUATION OF AUTOMATED VEHICLE MOTION PLANNING AND CONTROL ALGORITHMS

Kemal Furkan BEK

Master's Degree, Department of Mechanical Engineering

Supervisor: Prof. Dr. Selahattin Çağlar BAŞLAMIŞLI

May 2022, 117 pages

Automated vehicles can help to reduce accidents, stress on the driver and the ecological footprint of vehicles by utilizing motion planning and control algorithms. Ensuring the safety and comfort of drivers and passengers in automated vehicles requires delicate testing and verification process of newly developed algorithms. This study aims to establish an exchangeable and adjustable MATLAB® simulation environment with a flexible architecture to develop motion planning and control algorithms; and then test and evaluate the algorithms in conditions such as flowing traffic and different tire-road coefficient of frictions in compliance with the Automated Lane Keeping System regulations; to detect the design imperfections and identify the critical scenarios. The study yielded a Motion Planning Algorithm, a Simulation Environment in MATLAB® to test and evaluate algorithms, and an Automated Scenario generation and execution to identify critical scenarios and design flaws. Algorithms and parameters used in this research can be modified to perform sensitivity analysis for individual effects and contributions.

Keywords: automated driving, motion planning, trajectory planning, simulation environment, critical scenario identification, automotive safety.

ÖZET

OTONOM ARAÇLARIN HAREKET PLANLAMA VE KONTROL ALGORİTMALARININ SİMÜLASYON ORTAMINDA TESTİ VE DEĞERLENDİRİLMESİ

Kemal Furkan BEK

Yüksek Lisans, Makine Mühendisliği Bölümü

Tez Danışmanı: Prof. Dr. Selahattin Çağlar BAŞLAMIŞLI

Mayıs 2022, 117 sayfa

Hareket planlama ve kontrol algoritmalarını kullanan otonom araçlar, kazaların, sürücü üzerindeki stresin ve araçların ekolojik ayak izinin azaltılmasına yardımcı olabilmektedir. Otonom araçlarda sürücülerin ve yolcuların güvenliğini ve konforunu sağlamak, geliştirilen yenilikçi algoritmaların hassas bir şekilde test edilmesini ve doğrulanmasını gerektirir. Bu çalışma, hareket planlama ve kontrol algoritmaları geliştirmek için esnek mimariye sahip değiştirilebilir ve ayarlanabilir bir MATLAB® simülasyon ortamı kurmayı; daha sonra da Otomatik Şeritte Kalma Sistemi yönetmeliklerine uygun olarak akan trafik ve farklı lastik-yol sürtünme katsayıları gibi koşullarda algoritmaları test edip değerlendirmeyi ve tasarım kusurlarını tespit etmeyi ve kritik senaryoları belirlemeyi amaçlamaktadır. Bu çalışmanın sonucu olarak, Hareket Planlama Algoritması, algoritmaları test etmek ve değerlendirmek için MATLAB®'da bir Simülasyon Ortamı ve kritik senaryoları ve tasarım kusurlarını belirlemek için bir Otomatik Senaryo oluşturma ve yürütme sistemi elde edilmiştir. Bu araştırmada kullanılan algoritmalar ve parametreler, bireysel etkiler ve katkılar için duyarlılık analizi yapmak üzere değiştirilebilecektir.

Anahtar Kelimeler: otomatik sürüş, hareket planlama, rota planlama, dinamik ortamlar, kritik senaryo tanımlama, otomotiv güvenliği.

ACKNOWLEDGEMENT

I would like to dedicate this work to:

First, to my family:

To my father Zeki, mother Kevser and brother Kerim Yusuf for believing in me.

Then, to my advisor in life, my Uncle Engin.

Second, to my friends:

To my hopefully life-long companion Venüs, my friend Samet and my cousin Turgut for the joy and hope they bring into my life.

Then, I would like to thank to my colleagues:

To Mr. Mesut and Mr. Yavuz for their continuous support and advice throughout my troubles. Then to Mr. Süha and Mr. Taner, for their wisdom and leadership.

Finally, I would like to express my gratitude to Dr. Selahattin Çağlar Başlamışlı for his precious time, experience, and supervision. This work is done thanks to motivation and guidance he gave me.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

a_x	Longitudinal acceleration of the vehicle
a_y	Lateral acceleration of the vehicle
a_t	Throttle for the longitudinal acceleration input to the vehicle
α_f, α_r	Front and rear-wheel slip angles
A_f	Frontal area of the vehicle for wind drag disturbance
C_f, C_r	Front and rear wheel cornering stiffness
d_{x0}	Initial relative distance between the ego and lead vehicle in Scenario
F_x	Longitudinal forces applied to the vehicle
F_y	Lateral forces applied to the vehicle
F_{ext}	External forces applied to the vehicle from driveline and brakes
I_{zz}	Vehicle body moment of inertia
j_x	Longitudinal jerk of the vehicle
j_y	Lateral jerk of the vehicle
l_d	Lateral deviation of the vehicle from the road center
l_f	Distance of front wheels from the vehicle CG
l_r	Distance of rear wheels from the vehicle CG
m	Vehicle body mass
M_z	Yaw moment about vehicle CG
M_{ext}	External moments about vehicle CG from driveline and brakes
P_{air}	Environmental absolute pressure for wind drag disturbance
R_{air}	Atmospheric specific gas constant for wind drag disturbance
R	Curvature radius of the road

T_{air}	Environmental air temperature for wind drag disturbance
U	Set longitudinal velocity of the actor vehicle for state-space estimation
V_x	Longitudinal velocity of the vehicle
V_y	Lateral velocity of the vehicle
V_{e0}	Initial longitudinal velocity of the ego vehicle in Scenario
V_{o0}	Initial longitudinal velocity of the lead vehicle in Scenario
w	Wind speed, along the vehicle-fixed x, y, and z axes for wing drag
W	Wind speed, along inertial X, Y, and Z axes for wing drag
x	Vehicle CG displacement along x-axis
y	Vehicle CG displacement in y-axis
ψ	Yaw angle of the vehicle
ψ_r	Relative yaw angle between vehicle’s longitudinal direction and road
μ	Friction coefficient between vehicle’s tires and the road
δ_f	Front-wheel steering angles for the vehicle

Abbreviations and Acronyms

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assist Systems
ADS	Automated Driving Systems
AEB	Autonomous Emergency Braking
ALKS	Automated Lane Keeping Systems
DDT	Dynamic Driving Task
DS	Default Spacing
FC	Final Conditions
IC	Initial Conditions
LCA	Lane-Change Assist
LKA	Lane Keeping Assist
LQR	Linear-Quadratic Regulator
MPC	Model Predictive Control
ODD	Operational Design Domain
SD	Safe Distance
TG	Time Gap

1. INTRODUCTION

In recent studies, automated vehicles and intelligent road systems have become more relevant than before. Researchers expect a variety of automated vehicles to emerge by 2030 [1]. Automated vehicles can potentially increase the safety of drivers and improve their driving comfort. While the positive outcomes of automated cars are promising, they must be tested with up-to-date standards to prove reliability, which requires intensive and extensive verification in compliance with safety standards for general automotive development and testing.

Traditional approaches for verification heavily depend on testing in the real-world and driving data collection. This usually covers ordinary traffic conditions, which are not necessarily critical. Those tests require an impractical amount of time and effort and may still not be able to explore the necessary critical traffic conditions, especially requiring inspection and investigation. The simulation-based testing approach presents a much cheaper way of analysis. This approach is much faster than real-world driving and test execution, and it is also much safer. However, it does not mean that one can rule out the need for real-life testing. In simulation-based testing, the operational domain can be explored thoroughly with automated testing, and the results can be used to detect error-failure chains.

Automated driving can benefit society in many ways, such as reducing accidents, driver and passengers' stress, and the ecological footprint of modern transportation. Automated vehicles have already demonstrated their ability to maintain a distance, maintain lanes, perform intelligent path planning, perform off-road navigation, and communicate with vehicles on the road.

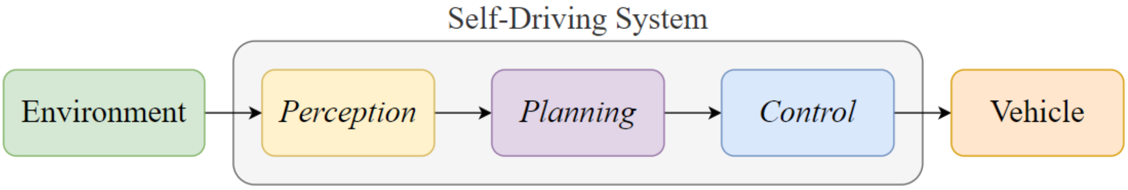


Figure 1-1 Self-Driving System's Mainframe

The self-driving system's mainframe includes three elements: perception, planning, and control [2]. The mainframe can be inspected in Figure 1-1. *Perception*, in this context, means an automated vehicle's recognition of the objects and agents around the vehicle and the condition of the vehicle itself by utilizing a range of built-in sensors such as lidar, cameras, GPS, etc. *Planning,* means analyzing the sensor data and the vehicle's status to decide the following action. Finally, *Control,* is taking self-driving actions depending on the analysis of the environmental information. Currently, 4–10% of all collisions in regular road traffic are due to driver errors when overtaking [3]. Overtaking is an operation to be handled carefully in many aspects. Reliable and efficient overtaking is a challenge for automated driving cars. Information from other vehicles is required for automated driving cars to be able to maneuver. This information may include the position, velocity, distance, or yaw angle of another vehicle.

Latest studies show great interest in advanced driver assistance systems (ADAS) which prove notable advances in both driver safety and comfort. Apart from well-researched adaptive cruise control (ACC), automated emergency braking (AEB) and lane keeping assist (LKA), the requirement for a lane change and overtake maneuver assistance system is evident because lane changes are typical maneuvers for daily driving. ADAS are assistive systems that are implemented to assist drivers in parking and driving functions. They can utilize a human-machine interface to alert the driver or communicate the detected situation to inform the driver. However, automated vehicles are being researched to perform the previously mentioned assistive driving tasks in an automated fashion. Thus, apart from the assistance systems, the autonomy level should be expressed when explaining the automated driving system (ADS). The ADS can include the assistive systems alone or in combination. Furthermore, the ADS often includes a decision capability to perform automated.

Developing an assistive system with an autonomy, requires intensive testing and evaluation. The simulation-based testing approach presents a much cheaper way of investigation. Furthermore, the simulation approach is much faster than real-world driving and test execution, but also much safer. Rapid development and testing for automated vehicles require a simulation environment that has an exchangeable and adjustable architecture. This architecture shall be able to be utilized to test and evaluate the development performance according to standards. The final evaluation of results shall point to the strengths and weaknesses of the researched topic and create an opportunity for the improvement of the overall safety of the vehicle and detection of critical scenarios.

This study focuses on developing a motion planning and control algorithms for;

- an implementation of lane change and overtake maneuver assistive system, to the well-researched advanced driver assistance systems -such as adaptive cruise control, automated emergency braking and lane keeping assist-, in a MATLAB$^{®}$ simulation environment with a flexible architecture;
- and simulation-based testing and evaluation of the algorithm in flowing traffic and different road adhesion coefficient conditions in compliance of ALKS regulations; to improve the overall safety and to detect critical scenario conditions.

2. LITERATURE REVIEW

In this section, previous studies available in the literature that are related to the key aspects of this study are reviewed and the open points in the studies are addressed. The studies reviewed in this section are on the topics of Trajectory Planning, Path Following and Simulation Environment. Trajectory Planning and Path Following algorithms are the core function of an automated vehicle for it to be able to create new paths in any given traffic situation. Simulation Environment is required to test the developed algorithms for safety and comfort for verification.

2.1.Trajectory Planning and Path Following

This study focuses on an appropriate motion planning algorithm for lane change and overtake problem which is a difficult challenge that involves active trajectory planning in flowing traffic where the vehicle states change in both longitudinal and lateral directions. The active planning of the trajectory should ensure the driver's safety while maintaining comfort. Furthermore, this task involves the design of a suitable control algorithm for the path following problem which requires high performance tracking of planned trajectory especially in safety-critical conditions.

In the literature, there are several methods to represent a suitable trajectory function. Spline curves such as quartic and B-spline, trapezoidal acceleration curves, 3D Bezier curves and polynomial curves were researched in the previous studies. Ziegler et al. used a quartic spline curve method to design the desired trajectory [4]. The shortest path algorithm is used to find the suitable trajectory among graphs that separates the available space. However, the search-based algorithm requires optimization to reduce its computational cost before being applied to automated vehicles. Meanwhile, the quartic spline profile results in a non-continuous jerk profile which is a main concern for driver comfort. This fact will be mentioned later in this thesis as an improvement opportunity. Rousseau et al. used the B-spline curve method to achieve the desired trajectory [5]. This method requires optimization as in Ziegler's quartic curve method to reduce its computational cost for real-world applications. Yin et al. used trapezoidal acceleration curve as a motion planning method [6]. This method yields a continuous velocity profile however the continuity of acceleration profile is not achieved. Chen et al used the 3D Bezier curve method to represent the desired trajectory [7]. This method yields a continuous acceleration profile but still, the resulting jerk profile is non-continuous.

Using a polynomial to express the desired trajectory is a frequent method that satisfies both the computational cost requirements and driver comfort constraints. By increasing the polynomial order, a continuous profile for velocity, acceleration and jerk can be achieved while maintaining the computational cost advantages. Nelson et al. proposed the polynomial method to describe the desired trajectory [8]. McNally et al. used a cubic polynomial method to obtain the desired trajectory [9]. Nilsson et al. used the quadratic polynomial method to achieve the desired trajectory [10]. Wei et al. used the quintic polynomial method which is a suitable method that has continuous velocity, acceleration and jerk profiles and has a convenient computational cost [11].

Nevertheless, above mentioned studies have several limitations. A common limitation is the lack of real-world applicability with the assumption of a steady traffic state with constant actor velocities instead of a dynamic traffic state. Another common approach is related to assuming perfect road conditions such as road adhesion coefficient taken as 1.0, which ignores the real-world vehicle dynamics problems such as lateral stability. This leads to problems such as accurate path tracking in conditions involving high velocity and/or low road adhesion coefficient, where vehicle stability becomes a main concern. Similarly, the straight road assumption is very common in the above studies. One may argue that it is not recommended to perform lane changes or overtake maneuvers on a curved road; however, the requirement persists since there is an urgent reaction needed on a curved road during obstacle avoidance maneuver. Oosterhaven and Iaco et al. suggested utilizing the Frenet frame method to generalize trajectory planning on roads with curvatures [12-13]. With that being said, the evident requirement for active motion planning emerges when the environment has a flowing traffic state with changing road conditions such as road adhesion coefficient and road curvature.

There are existing numerical studies that exclude the design of a control algorithm or the consideration of vehicle dynamics during trajectory planning [14-15-16]. Zhang et al. include re-planning with a quintic polynomial in dynamic environments [17]. However, the study did not consider road curvature, control algorithm design, or vehicle dynamics, which are all necessary for real-world applications. Lex et al. used re-planning with quintic polynomial and included a sensitivity analysis of parameters including road adhesion coefficient [18]. The computation cost challenge was overcome by pre-stored look-up tables. A linear quadratic regulator (LQR) method was used as the path following controller. However, the study did not include curved roads in pre-stored look-up tables which is necessary for real-world applications. Some studies tested and proposed several types of controllers based on vehicle dynamics with a single-track bicycle model. Tota et al. compared proportional derivative control strategy with and without static linear feedforward design for path tracking control [19]. Baslamisli et al. used an H_∞ controller for increasing vehicle handling stability in front steer vehicle models [20]. Similarly, Norouzi et al. used adaptive sliding mode control with a fuzzy boundary layer for lateral control. Zhou et al. designed a model predictive controller (MPC) for the path following controller and evaluated it through simulation [21]. In addition, Lin et al. evaluated MPC further on an electric golf cart [22]. Yet in the study, the simplified path planning approach limits the possible traffic applicability. Still, applications of MPC seem to be promising, especially in critical situations where large actuator inputs are required in a short period of time which creates highly non-linear tire-road dynamics. Therefore, He et al. proposed an MPC for emergency collision avoidance with ensured stability where trajectory planning is achieved by using the quintic polynomial method [23]. The study included simulation results as well as experimental results with hardware-in-the-loop. Takahama et al. explored the use of an MPC controller for practical adaptive cruise control in road traffic congestion [24]. Similarly, this study included simulation results as well as experimental results with hardware-in-the-loop. The study also included a performance comparison of MPC with LQR. MPC showed high performance compared to LQR and other common controllers with highly responsive actuator utilization. In addition, it was shown that the weights of the MPC could be adjusted to adapt to different kinds of operating conditions in various driving environments. However, the computational power requirements for MPC are a notable disadvantage. The computational performance of microprocessors is predicted to improve in the future; however, an optimized control system is still desirable since the functions included in an automated driving system will also increase.

In the present work, a lane change and overtake maneuver assistive system is studied and implemented. The quintic polynomial method is selected for trajectory planning. Dynamic re-planning of the trajectory added the possibility of application in dynamic traffic conditions. The inclusion of the Frenet frame method extended the applicability to curved road scenarios. A single-track bicycle model was selected for vehicle dynamics to represent the tire-road interaction which included real-world problems such as lateral stability and tire forces and slip. MPC was employed for path following. The controller weights were adjusted for accurate path tracking that ensures the driver's safety and comfort while preserving actuator health.

2.2.Simulation Environment

The present study includes the design of a simulation environment to satisfy the requirement for testing and evaluation of the developed algorithms. The simulation environment requires to have an exchangeable and adjustable architecture to assess the performance extensively with different vehicle dynamics, perception and controller methods. The flowing traffic conditions, the different map settings with changing road curvatures and variable road adhesion coefficients are necessary to simulate realistic driving scenarios which are required by the standards. The ALKS regulations include dynamic traffic conditions where the vehicles have swerving mechanics and changing motion profiles.

In literature, there are several methods to build a suitable simulation environment such as LGSVL [25], Carla [26] and Airsim [27]. These simulators can provide ground truth information regarding traffic states and surrounding environment settings. However, there is an evident requirement for flexibility, customization and adjustability. There are commercially available simulators like CarMaker® and CarSim® that simulates realistic vehicle dynamics. Traffic simulators like SUMO® (Simulation of Urban Mobility) can accurately simulate flowing traffic conditions. Meanwhile, MATLAB® supports a stable connection with most of the previously mentioned simulation opportunities. In addition, MATLAB® RoadRunner enables map and scenario creation, MATLAB® Automated Driving Toolbox enables sensor fusion studies, MATLAB® Vehicle Dynamics Blockset provides fully assembled reference application models that simulate driving maneuvers and an interface for Unreal Engine 4 supports the realistic visualization of the vehicles modeled in MATLAB® Simulink.

In this work, a simulation environment is studied and established. MATLAB® is selected for both algorithm development and simulation environment as it provides a flexible architecture for development. In addition, it supports stable external connections with other simulation opportunities. Vehicle dynamics, perception to a limited extend, motion planning and control algorithms are used and developed as exchangeable modules. Scenario generation for the entire operational design domain (ODD) was automated with

MATLAB® scripts. Similarly, rapid and intense testing was obtained with automated scenario execution and simulation results were exported for post evaluation.

To clarify this work's scope, the aim was neither to develop a “perfect” MPC nor to develop the “best” motion planning algorithm or to optimize the critical scenario identification problem. Instead, the aim was to establish an exchangeable and adjustable simulation environment for developing motion planning and control algorithms. Then further objectives were to test and evaluate the developed algorithm in the established simulation environment with safety standards and regulations for detecting the design imperfections and identifying the critical scenarios.

To sum up, the quintic polynomial method was selected for trajectory planning of lane change and overtake maneuvers. Dynamic re-planning of trajectory added the possibility of application in flowing traffic conditions. The inclusion of the Frenet frame method extended the applicability to the curved road scenarios. MATLAB® was selected for the development and simulation environment. A single-track bicycle model is selected for vehicle dynamics to include tire forces and slip. MPC was employed for path following. Scenario generation and execution were automated with MATLAB® scripts and simulation results were exported for post evaluation.

The main contributions of this work consist of:

- a Motion Planning Algorithm; with a dynamic re-planning of trajectory which is represented by a quintic polynomial and based on the Frenet frame.
- a Simulation Environment in MATLAB®; with a flexible architecture including vehicle dynamics, perception, motion planning and control algorithms.
- an Automated Scenario generation and execution; for exploration of operational design domain and identification of critical scenarios and design imperfections.

The organization of the rest of this study is as follows:

Section 3 describes the terms and concepts by presenting the standards and regulations for the automated vehicles. Section 4 presents the simulation environment for algorithm development in detail consisting of architecture, vehicle dynamics, perception, motion planning, control unit and scenario reader titles. Then, Motion planning and Control Algorithms are described in the Section 5. Section 6 delivers the test results of the developed algorithm in a simulation environment and discussion. Furthermore, the section discusses and evaluates the results. Finally, the Section 7 consists of concluding thoughts on the study and recommendations for further works are expressed.

3. TERMS AND CONCEPTS

3.1.Automated Driving and Vehicles Standard: SAE J3016 [28]

This proposed practice provides a fully descriptive classification of levels of driving automation in motor vehicles on the road and includes working definitions for advanced levels of driving automation as well. as related terms and definitions. This recommended practice does not provide specifications or impose requirements for the operation of automation systems.

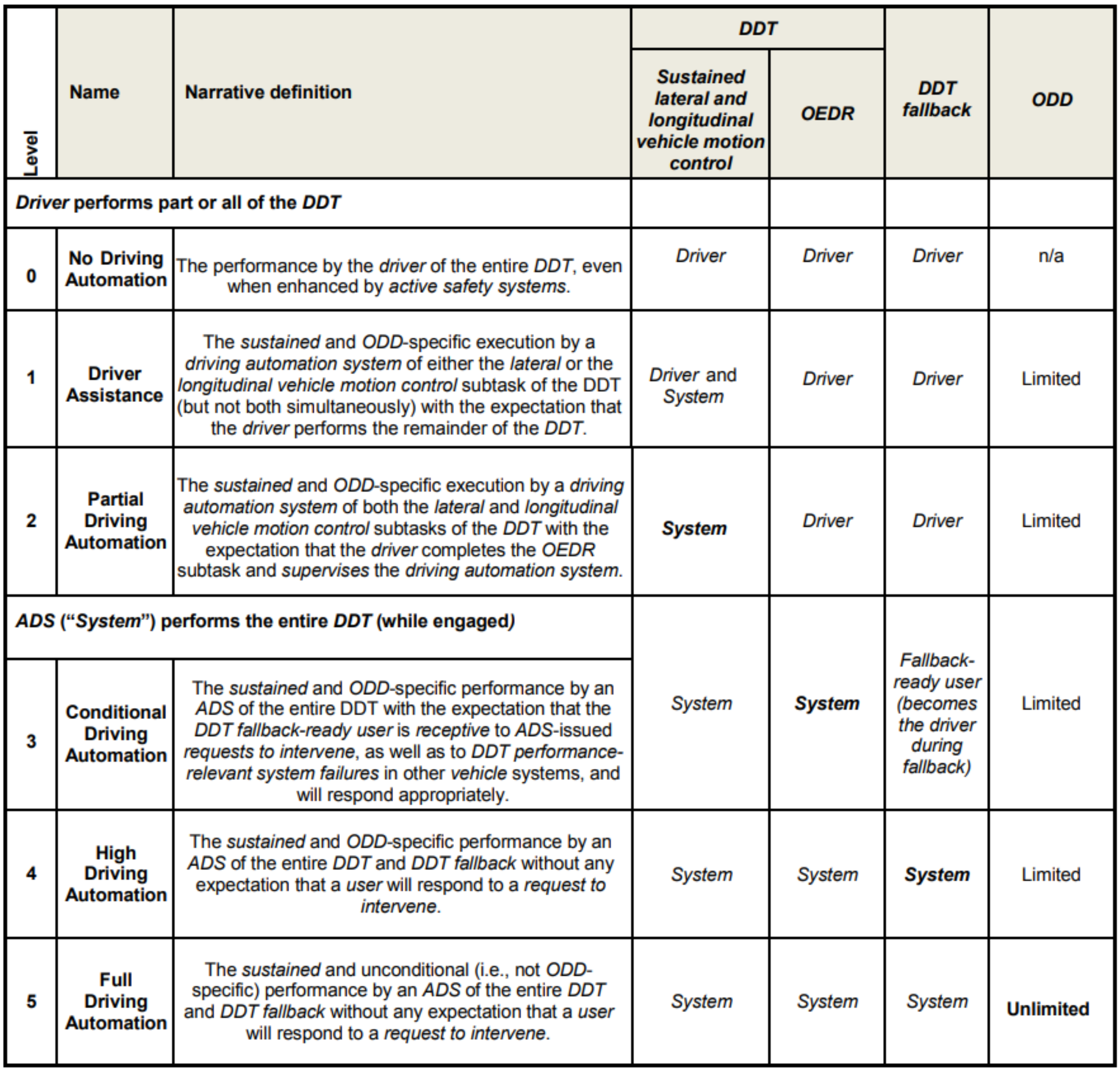
In SAE J3016 [28], the standardization of levels of driving automation and related terminology serves several purposes, related to:

- *Clarification of the role of the (human) driver, if any, when participating in the automated driving system.*
- *Answering questions about scope when developing laws, policies, regulations, and standards.*
- *Providing a useful framework for driving automation specifications and requirements.*
- *Providing clarity and stability in communication on the topic of autonomous driving, as well as a useful shortcut that saves considerable time and effort.*

3.1.1. Basic Terminology

This proposed practice provides a classification for automotive driving automation systems that perform some or all of the dynamic driving tasks (DDT) sustainably and at levels ranging from no driving automation (Level 0) to full driving automation (Level 5). It provides detailed definitions for these six levels of driving automation in the context of motor vehicles and how they operate on the roadways. These level definitions, along with the additional supporting terms and definitions provided here, can be used to fully describe the driver automation features fitted to the vehicle. mechanized in a functionally appropriate and consistent manner. "On-road" means publicly accessible roads (including parking lots and private grounds accessible to the public) that are generally accessible to vehicle users of all classes and degrees of driver automation (including the absence of driver automation), as well as motorcyclists, cyclists, and pedestrians.

As a summary, the Table 3-1 from SAE is given.



Level	**Name**	**Narrative definition**	***DDT***		***DDT fallback***	***ODD***
			Sustained lateral and longitudinal vehicle motion control	***OEDR***		
Driver* performs part or all of the *DDT						
0	**No Driving Automation**	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	**Driver Assistance**	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	**Partial Driving Automation**	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
ADS* (“*System*”) performs the entire *DDT* (while engaged*)						
3	**Conditional Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
4	**High Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	**Full Driving Automation**	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

Table 3-1 Summary of levels of driving automation [28]

Changes in the functionality of driving automation systems change the role of (human) users and provide the basis for classifying such systems, for example:

- If the driving automation system performs the DDT vertical and/or horizontal vehicle motion control subtasks, but the driver is still expected to complete the DDT in conditions such as DDT fallback: this corresponds to Levels 1 and 2.
- If the driving automation system runs the entire DDT; but when a performance-related DDT system error occurs, or if the driver automation system is about to terminate the Operations Design Domain (ODD), the user with DDT fallback is expected to take over the DDT. The user is receptive and can resume DDT performance when prompted. This distribution of roles corresponds to Level 3.

- Finally, if the driving automation system can perform all DDT and DDT fallback within a given ODD or in all driver-controllable on-road driving conditions (unlimited ODD). The users in the vehicle, while ADS is performing all DDT tasks, becomes the passengers. This distribution of roles corresponds to Levels 4 and 5.

It is important to note that, the Level 5 Full Driving Automation is an unconditional and is not ODD specific. On the other hand, Level 4 High Driving Automation is ODD-specific. This can be further inspected in the Table 3-1 from SAE J3016 [28].

3.2.Automated Lane Keeping Systems (ALKS): UN No. 157 [29]

There are several UN Regulations regarding Automated Driving System (ADS) features. Among them, the ALKS standard is emphasized strongly since it requires a stable performance with changing traffic states and changing environmental conditions. This means the vehicle should be able to perform the DDT on roads with curvature, roads with realistic friction and in dynamic traffic conditions. Therefore, not only the framework should be able to provide this testing environment for ALKS scenarios, but also the motion planning algorithms must be able to calculate a trajectory dynamically.

Goal of the regulation is to provide consistent requirements for vehicle certification for Automated Lane Keeping Systems (ALKS). Without additional driver input, ALKS regulates the vehicle's lateral and longitudinal movement over lengthy periods. ALKS is a vehicle control system in which the activated system is in primary control.

The ALKS standard has defined a certain ODD for Automated Driving System (ADS) to operate. The original wording of this Regulation sets a maximum operating speed of 60 km/h for passenger automobiles and commercial vehicles (M1 vehicles).

This Automated Driving System feature combined with above mentioned ODD places this Automated Lane Keeping System under the SAE J3016 Automation Level 3.

General standards for system safety and failsafe reaction are included in this regulation. When the ALKS is turned on, it will take over the driving responsibility from the driver, i.e., it will handle all scenarios, even failures, and it will not jeopardize the safety of the vehicle's occupants or other road users. The driver does, however, can overrule the system at any moment. The Regulation also specifies how the ALKS must safely hand over the driving duty to the driver, including the capacity for the system to come to a halt if the driver does not respond correctly.

3.3.Scenario Definition and Critical Scenario Concept: ISO-34501 [30]

ISO 34501 defines concepts for automated driving system (ADS) test scenarios. The contents are intended for use with ADS of Level 3 and higher, as specified by SAE J3016, also known as ISO/SAE PAS 22736 [28]. At the time of this study, the ISO-34501 is still in development progress. The current definitions from the standard are presented in what follows.

3.3.1. Dynamic Driving Task (DDT)

All operational and tactical activities that are required to operate a vehicle in on-road activity instantaneously, eliminating strategic operations such as trip planning and destination and waypoint selection.

3.3.2. Operational Design Domain (ODD)

The exact circumstances in which a given driving automation system or feature, such as driving modes, is designed to operate.

3.3.3. Automated Driving System (ADS)

This term is used to designate a Level 3, 4, or 5 driving automation system that is capable of continuously executing the complete dynamic driving task (DDT), regardless of whether it is constrained to a certain operational design domain (ODD).

3.3.4. Subject Vehicle

The vehicle under observation. In this study, “Ego Vehicle” is used to express the same meaning.

3.3.5. Entity

Element of interest of a scenario.

3.3.6. Dynamic Environment

Set of dynamic entities that are part of the environment.

3.3.7. Scene

Snapshot of all entities including the ADS/Subject Vehicle, scenery, dynamic environment, and all actor and observer self-representations, and the relationships between those entities.

3.3.8. Scenario

Sequence of the scenes integrated with the ADS(s)/Subject Vehicle(s), and its/their interactions in the process of performing (a) certain Dynamic Driving Task(s) (DDT).

3.3.9. Event

State change of an entity within the scenario.

3.3.10. Trigger

Event that initiates or ends an action.

3.3.11. Actor

Traffic participant with the capability to act and react in the scenario.

3.3.12. Situation

Scene from the perspective of an actor.

3.3.13. Maneuver

Series of actions to change or maintain the position of an actor.

In addition to the mentioned definitions from ISO 34501, road adhesion coefficient and clearance is explained as follows:

- Road adhesion coefficient is a friction coefficient between the road and vehicle tire. In study, tire-road coefficient of friction is used to express the same meaning.
- Clearance is a convenient relative distance for the safety of the vehicle. In study, convenient distance is used to express the same meaning.

4. SIMULATION ENVIRONMENT FOR ALGORITHM DEVELOPMENT

The simulation environment is established to satisfy the requirement for testing and evaluation of the developed algorithm. The simulation environment created during this thesis work has an exchangeable and adjustable architecture. This lays the possibility of simulation with different vehicle dynamics, perception and controller methods.

In the created simulation environment, the vehicle dynamics can be adjusted to test robustness, the perception can be altered to test error propagation and different controller types can be utilized to compare performances. The flowing traffic conditions, the different map settings with changing road curvatures and variable road adhesion coefficients are implemented with the Scenario Reader block. The block performs the initialization for controller and scenario parameters such as initial traffic state, map state and road conditions. The Scenario Visualization Block enables the visualization of the running simulation and performed the recording of the simulation parameters.

The simulation environment has the following properties:

- Automated scenario generation and execution, with real-time and offline visualization;
- Flowing traffic environment including different actors and adjustable actor behaviors on different conditions by roads (road adhesion coefficient and curvature);
- Customizable vehicle models with lateral dynamics to evaluate the performances and stability.

The simulation environment is built in MATLAB®. The main body of the simulation consists of the MATLAB® Simulink model where functions and scripts are developed by using MATLAB® programming language.

The general overview of the simulation environment is given in Figure 4-1.

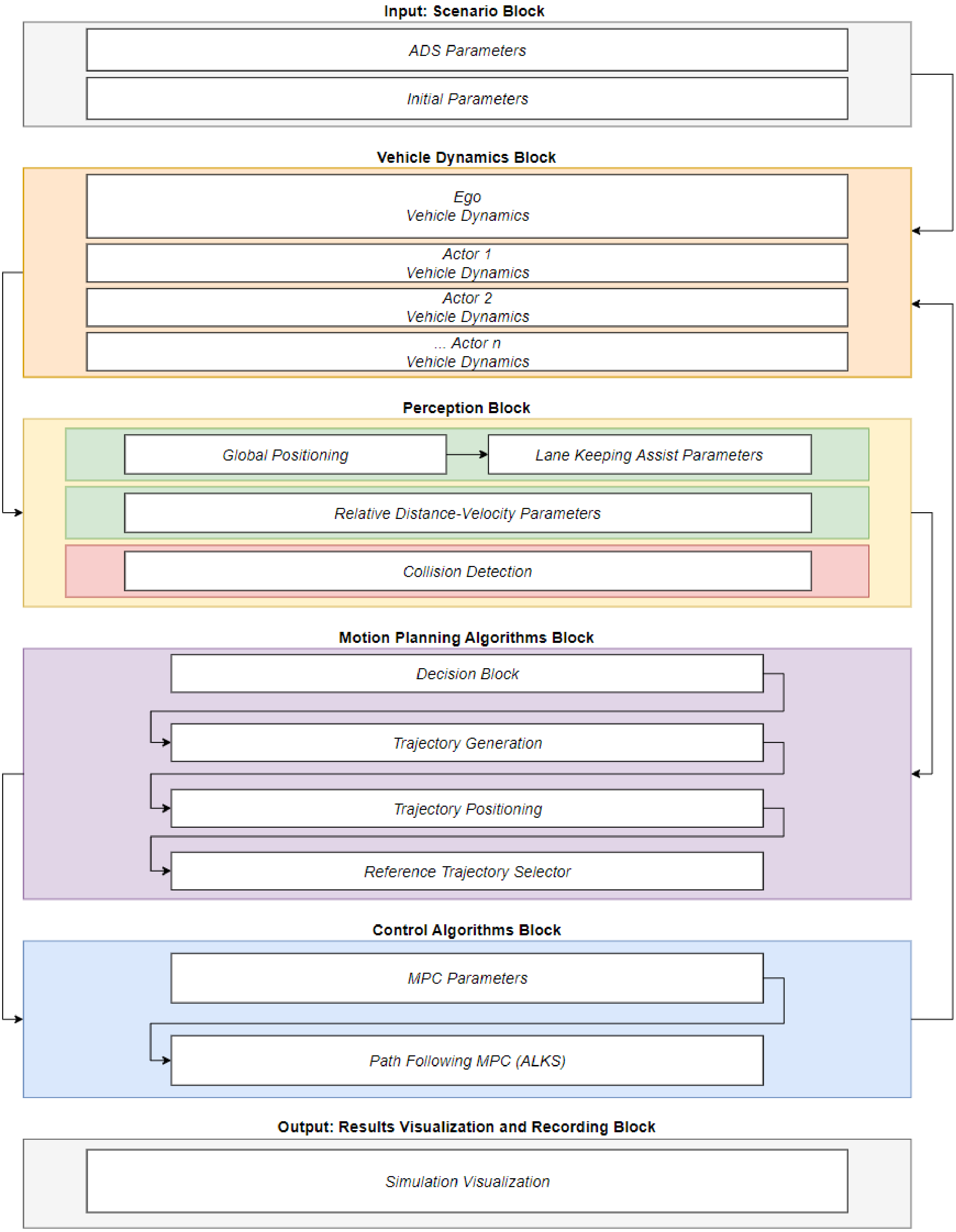


Figure 4-1 Overview of the Simulation Environment

4.1.Architecture

In this section, the architecture of the simulation environment will be inspected in detail. The architecture consists of several blocks which are

- Scenario Reader: a block for initialization of the controller and scenario parameters;
- Vehicle Dynamics Block: a block for vehicle dynamics of both subject vehicle and actors;
- Perception Block: a block for simulation of perception for the sensory domain under interest;
- Motion Planning Algorithms Block: a block for motion planning studies where decision-based trajectory generation and selection are utilized;
- Control Algorithms Block: a block for controller implementation to perform actions such as path following;
- Results Visualization and Recording Block: a block for real-time visualization of the simulation running and plotting of results.

The simulation environment has parameters to define solver configuration and system communication rates. The standard communication rate of 10 Hz was selected for the main sampling frequency. The vehicle dynamics block has the same sampling frequency as the simulation to provide suitable accuracy of the motion behavior of the vehicle. The configuration parameters of the simulation environment are given in Table 4-1.

Table 4-1 Configuration Parameters

Configuration Parameters		
Value	*Unit*	*Description*
ode4	-	Runge-Kutta for solver method
0.01	s	Fixed-step size for a fundamental sample time of the simulation
100	Hz	Vehicle Dynamics Block sampling frequency (same as the simulation)
10	Hz	Sensor Perception Block sampling frequency
10	Hz	Motion Planning Algorithms Block sampling frequency
10	Hz	Control Algorithms Block sampling frequency

In the following subsections, each block will be explained.

4.2.Vehicle Dynamics

The vehicle dynamics contain systems for the subject vehicle and the actors. The system has an overview as follows (Figure 4-2).

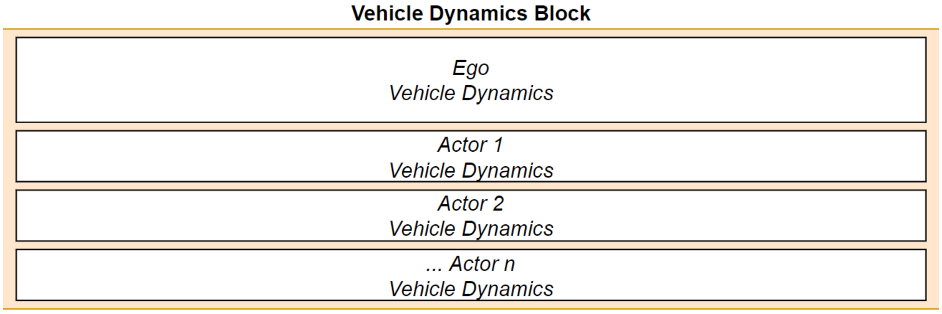


Figure 4-2 Overview of the Vehicle Dynamics Block

As far as vehicle dynamics is concerned, a single-track bicycle model evaluates longitudinal, lateral, and yaw motion using a rigid two-axle vehicle body model. The block includes the vehicle mass and aerodynamic drag induced by acceleration and steering between the axles. The single-track model is common in automated driving studies to mimic nonholonomic vehicle motion, especially when pitch, roll, and vertical motion are not significant [32].

The single-track bicycle model diagram is presented in Figure 4-3.

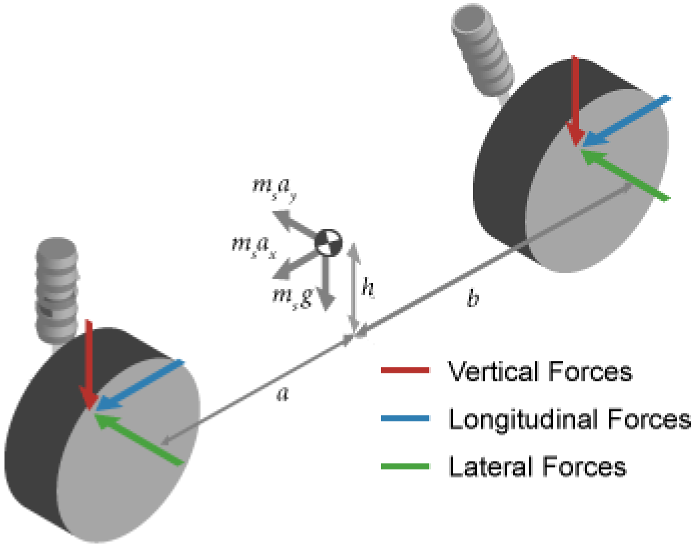


Figure 4-3 Single-track Bicycle Model Diagram [32]

The single-track model utilized the “External Longitudinal Forces” equations mode in the prebuilt MATLAB® block. The following equations were used to estimate vehicle’s motion and drag values for the single-track model.

The rigid body planar dynamics are calculated as:

$$\ddot{x} = \dot{y}r + \frac{F_{xf} + F_{xr} + F_{xext}}{m}$$ Equation 4.1a

$$\ddot{y} = -\dot{x}r + \frac{F_{yf} + F_{yr} + F_{yext}}{m}$$ Equation 4.2b

$$\dot{r} = \frac{aF_{yf} - bF_{yr} + M_{zext}}{I_{zz}}$$ Equation 4.3c

$$r = \dot{\Psi}$$ Equation 4.4d

The external forces and moments are calculated as:

$$F_{x,y,z\,ext} = F_{d\,x,y,z} + F_{x,y,z\,input}$$ Equation 4.2a

$$F_{x,y,z\,ext} = F_{d\,x,y,z} + F_{x,y,z\,input}$$ Equation 4.2b

$$F_{xft} = F_{xf\,input}$$ Equation 4.2c

$$F_{yft} = -C_{yf}\alpha_f\mu_f\frac{F_{zf}}{F_{z\,nom}}$$ Equation 4.2d

$$F_{xrt} = F_{xr\,input}$$ Equation 4.2e

$$F_{yrt} = -C_{yr}\alpha_r\mu_r\frac{F_{zr}}{F_{z\,nom}}$$ Equation 4.2f

The tire forces are calculated as:

$$\alpha_f = \text{atan}\left(\frac{\dot{y} + ar}{\dot{x}}\right) - \delta_f$$ Equation 4.3a

$$\alpha_r = \text{atan}\left(\frac{\dot{y} - br}{\dot{x}}\right) - \delta_r$$ Equation 4.3b

$$F_{xf} = F_{xft}\cos\left(\delta_f\right) - F_{yft}\sin(\delta_f)$$ Equation 4.4a

$$F_{yf} = -F_{xft}\sin\left(\delta_f\right) + F_{yft}\cos(\delta_f)$$ Equation 4.4b

$$F_{xr} = F_{xrt}\cos\left(\delta_f\right) - F_{yrt}\sin(\delta_r)$$ Equation 4.4c

$$F_{yr} = -F_{xrt}\sin(\delta_r) + F_{yrt}\cos(\delta_r)$$ Equation 4.4d

The aerodynamic drag forces and moments are calculated as:

$$w_x = W_x \cos(\Psi) + W_y \sin(\Psi)$$ Equation 4.5a

$$w_y = W_y \cos(\Psi) - W_x \sin(\Psi)$$ Equation 4.5b

$$w_z = W_z$$ Equation 4.5c

$$\bar{w} = \sqrt{(\dot{x} - w_x)^2 + (\dot{y} - w_y)^2 + (w_z)^2}$$ Equation 4.5d

$$F_{dx} = -\frac{1}{2TR} C_d A_f P_{abs} (\bar{w})^2$$ Equation 4.6a

$$F_{dy} = -\frac{1}{2TR} C_s A_f P_{abs} (\bar{w})^2$$ Equation 4.6b

$$F_{dz} = -\frac{1}{2TR} C_l A_f P_{abs} (\bar{w})^2$$ Equation 4.6c

$$M_{dr} = -\frac{1}{2TR} C_{rm} A_f P_{abs} (\bar{w})^2 (a + b)$$ Equation 4.7a

$$M_{dp} = -\frac{1}{2TR} C_{pm} A_f P_{abs} (\bar{w})^2 (a + b)$$ Equation 4.7b

$$M_{dy} = -\frac{1}{2TR} C_{ym} A_f P_{abs} (\bar{w})^2 (a + b)$$ Equation 4.7c

These equations are used to express the dynamics of the single-track bicycle model.

In this section, the subject vehicle and actor dynamics will be inspected separately in 4.2.1 and 4.2.2.

4.2.1. The Subject Vehicle

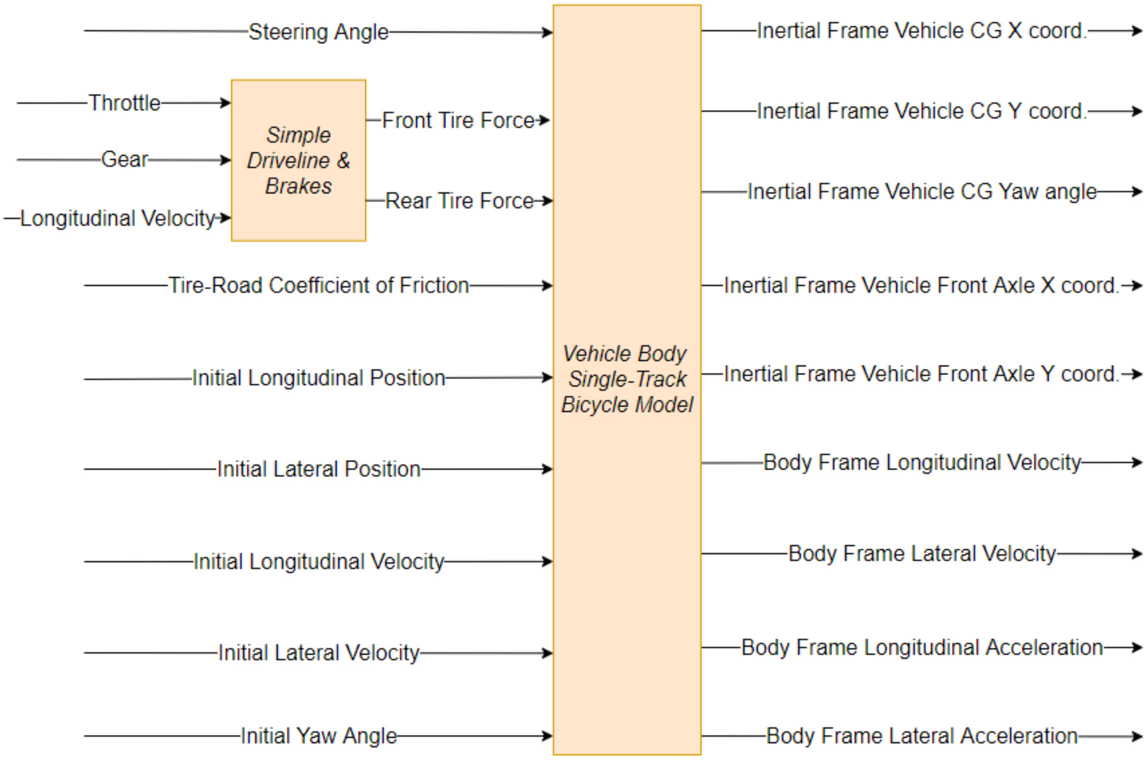


Figure 4-4 Vehicle Dynamics Mechanism of the Subject Vehicle

The subject vehicle system consists of a single-track bicycle model and a simple driveline-brakes model as presented in Figure 4-4.

The system loads the initial values for the subject vehicle from the Scenario Reader. Then it takes the control inputs produced by the controller such as throttle and steering angle. Road adhesion coefficient is supplied to evaluate vehicle handling stability.

The system produces signals representing the current state of the vehicle such as the current position on the track in the inertial frame for both the center of gravity of the vehicle (CG) and the front axle of the vehicle. The longitudinal and lateral motion signals such as velocity and acceleration in the body frame are also calculated.

The block accepts inputs such as external longitudinal velocity or external longitudinal forces. The longitudinal forces are introduced by the simple driveline and brakes model. The lateral forces are calculated based the tire slip angles and linear cornering stiffness. Then the block is modified to accept external longitudinal forces to calculate vehicle dynamics. Thus, the study included the changes in the longitudinal velocity caused by the lateral and yaw motion.

The Vehicle Dynamics Block has the following input and output signals (Table 4-2).

Table 4-2 Vehicle Dynamics Block Input and Output Signals of the Subject Vehicle

Vehicle Dynamics Block Input and Output Signals

Inputs	*Block*	*Outputs*
Steering Angle →		→ Inertial Frame Vehicle CG X coord.
Throttle →		→ Inertial Frame Vehicle CG Y coord.
Gear →		→ Inertial Frame Vehicle CG Yaw angle
Longitudinal Velocity →		→ Inertial Frame Vehicle Front Axle X coord.
Tire-Road Coefficient of Friction →		→ Inertial Frame Vehicle Front Axle Y coord.
Initial Longitudinal Position →		→ Body Frame Longitudinal Velocity
Initial Lateral Position →		→ Body Frame Lateral Velocity
Initial Longitudinal Velocity →		→ Body Frame Longitudinal Acceleration
Initial Lateral Velocity →		→ Body Frame Lateral Acceleration
Initial Yaw Angle →		

The Subject Vehicle block also contains a simple driveline and brakes model. The simple driveline and brakes system uses two low-level transfer functions (TF) as equations 4.8a and 4.8b, to represent the dynamics of powertrain forces and braking forces which are included in the external forces as inputs to the vehicle block.

$$Powertrain\ TF = \frac{1}{\tau \cdot s + 1}$$ Equation 4.8a

$$Braking\ TF = \frac{1}{\tau_2 \cdot s + 1}$$ Equation 4.8b

The parameters of the subject vehicle are as follows (Table 4-3).

Table 4-3 Subject Vehicle Parameters

Subject Vehicle Parameters

Symbol	*Value*	*Unit*	*Description*
m	1670	kg	The total mass of the vehicle
I_{zz}	2100	kgm^2	Yaw moment of inertia of the vehicle
l_f	0.99	m	Longitudinal distance from CG to front tires
l_r	1.7	m	Longitudinal distance from CG to rear tires
Cf	61595	N/rad	Cornering stiffness of front tires
Cr	52095	N/rad	Cornering stiffness of rear tires
g	9.81	m/s^2	Gravitational constant

The parameters of the simple driveline and brakes are as follows (Table 4-4).

Table 4-4 Simple Driveline and Brakes Parameters

Simple Driveline and Brakes Parameters		
Symbol	*Value*	*Description*
tau	0.50	The time constant of powertrain dynamics
tau_2	0.07	The time constant of braking dynamics

The parameters to represent the physical dimensions of the vehicles and actors are also included in the initialization of scenario phase. Physical dimensional properties become important for maneuvers since the lateral intervehicle distance becomes important especially when vehicles become adjacent. Lane change and overtake maneuvers can trigger ADS response in this kind of situation. Emergency maneuvers for obstacle avoidance may create situations with close lateral distances between the subject vehicle and other actors.

The parameters for the physical dimensions of the Subject Vehicle and actors are as follows (Table 4-5).

Table 4-5 Physical Dimension Parameters

Physical Dimension Parameters		
Value	*Unit*	*Description*
1.8	m	The width of the Subject Vehicle
4.5	m	The length of the Subject Vehicle
1.8	m	The width of the Actor Car
4.5	m	The length of the Actor Car
2.5	m	The width of the Actor Truck
8.2	m	The length of the Actor Truck
1.7	m	The width of the Actor Bicycle
0.45	m	The length of the Actor Bicycle
0.45	m	The width of the Actor Pedestrian
0.24	m	The length of the Actor Pedestrian

In the architecture, the actor subsystem is placed under the vehicle dynamics block. The actor subsystem can be placed separately since the subsystem has a standalone control loop from the simulation. The actor subsystem loads the initialization parameters from the Scenario Reader block and outputs the parameters representing the current state of the actor to the Perception block. Therefore, it is convenient to place the actor subsystem between the Perception block and Scenario Reader block.

4.2.2. The Actor Subsystem

The Actor subsystem contains different motion profiles for different types of actors. Actor vehicles can follow the road center with constant or changing velocity profiles as their main driving task. Additionally, actor vehicles can swerve about the road center or perform maneuvers such as cutting into or cutting out of the original driving lane. Pedestrians can try to cross the road perpendicularly which can be utilized to simulate emergency braking in scenarios. The actor motion profiles will be explained further in the section dedicated to Scenario Reader.

The overview of the Actor Subsystem is given in Figure 4-5.

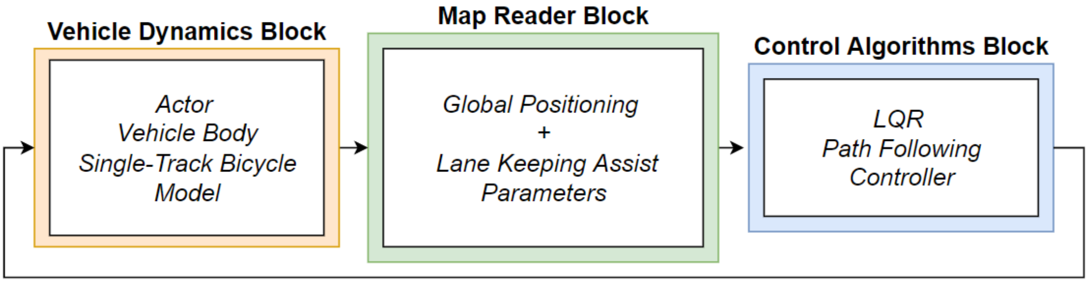


Figure 4-5 Overview of the Actor Subsystem

The Actor subsystem is relatively uncomplicated. Similar to the Subject Vehicle, actors have a vehicle dynamics block, map reader block and control algorithms block. The vehicle dynamics block is exchangeable and adjustable as in the case of the Subject Vehicle. As previously mentioned, the vehicle dynamics for the Subject Vehicle was single-track bicycle model with “External Longitudinal Forces” mode. However, in the actor subsystem, the single-track bicycle model with “External Longitudinal Velocity” mode in the prebuilt MATLAB® block was preferred. By defining the set longitudinal velocity, the model can be controlled directly with the velocity signal. The velocity signal can be adjusted in simulation to perform flowing traffic situations.

The parameters of the actor vehicle are as follows (Table 4-6).

Table 4-6 Actor Vehicle Parameters

Actor Vehicle Parameters			
Symbol	*Value*	*Unit*	*Description*
m	1670	kg	The total mass of the vehicle
I_{zz}	2100	kgm^2	Yaw moment of inertia of the vehicle
l_f	0.99	m	Longitudinal distance from CG to front tires
l_r	1.70	m	Longitudinal distance from CG to rear tires
Cf	61595	N/rad	Cornering stiffness of front tires
Cr	52095	N/rad	Cornering stiffness of rear tires
g	9.81	m/s^2	Gravitational constant

The Map Reader block provides the lane keeping assist parameters to the controller block. This block will be explained further in the next section for perception. The control algorithms block may contain a PID controller, LQR or even MPC. In this study, LQR was selected due to the simplicity of the actors' tasks. Moreover, this control type is applicable in real-life and has acceptable computational cost efficiency. Since the main focus of the study is the Subject Vehicle and its maneuvers, the actor subsystem is kept plain and straightforward (Figure 4-6).

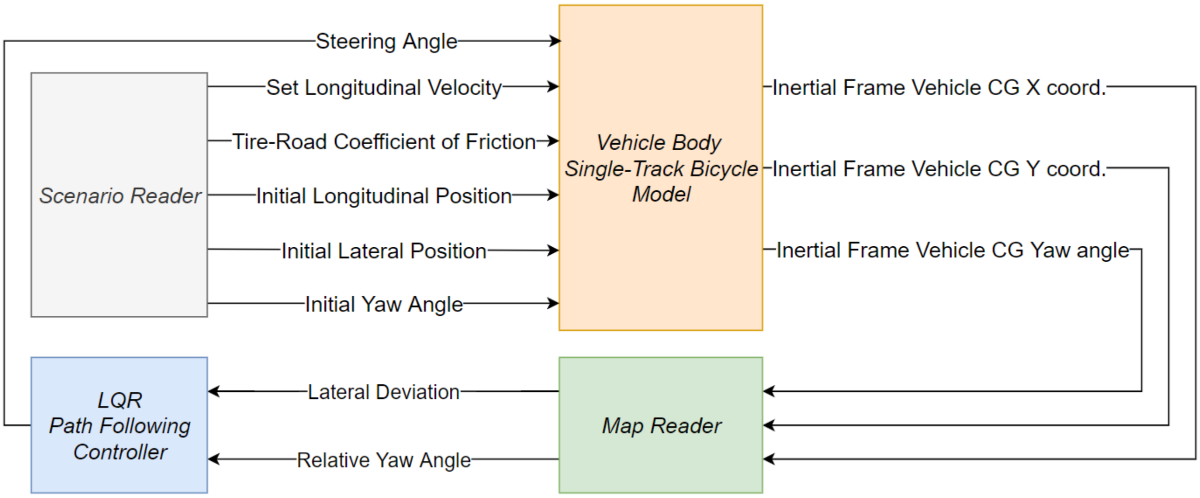


Figure 4-6 Vehicle Dynamics Mechanism of the Actor Subsystem

It is important to explain the standpoint of this subsystem for further clarification of the situation. The subsystem has a standalone control loop from the simulation. Still, the perception block can acquire information from the actor subsystem. For example, the relative distance and velocity data is assumed be acquired with V2V communication between vehicles.

The Actor Subsystem has the following input and output signals (Table 4-7).

Table 4-7 Actor Subsystem Input and Output Signals

Actor Subsystem Input and Output Signals				
Inputs		*Block*		*Outputs*
Steering Angle	→		→	Inertial Frame Vehicle CG X coord.
Set Longitudinal Velocity	→		→	Inertial Frame Vehicle CG Y coord.
Tire-Road Coefficient of Friction	→		→	Inertial Frame Vehicle Front Axle Y coord.
Initial Longitudinal Position	→		→	Body Frame Longitudinal Velocity
Initial Lateral Position	→		→	Current Lane on the Road
Initial Yaw Angle	→			

4.3.Perception Block

The Perception block contains sensors such as global positioning, lane keeping assist parameters, relative parameters and collision detection. In this work, the primary focus was to develop motion planning and control algorithms. However, the perception block is necessary to obtain the necessary information for both motion planning and control algorithms. Therefore, the perception block is built assuming there are perfect V2V and V2X communications available and sensor noise is not included for the sake of simplicity. Thus, motion planning and control algorithms are assumed to utilize ground truth information from the required channels.

The overview of the perception block is given in Figure 4-7.

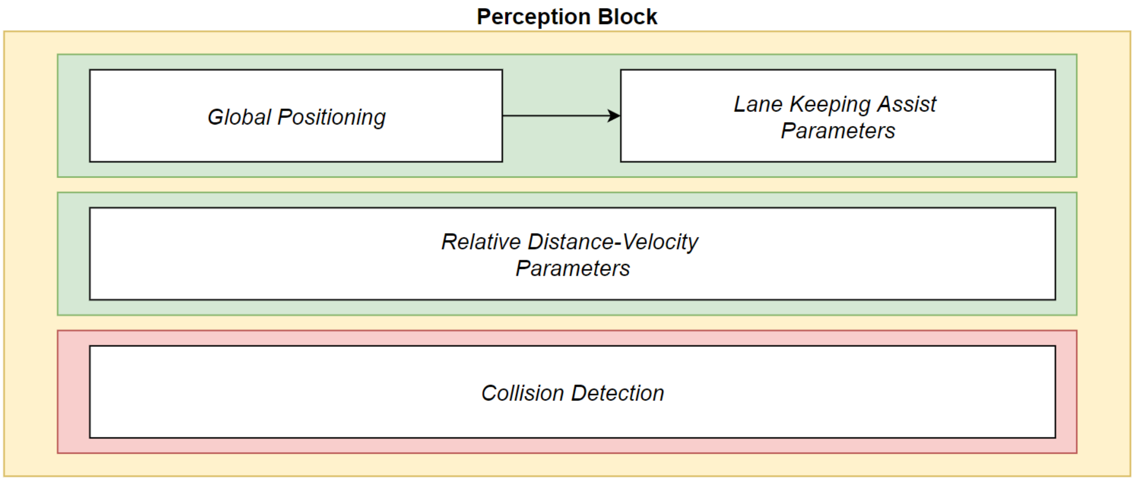


Figure 4-7 Overview of the Perception Block

4.3.1. Global Positioning and Lane Keeping Assist Parameters

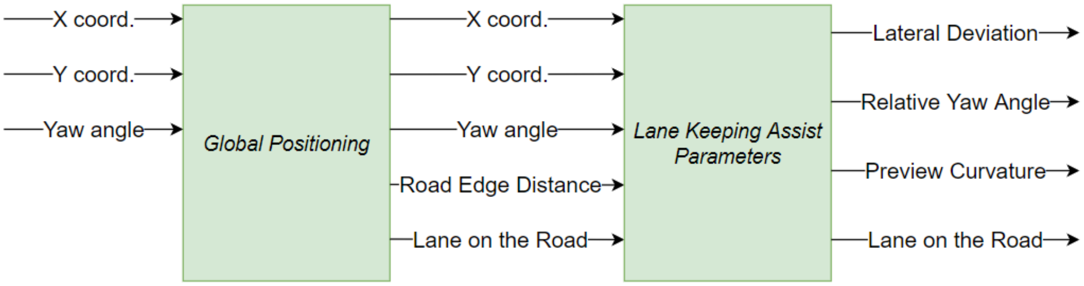


Figure 4-8 Mechanism of the Global Positioning and Lane Keeping Assist Parameters Blocks

The global positioning sensor transmits the necessary information about the current state of the vehicle. The subject vehicle is assumed to have V2X communication. The main purpose of this sensor is to provide the distance from the edge of the whole road with multiple lanes and to extract current lane information on the road.

The lane keeping parameters from MathWorks are as follows (Figure 4-9).

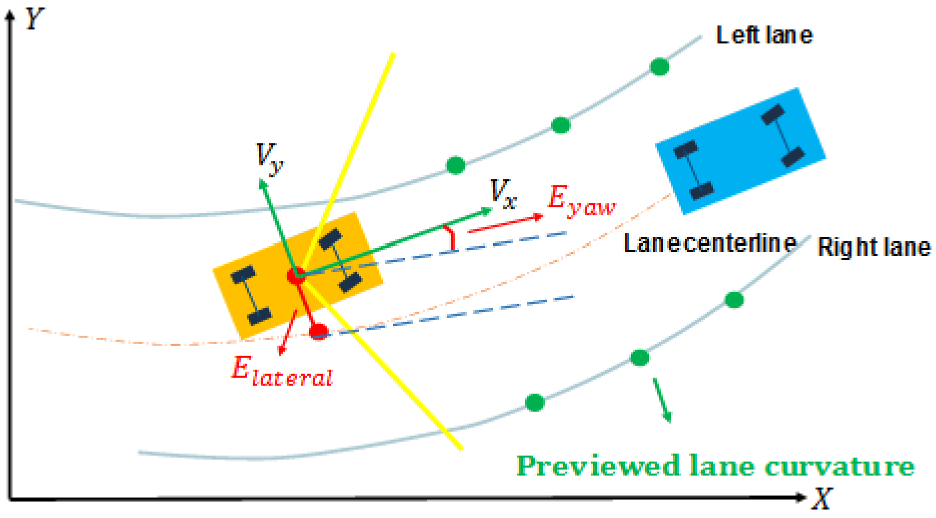


Figure 4-9 Lane Keeping Parameters Diagram [33]

- Lateral deviation is the distance between the center of the front axle of the subject vehicle and the center of the road.
- Relative yaw angle is the angle between the yaw angle of the subject vehicle and the tangent for the center of the road.
- Preview curvature is the road curvature for the road ahead. The road curvature can be specified as 1/R, where R is the radius of the curve.

Lateral deviation and relative yaw angle are scalar signals which are easy to implement and use. The preview curvature produces the information for the road ahead. This signal can be a scalar or vector. However, if the MPC is used, this signal’s length must be less than or equal to the Prediction Horizon. The controller parameters will be explained further in the 5.2.6.

It is important to note that, since the lane keeping sensors for lane edge detection are placed further to the front of the CG, it is useful to use the front axle states for the global positioning and lane keeping assist parameters sensors. Thus, the error can be directly correlated with the steering section of the subject vehicle.

The Global Positioning and Lane Keeping Assist Parameters Sensor has the following input and output signals Table 4-8.

Table 4-8 Global Positioning and Lane Keeping Assist Parameters Sensor Input and Output Signals

Global Positioning and Lane Keeping Assist Parameters Sensor Input and Output Signals

Inputs		*Block*		*Outputs*
X coord.	→		→	Lateral Deviation
Y coord.	→		→	Relative Yaw Angle
Yaw angle	→		→	Preview Curvature
			→	Current Lane on the Road

The Map Reader block mentioned in 4.2.2 works in a similar principle. In the actor subsection, a LQR was preferred, therefore the map reader block generates one less parameter which is the preview curvature. If the MPC was preferred, the preview curvature could be generated from the Map Reader block.

4.3.2. Relative Parameters Sensor

The Relative Parameters Sensor produces the necessary information about the current state of the flowing traffic. The block obtains the position and velocity information from the vehicles and process this information to produce the relative distance and relative velocity parameters for the motion planning and control algorithms (Figure 4-10).

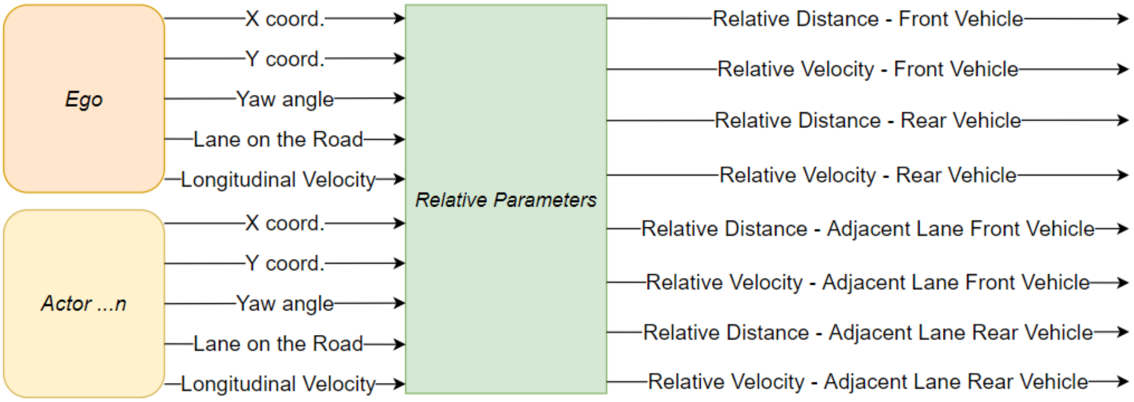


Figure 4-10 Mechanism of the Relative Parameters Block

The Relative Parameters block provides crucial information about the current state of the flowing traffic. The relative distance and the relative velocity between the Subject Vehicle and the leading vehicle are mainly required for ACC and AEB. The parameters related to the adjacent lanes are also required for the motion planning algorithms since the main focus is to create a secure and comfortable trajectory for the Subject Vehicle to safely follow.

The Relative Parameters Sensor has the following input and output signals (Table 4-9).

Table 4-9 Relative Parameters Sensor Input and Output Signals

Relative Parameters Sensor Input and Output Signals				
Inputs		*Block*		*Outputs*
X coord. (Ego)	→		→	Relative Distance - Front Vehicle
Y coord. (Ego)	→		→	Relative Velocity - Front Vehicle
Yaw angle (Ego)	→		→	Relative Distance - Back Vehicle
Current Lane on the Road (Ego)	→		→	Relative Velocity - Back Vehicle
Longitudinal Velocity (Ego)	→		→	Relative Distance - Adjacent Lane Front Vehicle
X coord. (Actor n)	→		→	Relative Velocity - Adjacent Lane Front Vehicle
Y coord. (Actor n)	→		→	Relative Distance - Adjacent Lane Back Vehicle
Yaw angle (Actor n)	→		→	Relative Velocity - Adjacent Lane Back Vehicle
Current Lane on the Road (Actor n)	→			
Longitudinal Velocity (Actor n)	→			

The global positioning sensor, the lane keeping assist parameters sensor and the relative parameters sensor provide the necessary information for the motion planning and control algorithms.

4.3.3. Collision Detection

The collision detection sensor produces the minimum distance information between the subject vehicle and actors and constantly checks the occurrence of a collision. This information is vital for the simulation. Since the study is mainly related to motion planning and control algorithms, the collision detection and minimum distance calculation produces precious information about the health and performance of the algorithm.

The collision block obtains the position and yaw angle information from Global Positioning sensor. Then, the block calculates the minimum distance based on the previously mentioned length and width parameters for the subject vehicle and actors (Table 4-5). The calculation is done by a minimum distance between two rotated rectangles. Since the CG positions, yaw angles and physical dimensions are known, the algorithm calculates the minimum distance between all actors and whether there is a collision or not (Figure 4-11).

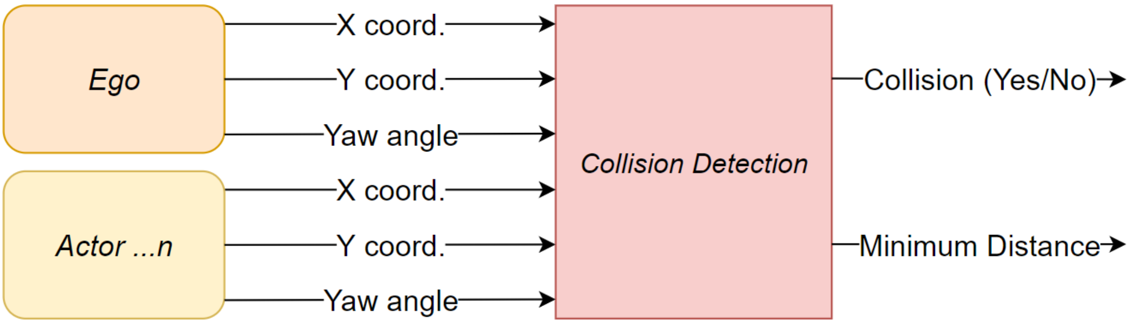


Figure 4-11 Mechanism of the Collision Detection Block

The collision detection sensor’s signals are directly included in the simulation results and exported. The simulation is terminated if there is a collision and the final scene is annotated for later evaluation.

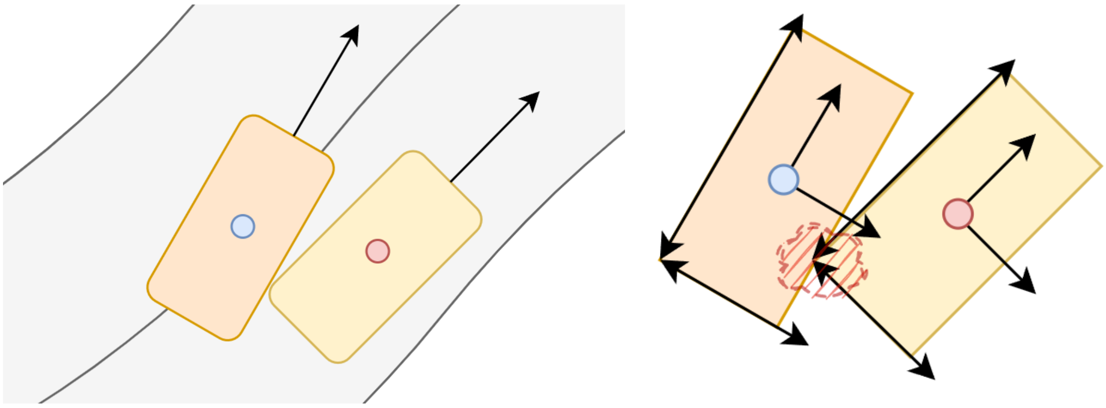


Figure 4-12 Collision Calculation via “Minimum Distance Between Two Rotated Rectangles” Method

A collision situation is presented in Figure 4-12. In that case the subject vehicle is seen to be unable to perform the collision avoidance maneuver.

The collision detection sensor also inspects other cases for the scenario termination. The actor vehicles’ only objective is to follow their respective road center. However, the subject vehicle is capable of changing lanes and performing overtaking maneuvers. Therefore, the simulation gets terminated by the collision block in case of contact between the subject vehicle and the road borders and/or other actors.

The Collision Detection Sensor has the following input and output signals (Table 4-10).

Table 4-10 Collision Detection Sensor Input and Output Signals

Collision Detection Sensor Input and Output Signals				
Inputs		*Block*		*Outputs*
X coord. (Ego)	→			
Y coord. (Ego)	→			
Yaw angle (Ego)	→		→	Collision (Yes/No)
X coord. (Actor n)	→		→	Minimum Distance
Y coord. (Actor n)	→			
Yaw angle (Actor n)	→			

The block gathers information directly from the simulation as ground truth.

4.4.Motion Planning

The overview of the Motion Planning system is given below (Figure 4-13).

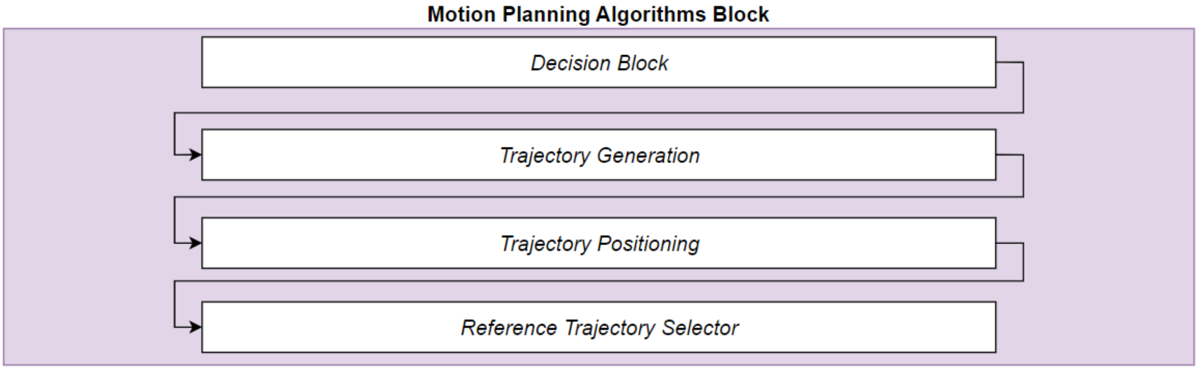


Figure 4-13 Overview of the Motion Planning Algorithms Block

The motion planning block contains a decision block, a trajectory generator block, a trajectory positioning block and a reference trajectory selector block.

The decision block obtains the related information to evaluate the situation and decides if a corrective maneuver is necessary or not. Then, if required, trajectory generation block generates a safe and comfortable trajectory. The trajectory positioning block functions as the Map Reader block in the previously mentioned actor subsystem which generates the trajectory following parameters like parameters for lane keeping assist. Finally, the reference trajectory selector block acquires the available references and then feeds the selected one to the Control Unit block.

4.4.1. Decision Block

The decision block evaluates the current situation of the flowing traffic and decides if there is a necessity for the subject vehicle to perform maneuver. The Decision block sends the road information and available spacing information to the trajectory generation block (Figure 4-14).

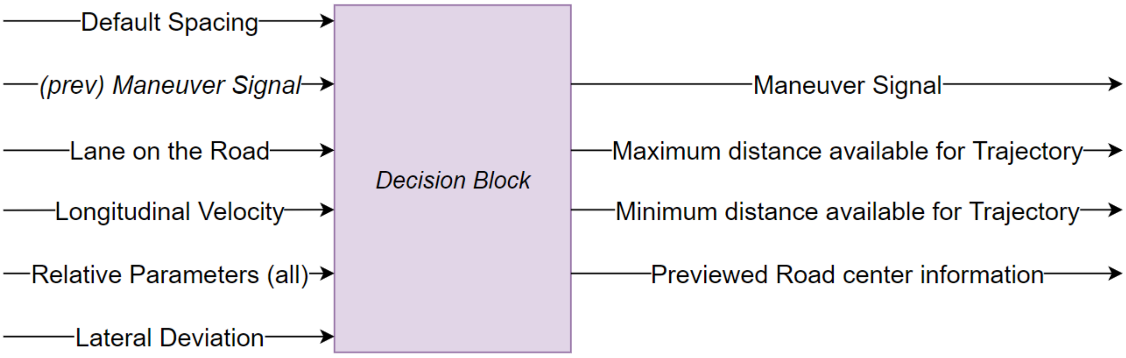


Figure 4-14 Mechanism of the Decision Block

The decision scheme for the decision block is as the follows (Figure 4-15).

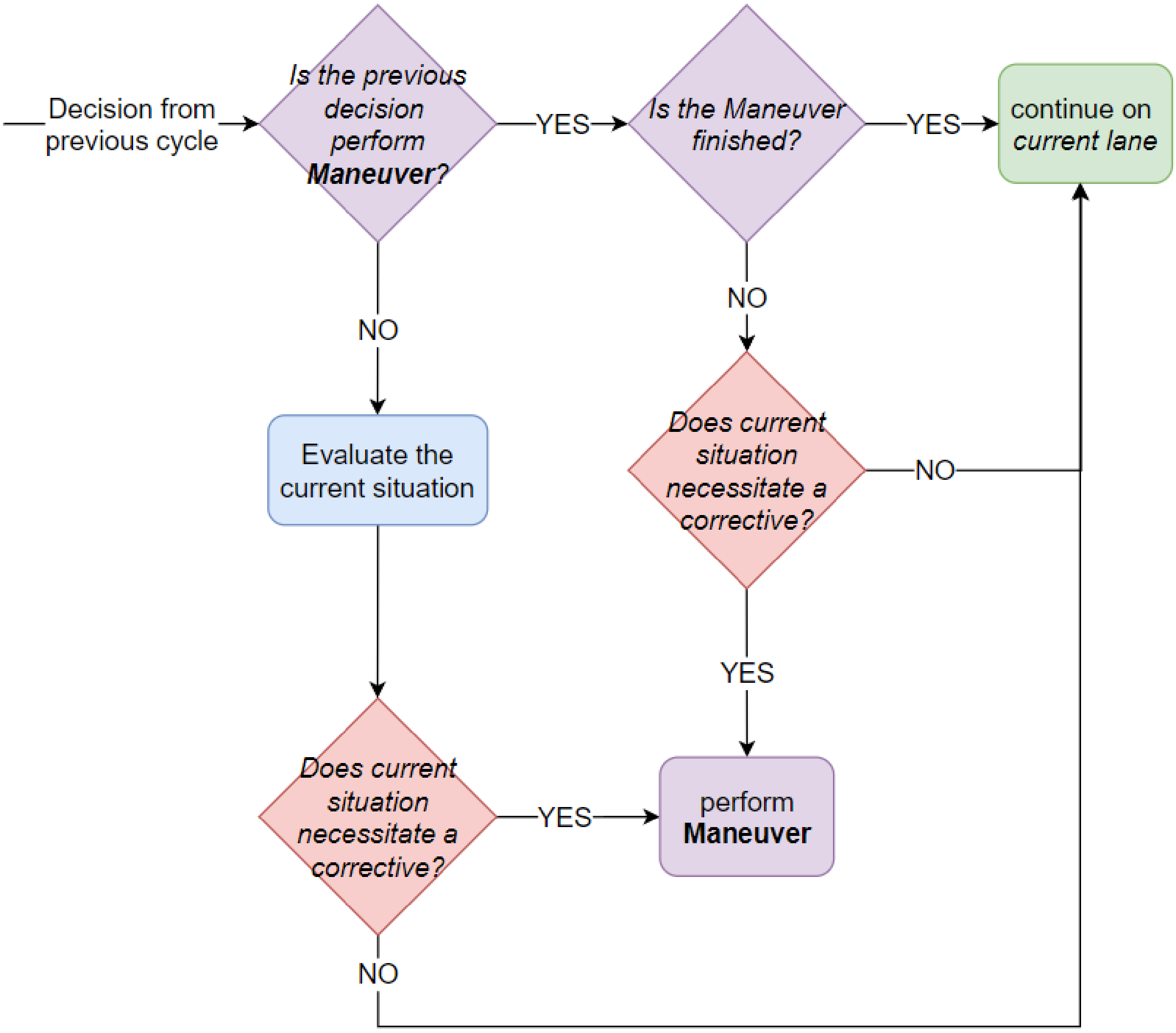


Figure 4-15 Decision Scheme of the Decision Block

A maneuver can be triggered by different situations and events. The result for the Subject Vehicle can be a lane change, overtake or collision avoidance. The convenient distance is defined as *Clearance* as given in the equation 4.9a where Time Gap (TG) and Default Spacing (DS) is given in Table 5-8.

$$Clearance = V_x * TG + DS \qquad \text{Equation 4.9a}$$

The distance becomes critical when the relative distance is smaller than the clearance.

$$Relative\ Distance \leq Clearance \qquad \text{Equation 4.9b}$$

The trigger functions used to evaluate the current situation are presented in Figure 4-16 and Figure 4-17.

1. If the relative distance at the front of Subject Vehicle is smaller than *convenient* and the leading vehicle's relative velocity is negative (Equation 4.9a and 4.9b)
2. If the relative distance at the behind of Subject Vehicle is smaller than *convenient* and trailing vehicle's relative velocity is positive (Equation 4.9a and 4.9b)

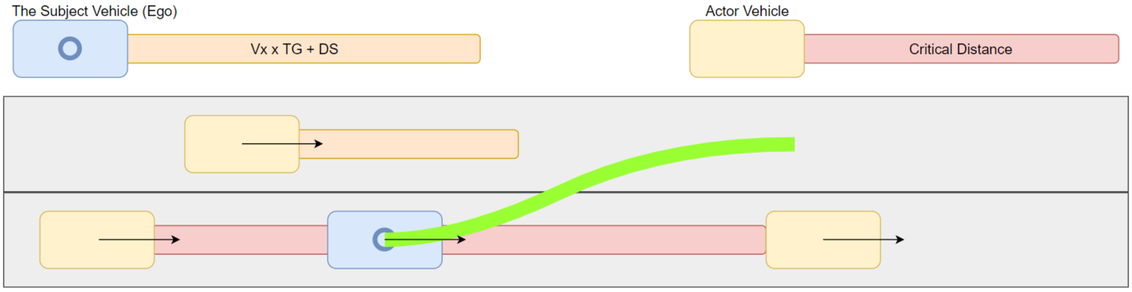


Figure 4-16 Relative Distance Trigger for Maneuver

3. If the current lane is used only for overtaking

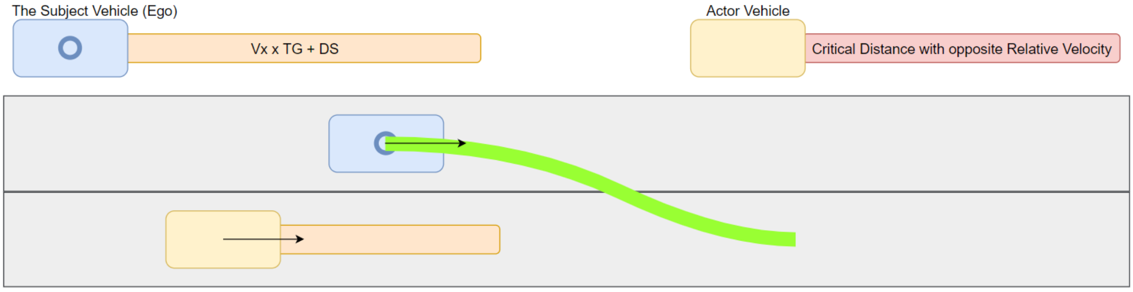


Figure 4-17 Passing Lane Trigger for Maneuver

The maneuver action can be terminated where the maneuver is completed. The terminate function when evaluating the current situation is given below.

1. If the lateral deviation error on the targeted lane is less than 0.10 meters

The Decision Block has the following input and output signals (Table 4-11).

Table 4-11 Decision Block Input and Output Signals

Decision Block Input and Output Signals

Inputs		*Block*		*Outputs*
Default Spacing	→			
(prev) Maneuver Signal	→		→	**Maneuver Signal**
Current Lane on the Road	→		→	Maximum distance available for Trajectory
Longitudinal Velocity	→		→	Minimum distance available for Trajectory
Relative Parameters (all)	→		→	Previewed Road center Information
Lateral Deviation	→			

The maximum distance and minimum distance available are the main input of the trajectory generation block. The trajectory generation block evaluates the available region for suitable trajectory generation.

4.4.2. Trajectory Generation

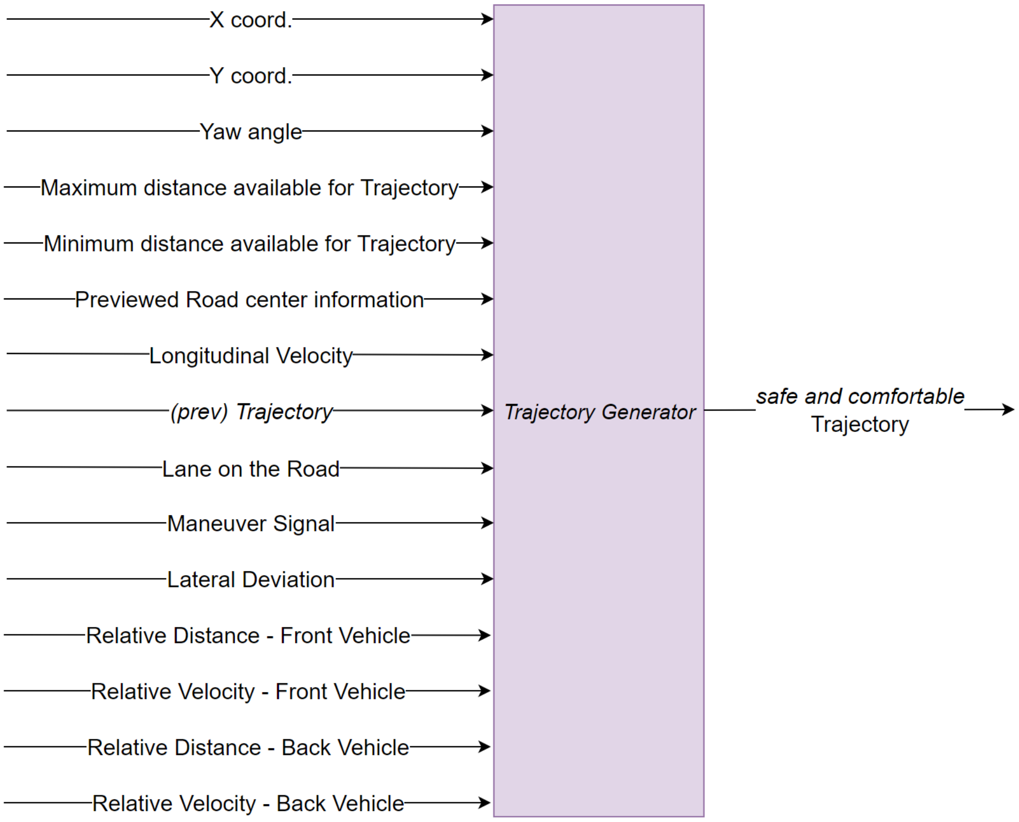


Figure 4-18 Mechanism of the Trajectory Generation Block

The trajectory generation block acquires the triggering signal related to maneuver generation. In such a case, this block uses the available trajectory region to calculate a comfortable and safe trajectory within the minimum and maximum distance available. The trajectory will be evaluated for both safety and comfort.

Normally, in a safe situation where the subject vehicle undertakes a simple lane change, comfort limits apply as given in equations 4.10a-b-c. However, if the situation is critical, these comfort limits will be increased to the vehicle's handling limits to perform the necessary avoidance maneuver. In the following sections of this study, it can be seen that the trajectory generated with comfort limits of 3.0 m/s^3, usually results in lateral accelerations less than 1.0 m/s^2.

If the motion profile for the planned trajectory has:

$$j_{y\,max} \leq 3.0\ m/s^3 \qquad \text{Equation 4.10a}$$

$$a_{y\,max} \leq 3.0\ m/s^2 \qquad \text{Equation 4.10b}$$

$$v_{y\,max} \leq 3.0\ m/s \qquad \text{Equation 4.10c}$$

then the trajectory satisfies the comfort limits.

The decision scheme for the trajectory generation block is presented in Figure 4-19. The design limits for the trajectory change accordingly to the situation.

The situation can be considered critical when (Figure 4-20):

- The relative distance front is smaller than the safety threshold
- The relative distance behind is smaller than the safety threshold

$$Relative\ Distance \leq DS \qquad \text{Equation 4.11}$$

If the motion profile for the planned trajectory has:

$$j_{y\,max} \leq 10.0\ m/s^3 \qquad \text{Equation 4.12a}$$

$$a_{y\,max} \leq 10.0\ m/s^2 \qquad \text{Equation 4.12b}$$

$$v_{y\,max} \leq 10.0\ m/s \qquad \text{Equation 4.12c}$$

then the trajectory satisfies the critical limits.

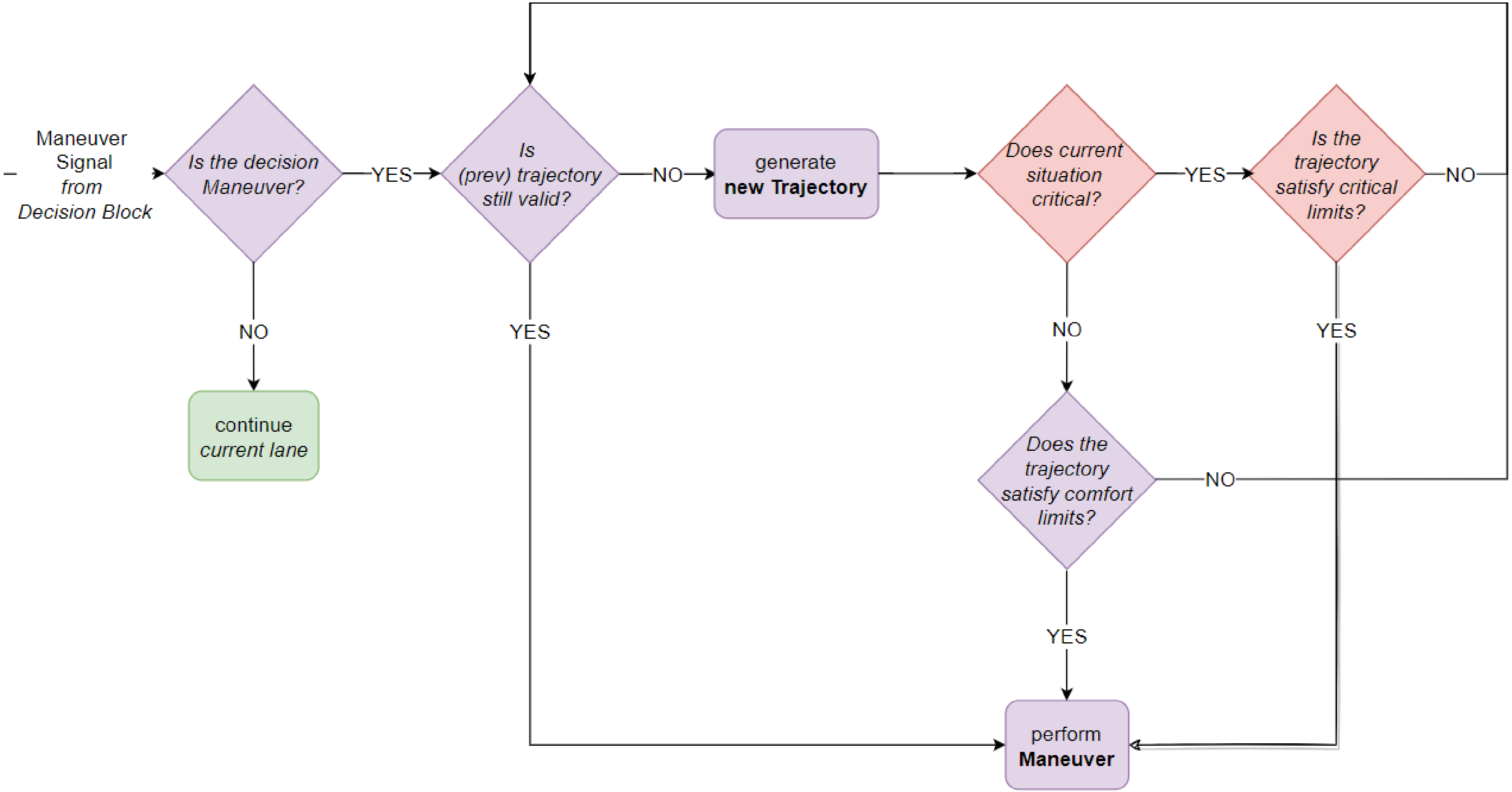


Figure 4-19 Decision Scheme of the Trajectory Generation Block

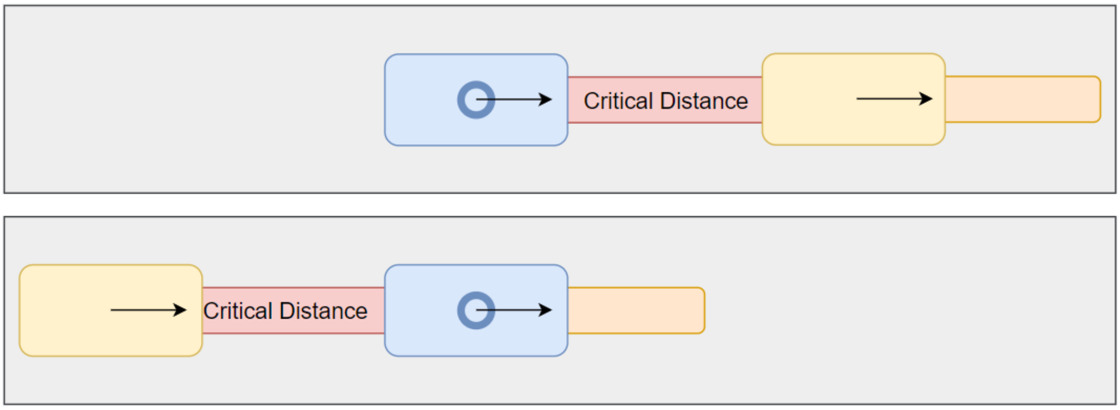


Figure 4-20 Critical Situation for Relaxed Trajectory Limits

It is important to note that in critical maneuvers, the maneuver performing time is shorter than in regular maneuvers. Therefore, the jerk profile of the critical maneuver will be higher than regular. Thus in these situations, the governing limit will be the Jerk limit.

The Trajectory Generator Block has the following input and output signals (Table 4-12).

Table 4-12 Trajectory Generator Block Input and Output Signals

Trajectory Generator Block Input and Output Signals

Inputs		*Block*		*Outputs*
X coord.	→			
Y coord.	→			
Yaw angle	→			
Maximum distance available for Trajectory	→			
Minimum distance available for Trajectory	→			
Previewed Road center information	→			
Longitudinal Velocity	→			
(prev) Trajectory	→		→	**Trajectory**
Current Lane on the Road	→			
Maneuver Signal	→			
Lateral Deviation	→			
Relative Distance - Front Vehicle	→			
Relative Velocity - Front Vehicle	→			
Relative Distance - Rear Vehicle	→			
Relative Velocity - Rear Vehicle	→			

The trajectory generation will be presented in detail in the Motion Planning and Control Algorithms Section 5.1.

4.4.3. Trajectory Positioning Block

The Trajectory Positioning block obtains the generated trajectory. This block works similar to the previously mentioned Lane Keeping Assist Parameters sensor and the Map Reader block in the Actor Subsystem in terms of providing the lateral control parameters (Figure 4-21).

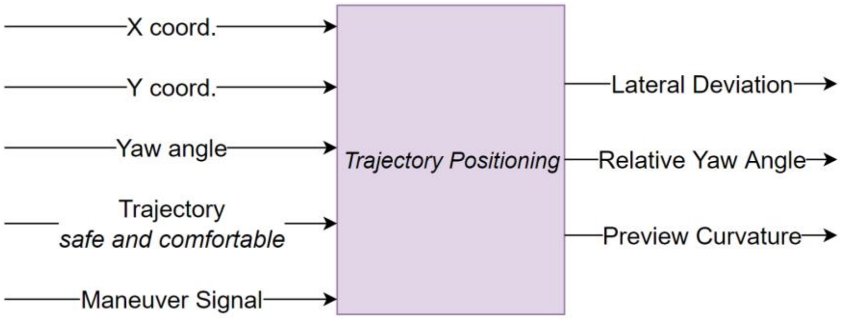


Figure 4-21 Mechanism of the Trajectory Positioning Block

The Trajectory Positioning block evaluates the current state of the vehicle, the generated trajectory and the maneuver signal. Then it produces the parameters for the trajectory following for the Control Unit block.

It is important to note that, since the vehicle estimates its own position, the accurate modeling of the vehicle becomes critically important. In normal maneuvers, the estimation works accurately. However, if the required maneuvers contain motion profiles that are out of the acceptable limits, the estimation can drift from the real position on the trajectory. In this study, this problem was overcome by limiting the vehicle’s motion profiles for both critical and normal maneuvering situations.

The Trajectory Positioning Block has the following input and output signals (Table 4-13).

Table 4-13 Trajectory Positioning Block Input and Output Signals

Trajectory Positioning Block Input and Output Signals		
Inputs	*Block*	*Outputs*
X coord. →		
Y coord. →		→ Lateral Deviation
Yaw angle →		→ Relative Yaw Angle
Trajectory →		→ Preview Curvature
Maneuver Signal →		

The parameters from the lane keeping assist parameters sensor and estimations from the trajectory positioning block are evaluated in the control unit block, where the required actuator inputs will be generated.

4.4.4. Reference Trajectory Selector

The Reference Trajectory Selector block is a utility block for the simulation. This block acquires the signals related to road center and trajectory (if available), and then calculates the next reference point for the subject vehicle to follow (Figure 4-22).

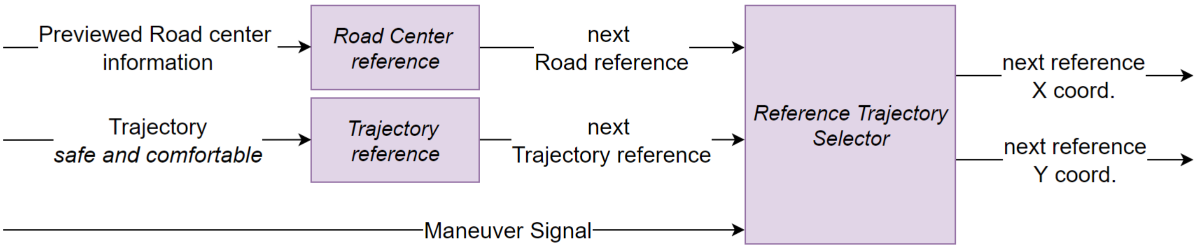


Figure 4-22 Mechanism of the Reference Trajectory Selector Block

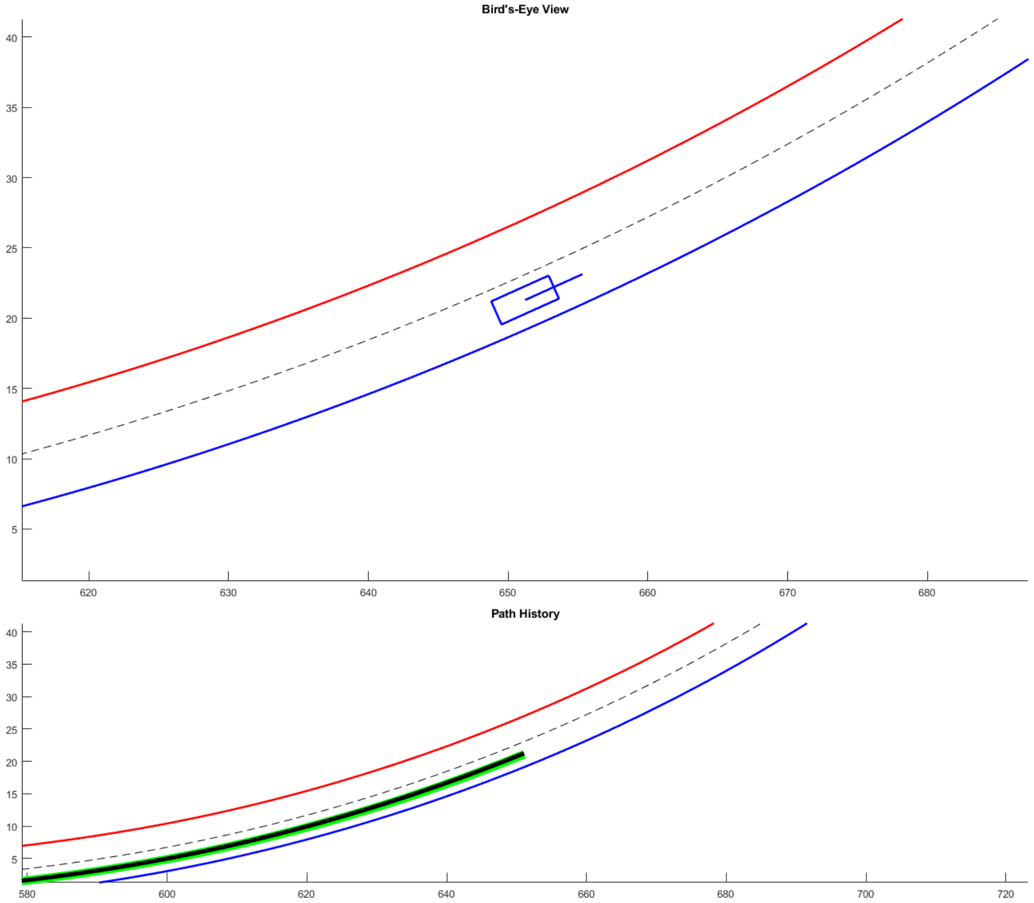


Figure 4-23 Example of Bird’s Eye View and Path History Plots

The Reference Trajectory Selector's signals are directly included in the simulation results and exported. The reference points and actual traveled points can be plotted in real-time or evaluated later after the simulation.

The following framed windows (Figure 4-23 and Figure 4-24) are directly taken from the Simulation Environment's interface. The view style indicates plots taken from the interface; this is due to differentiate the regular plots from the simulation interface. An example of bird's eye view and path history plots are given in Figure 4-23.

The path history can be inspected further to see the actual lateral errors for the followed reference. The results were plotted in Figure 4-24 where green is the reference and black is the actual traveled path.

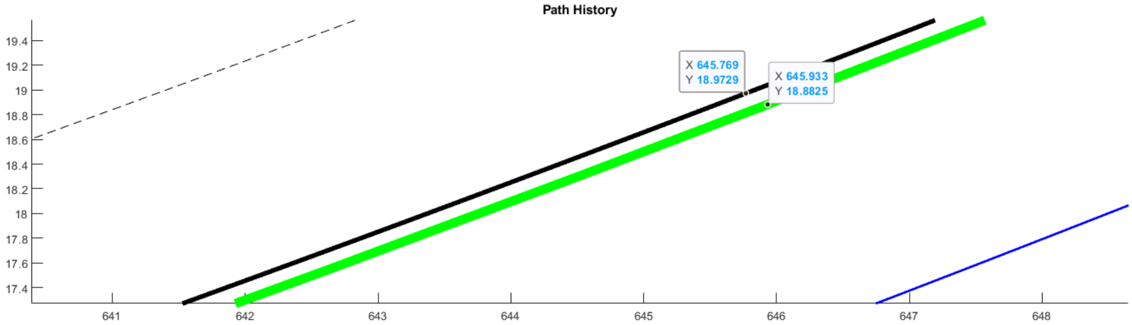


Figure 4-24 Example Path History Plot (reference in green, traveled path in black)

The Reference Trajectory Selector Block has the following input and output signals (Table 4-14).

Table 4-14 Reference Trajectory Selector Block Input and Output Signals

Reference Trajectory Selector Block Input and Output Signals				
Inputs		*Block*		*Outputs*
Previewed Road center information	→		→	Reference X coord.
Trajectory	→		→	Reference Y coord.
Maneuver Signal	→			

The block gathers information from the simulation for road center and trajectory reference points. The output signals are used to evaluate the developed algorithm.

4.5. The Control Unit

The Control Unit consists of MPC Parameters and Path Following MPC blocks. An overview of the system is given in Figure 4-25.

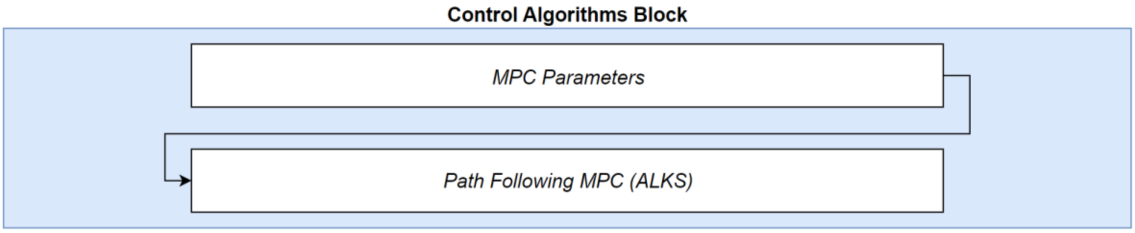


Figure 4-25 Overview of the Control Algorithms Block

It is important to note that, the Path Following MPC contains a Vehicle Mode Selector with a controller decision mechanism for Longitudinal and Lateral driver assistance systems such as:

- Automated emergency braking (AEB)
- Adaptive cruise control (ACC)
- Lane-keeping assist (LKA)

In addition to these, the lane change and overtake maneuver assistance system were implemented in Path Following MPC's scope.

- Lane change and Overtake assist (LCA)

It is possible to separate these assistance systems in longitudinal and lateral directions (Figure 4-26).

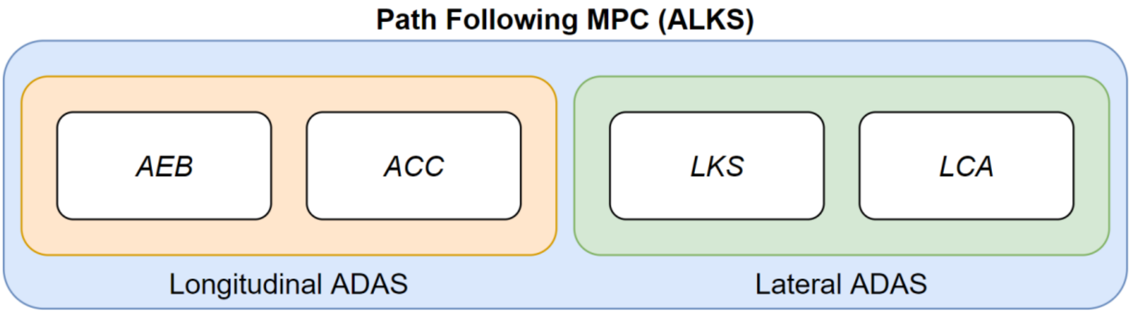


Figure 4-26 Overview of the Path Following MPC

This combined assistance system can be defined as an Automated Lane-Keeping System (ALKS) where the AEB, ACC, LKA and lane change and overtake maneuver assistance systems are combined.

4.5.1. MPC Parameters

The MPC parameters block obtains the lane keeping assist and path following parameters from the related blocks, and then feeds the suitable information to the path following MPC block (Figure 4-27).

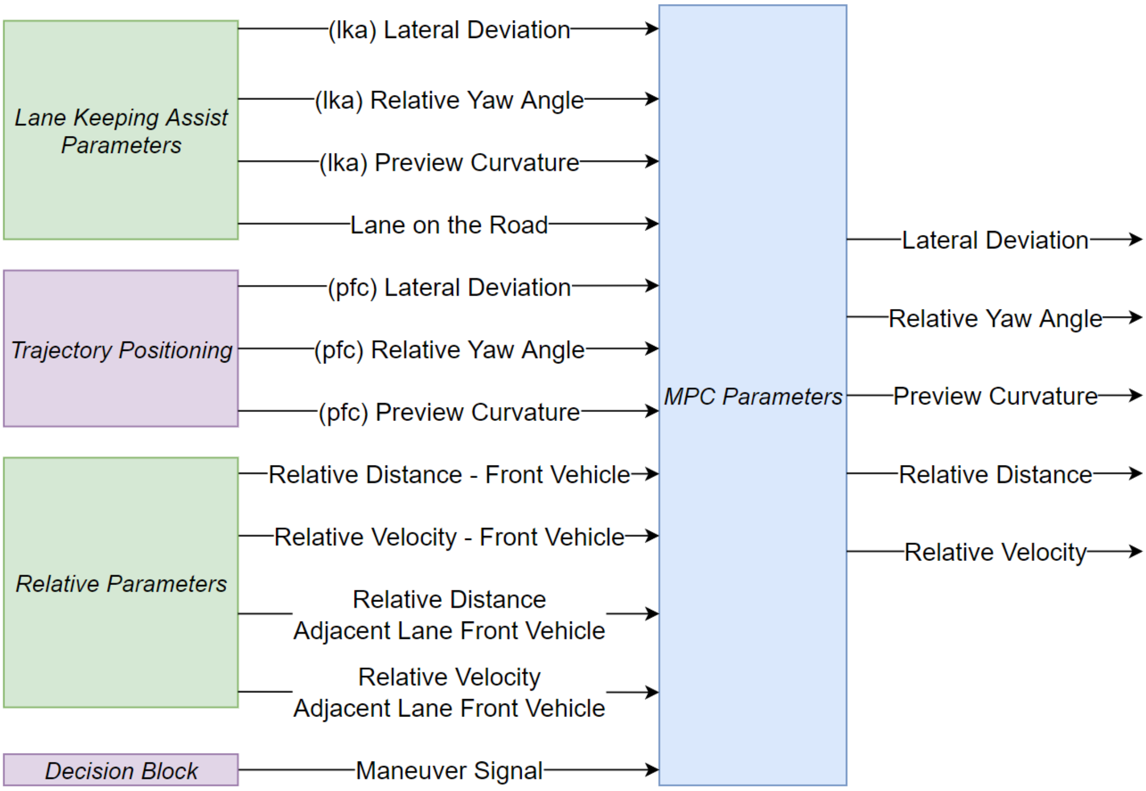


Figure 4-27 Mechanism of the MPC Parameters Block

The decision scheme for the MPC parameters block is as follows (Figure 4-28).

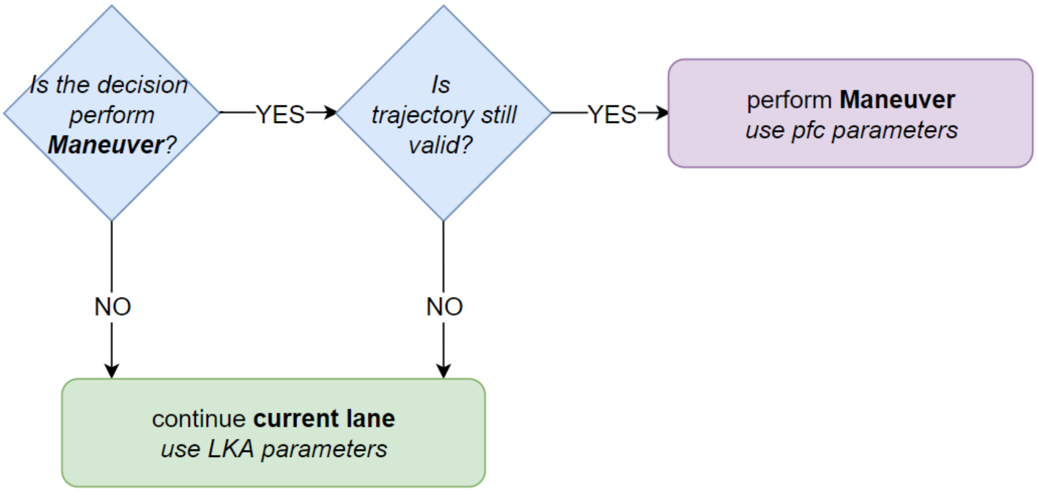


Figure 4-28 Decision scheme of the MPC Parameters Block

It is also important to note that, if the primary purpose is trajectory following to perform a maneuver, then the adjacent lane's traffic information becomes the primary concern. Therefore, this block also controls the relative distance and velocity parameters and feeds the essential information of the Path Following MPC block.

The MPC Parameters Block has the following input and output signals (Table 4-15).

Table 4-15 MPC Parameters Block Input and Output Signals

MPC Parameters Block Input and Output Signals		
Inputs	*Block*	*Outputs*
(lka) Lateral Deviation →		
(lka) Relative Yaw Angle →		
(lka) Preview Curvature →		
Current Lane on the Road →		
(pfc) Lateral Deviation →		→ Lateral Deviation
(pfc) Relative Yaw Angle →		→ Relative Yaw angle
(pfc) Preview Curvature →		→ Preview Curvature
Maneuver Signal →		→ Relative Distance
Relative Distance - Front Vehicle →		→ Relative Velocity
Relative Velocity - Front Vehicle →		
Relative Distance - Adjacent Lane Front Vehicle →		
Relative Velocity - Adjacent Lane Front Vehicle →		

The MPC parameters block decides whether it is suitable to follow the generated trajectory or continue to follow the road center with lane keeping assist parameters.

4.5.2. Path Following MPC

Path following MPC is the default controller of the Subject Vehicle (Figure 4-29).

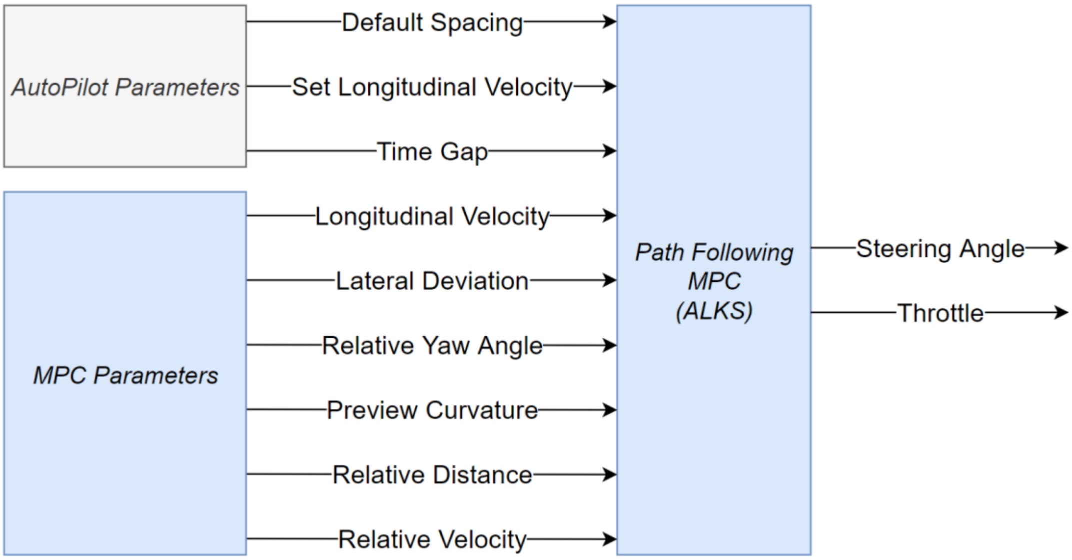


Figure 4-29 Mechanism of the Path Following MPC Block

The advantages of using MPC were mentioned in 5.2 and the controller structure will be discussed further in the Motion Planning and Control Algorithms Section 5.2.6.

The path following MPC block controls the actuators of the Subject Vehicle, which are the throttle and steering angle. The block can follow a path, while the path can be defined for the road center or trajectory waypoints of the maneuver. In addition, the path following MPC block contains a vehicle mode selector subsystem to switch between the defined ADAS such as ACC, AEB, LKA and finally lane change and overtake maneuver assistance system.

The Path Following MPC Block has the following input and output signals (Table 4-16).

Table 4-16 Path Following MPC Block Input and Output Signals

Path Following MPC Block Input and Output Signals				
Inputs		*Block*		*Outputs*
Default Spacing	→			
Set Longitudinal Velocity	→			
Time Gap	→			
Longitudinal Velocity	→		→	Steering Angle
Lateral Deviation	→		→	Throttle
Relative Yaw angle	→			
Preview Curvature	→			
Relative Distance	→			
Relative Velocity	→			

4.5.3. The Actor Subsystem: Controller

Apart from the main controller for the subject vehicle, there also exists an LQR controller used for the actor subsystem (Figure 4-30).

Figure 4-30 Mechanism of the Actor Subsystem Controller

The actor vehicle parameters were presented before in the actor subsystem in the Vehicle Dynamics section. The state-space model for the LQR was selected from [35]. The selected vehicle model for the LQR state-space is a 2DOF linear single-track bicycle model. The controller for the Actor subsystem has been briefly explained here. The Subject Vehicle’s controller, however, will be explained further in the Motion Planning and Control Algorithms Section 5.2.6.

4.6.Scenario Reader and Simulation Visualization

The Simulation environment and its main components has been explained from 4.1 to 4.6. Additionally, there are two utility blocks exist for the simulation environment. A Scenario Reader block that loads the scenario parameters and a Simulation Result Visualization block that exports the simulation results and plots the simulation in real-time.

4.6.1. Scenario Reader

The Scenario Reader block loads the scenario parameters (Figure 4-31).

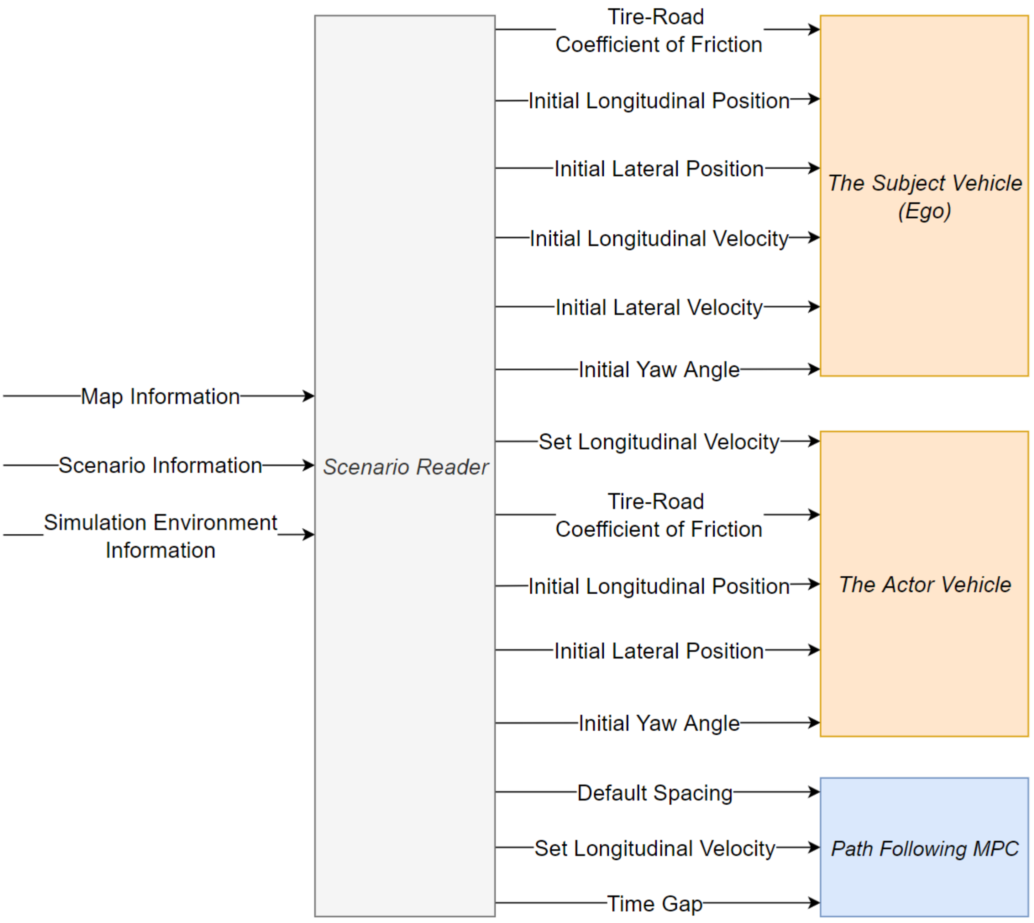


Figure 4-31 Mechanism of the Scenario Reader Block

There are parameters related to the perception block's performance. The perception block in this study is kept simple as the emphasis is put on the motion planning and control algorithms. Therefore, parameters such as roadway grade, lane markings, light conditions, and weather conditions that would normally be sent to perception block are not considered. Furthermore, in this study, the motion planning and control algorithms only consider the relative distance and relative velocity information from the flowing traffic. There are three types of parameters used as input for the Scenario Reader:

1. Map Information
2. Scenario Information
3. Simulation Environment Information

These parameters are loaded by Scenario Reader. The parameters specified in Table 4-17 are used for defining the scenarios in simulation where ✓ symbol means the parameter is considered and **x** symbol means the parameter is not considered.

Table 4-17 Template of the Scenario Parameters

Scenario Parameters Template				
Operating conditions	Roadway	Number of lanes	✓	*the number of adjacent lanes in the same direction*
		Lane Width	✓	*the width of each lane*
		Roadway grade	x	*grade of the roadway*
		Roadway condition	✓	*tire-road coefficient of friction*
		Lane markings	x	*the type, color, width, visibility*
	Environmental conditions	Lighting conditions	x	*the amount of light and direction (day, night, etc.)*
		Weather conditions	x	*the amount, type and intensity of wind, rain, snow, etc.*
Initial condition	Initial velocity	V_{e0}	✓	*Subject vehicle (ego)*
		V_{o0}	✓	*Leading vehicle*
		V_{f0}	✓	*Vehicle in front of the leading vehicle*
	Initial distance	d_{x0}	✓	*distance in the longitudinal direction between leading vehicle*
		d_{y0}	✓	*distance in the lateral direction between leading vehicle*
		d_{y0_f}	✓	*distance in the longitudinal direction between the vehicle in front of the leading vehicle*
		d_{x0_f}	✓	*distance in the lateral direction between the vehicle in front of the leading vehicle*
		d_{fy}	✓	*width of the vehicle in front of the leading vehicle*
		d_{oy}	✓	*width of the leading vehicle*
		d_{ox}	✓	*length of the leading vehicle*
Vehicle motion	Lateral motion	V_y	✓	*leading vehicle lateral velocity*
	Deceleration	G_{x_max}	x	*maximum deceleration of the leading vehicle in G*
		dG/dt	x	*deceleration rate (jerk) of the leading vehicle*

The map information holds the information related to the scenario environment (Table 4-18).

Table 4-18 Map Information Signals for Scenario Reader Block

Map Information Signals		
Inputs		*Block*
Road Center X coords.	→	
Road Center Y coords.	→	
Number of lanes	→	
Lane Width	→	
Roadway condition	→	

The Scenario Reader block can read the parameters of different maps. The maps can be generated from the X and Y coordinates of the road center, number of lanes and lane width. The road adhesion coefficient can be adjusted for the scenario. There are some map overviews available as follows (Figure 4-32).

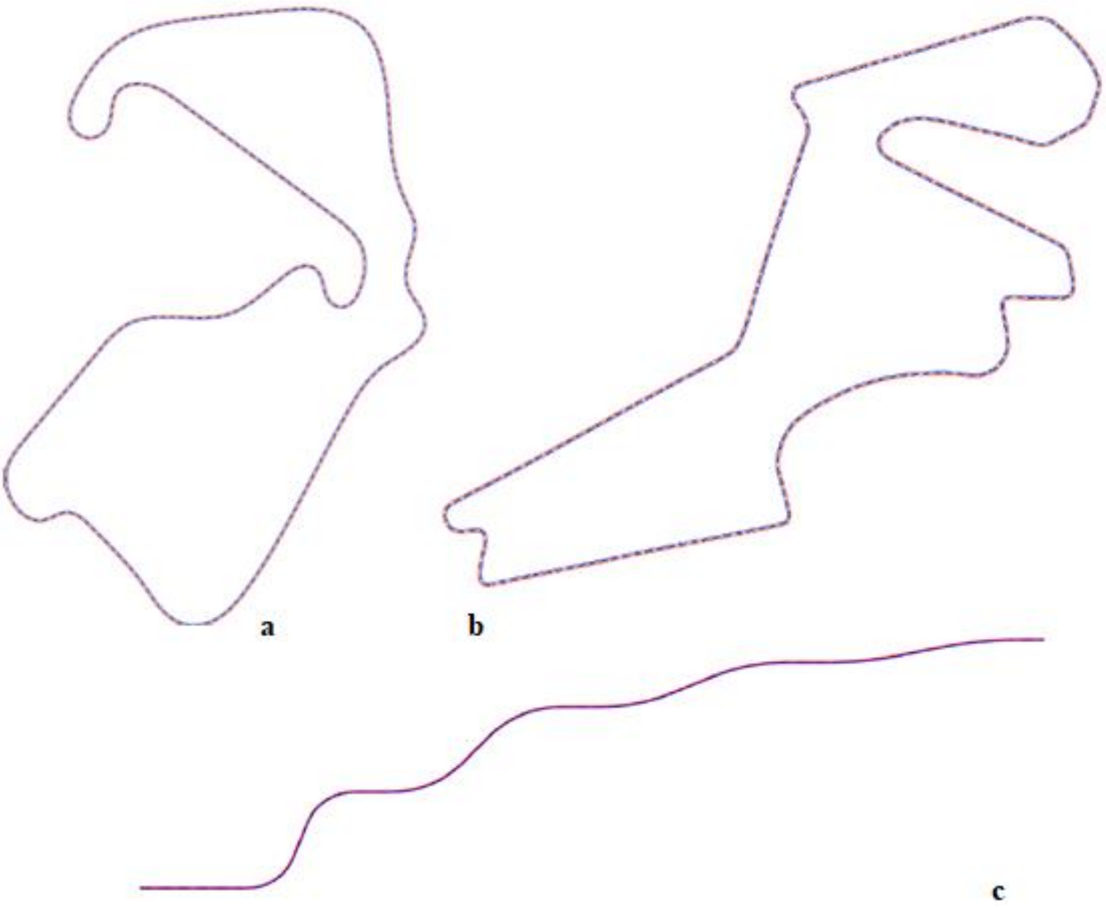


Figure 4-32 Example Map Overviews (**a**: Silverstone Circuit, **b**: İstanbul Park and **c**: Roads with Different Curvatures)

The scenario information holds the information related to the subject vehicle and actor initialization including the actors' behavior models (Table 4-19).

Table 4-19 Scenario Information Signals for Scenario Reader Block

Scenario Information Signals

	Inputs		*Block*
Initial Parameters	Initial Longitudinal Position (Ego)	→	
	Initial Lateral Position (Ego)	→	
	Initial Yaw Angle (Ego)	→	
	Initial Longitudinal Velocity (Ego)	→	
	Initial Lateral Velocity (Ego)	→	
	Set Longitudinal Velocity (Ego)	→	
	Vehicle Parameters (Ego)	→	
	Initial Longitudinal Position (Actors)	→	
	Initial Lateral Position (Actors)	→	
	Initial Yaw Angle (Actors)	→	
	Initial Longitudinal Velocity (Actors)	→	
	Initial Lateral Velocity (Actors)	→	
	Set Longitudinal Velocity (Actors)	→	
	Vehicle Parameters (Actors)	→	
Behavior	Actor type (Actors)	→	
	Swerving Distance (Actors)	→	
	Velocity Deviation (Actors)	→	
	Behavior: Crossing / Cut in / Cut out (Actors)	→	

The actor behaviors maybe lane crossing, cut in to or cut out of the subject vehicle's lane. In addition, to create a dynamic flowing traffic environment, the actors can vary their velocities or swerve within in their lanes. These create a dynamic environment which is the main reason of the trajectory re-planning requirement.

The actor behaviors are given in Figure 4-33, Figure 4-34, Figure 4-35 and Figure 4-36.

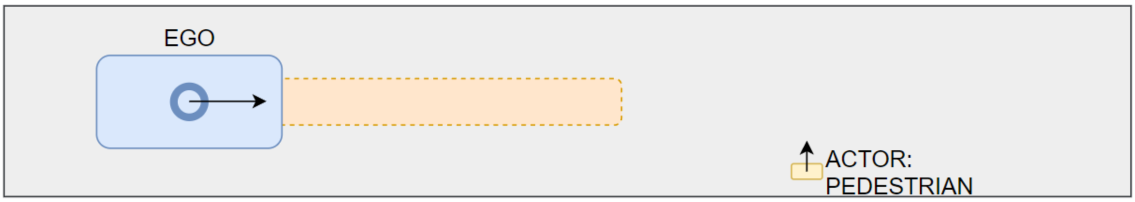


Figure 4-33 Lane Crossing Pedestrian Behavior

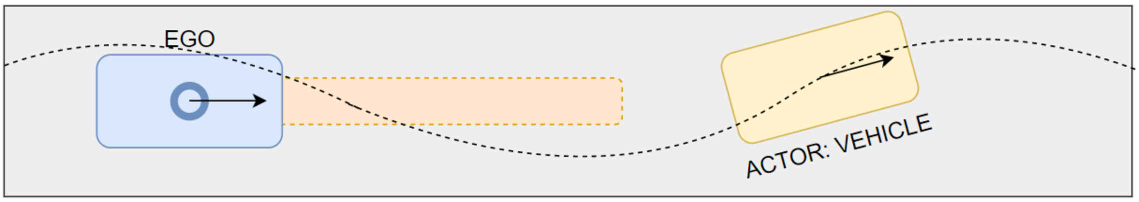


Figure 4-34 Swerving Lead Vehicle Behavior

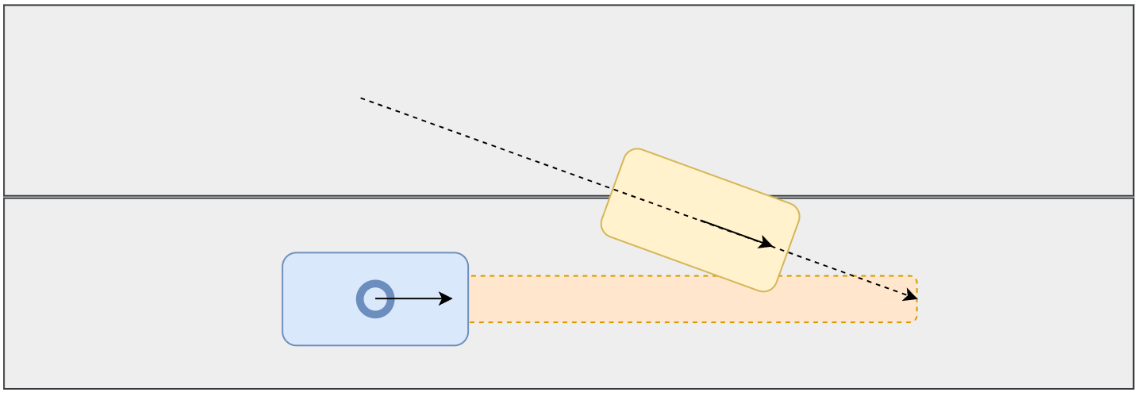


Figure 4-35 Cut In to Subject Vehicle's Lane

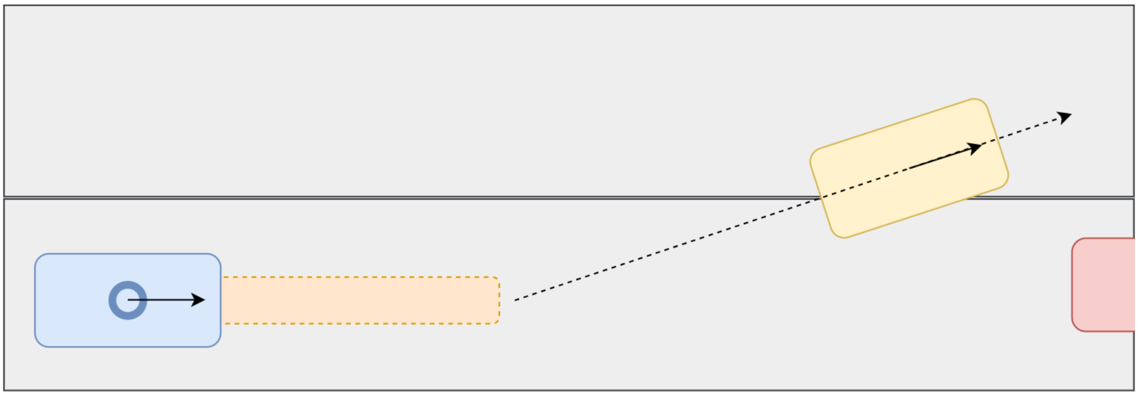


Figure 4-36 Cut Out of Subject Vehicle's Lane

The simulation environment information holds the information related to the simulation parameters related to the blocks (Table 4-20).

Table 4-20 Simulation Environment Information Signals for Scenario Reader Block

Simulation Environment Information Signals			
	Inputs		*Block*
Blocks	Subject Vehicle Parameters	→	
	Actor Vehicle Parameters	→	
	Path Following MPC Parameters	→	
Simulation	Fixed-step size of the simulation	→	
	Sampling frequency of the Simulation Blocks	→	
	Default Spacing	→	
	Time Gap	→	

To sum up, the Scenario Reader completes the initialization of the simulation environment by loading the information for the map, scenario and simulation.

4.6.2. Simulation Visualization

The simulation results can be plotted in real-time or can be exported for offline inspection. The view style indicates plots taken from the interface; this is due to differentiate the regular plots from the simulation interface.

The interface for the real-time visualization is as follows (Figure 4-37).

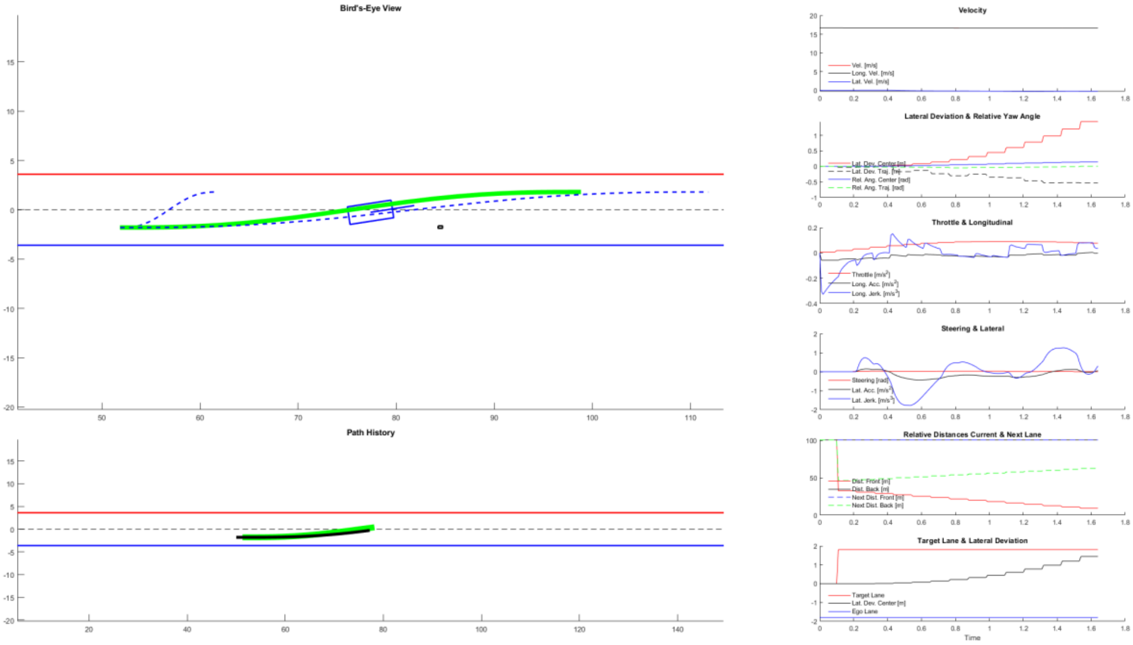


Figure 4-37 Real-time Visualization Interface of the Simulation Environment

The interface has several subsections:

- Bird’s-Eye View (Figure 4-38)
- Path History (Figure 4-39)
- Velocity Window
- Lateral Deviation and Relative Yaw Angle Window
- Throttle and Longitudinal Dynamics Window
- Steering and Lateral Dynamics Windows
- Relative Distances for Current and Adjacent Lane Window
- Target Lane and Lateral Deviation Window

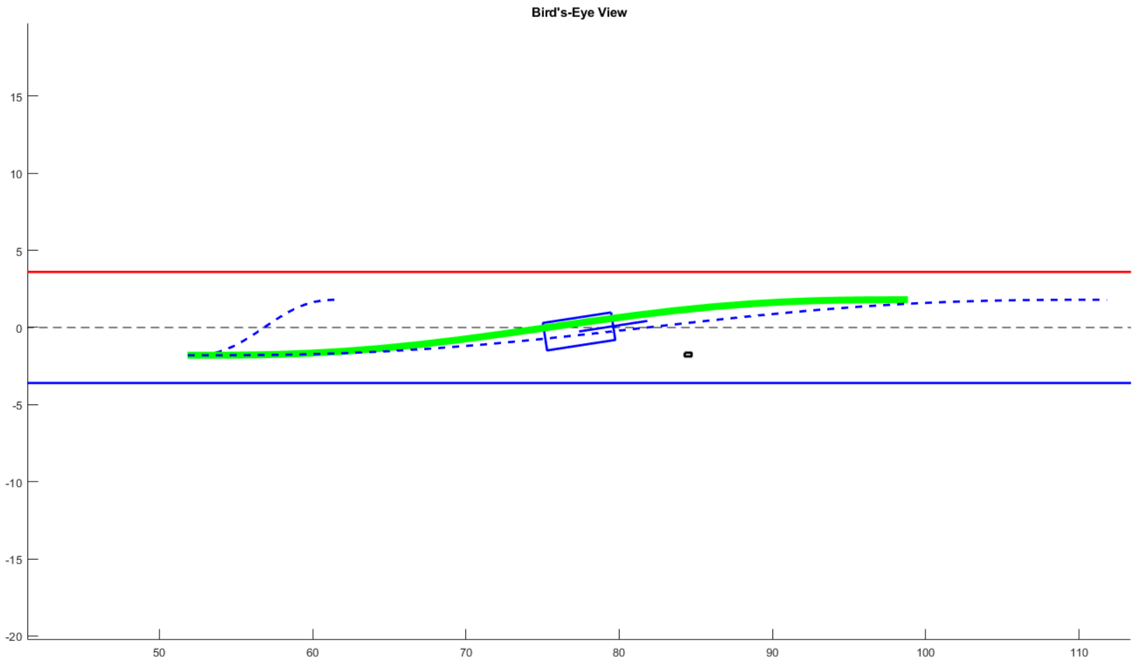


Figure 4-38 Bird’s Eye View in Real-time Visualization

The Bird’s Eye View window (Figure 4-38) allows evaluation of the situation. In the window, the Subject Vehicle (in blue) and a pedestrian actor (in black) can be observed. The yaw angle of the subject vehicle is indicated with a blue straight line. The planned trajectory for the avoidance maneuver is drawn in green. The dashed blue lines indicate the beginning and end of the available region for trajectory planning.

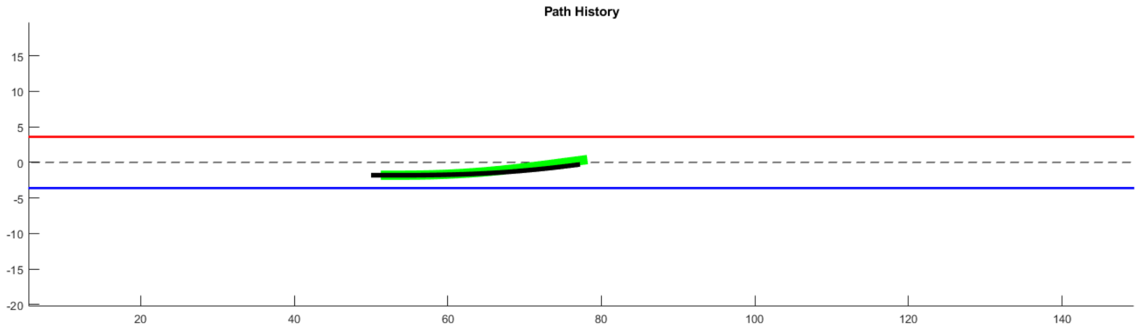


Figure 4-39 Path History in Real-time Visualization

The Path History window (Figure 4-39) allows inspection of the planned path (green) and the actual followed path (black). In addition, to examine and evaluate the simulation results, a visualization of previously executed scenario is possible.

4.7.Automated Scenario Generation and Execution

Developing an ADS requires intense testing and evaluation. Therefore, automated Scenario Generation and Execution blocks were included in the simulation environment.

4.7.1. Scenario Generation Block

The scenario generation is performed by a script executed before the simulations process.

First, the simplified ODD is defined. Then the parameters are selected for the sensitivity analysis. After that, the range and resolution of the selected parameters are defined. Finally, the script automatically generates the scenarios within the ODD to evaluate sensitivity analysis.

Example: The simplified ODD maybe defined as (Table 4-21):

Table 4-21 Example Parameters to Define Simplified ODD

Initial Ego Velocity [V_{e0}]	60 kph
Roadway Condition	0.8

Then the following scenario parameters maybe selected for sensitivity analysis as follows (Table 4-22).

Table 4-22 Example Scenario Parameters for Sensitivity Analysis

Selected Scenario Parameters				
Initial condition	Initial velocity	V_{e0}	x	*Subject vehicle (ego)*
		V_{o0}	✓	*Leading vehicle*
		V_{f0}	x	*Vehicle in front of the leading vehicle*
	Initial distance	d_{x0}	✓	*distance in the longitudinal direction between leading vehicle*
		d_{y0}	x	*distance in the lateral direction between leading vehicle*
		d_{y0_f}	x	*distance in the longitudinal direction between the vehicle in front of the leading vehicle*
		d_{x0_f}	x	*distance in the lateral direction between the vehicle in front of the leading vehicle*
		d_{fy}	x	*width of the vehicle in front of the leading vehicle*
		d_{oy}	x	*width of the leading vehicle*
		d_{ox}	x	*length of the leading vehicle*

Then range and resolution values for the selected parameters are defined as the following.

1. V_{o0}: Leading vehicle’s initial velocity

$$0\ kph\ \leq\ V_{o0} \leq 50\ kph \qquad with\ 10\ kph\ resolution$$

2. d_{x0}: Leading vehicle’s relative distance to the subject vehicle

$$2\ m\ \leq d_{x0} \leq 30\ m \qquad with\ 2\ m\ resolution$$

As a result, the scenario matrix is obtained and presented in Table 4-23.

4.7.2. Scenario Execution Block

The scenario execution is performed by a script to simulate previously generated scenarios. The simulation automatically loads the generated scenarios and executes the batch of scenarios. After the simulation matrix was completed, the results are extracted and tabulated as given in Table 4-24 which is an example of AEB testing.

As previously mentioned, scenario generation and automation for rapid and intense testing often require offline plotting of the scenario. After the batch execution, the scenarios can be inspected offline without the need for the main simulation environment.

Table 4-23 Empty Test Result Matrix of AEB Testing Example

Initial Ego Velocity [V_{e0}]	60	kph	Relative Distance m [d_{x0}]														
Roadway Condition	0.8		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
Lead Velocity [V_{o0}]	50.0	kph	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
	40.0	kph	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
	30.0	kph	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
	20.0	kph	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
	10.0	kph	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
	0.0	kph	2	4	6	8	#	#	#	#	#	#	#	#	#	#	#

Table 4-24 Executed Test Results Matrix of AEB Testing Example

Initial Ego Velocity [V_{e0}]	60	kph	Relative Distance m [d_{x0}]														
Roadway Condition	0.8		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
Lead Velocity [V_{o0}]	50.0	kph	*152*	*154*	*156*	*158*	*160*	*162*	*164*	*166*	*168*	*170*	*172*	*174*	*176*	*178*	*180*
	40.0	kph	*122*	*124*	*126*	*128*	*130*	*132*	*134*	*136*	*138*	*140*	*142*	*144*	*146*	*148*	*150*
	30.0	kph	*92*	*94*	*96*	*98*	*100*	*102*	*104*	*106*	*108*	*110*	*112*	*114*	*116*	*118*	*120*
	20.0	kph	*62*	*64*	*66*	*68*	*70*	*72*	*74*	*76*	*78*	*80*	*82*	*84*	*86*	*88*	*90*
	10.0	kph	*32*	*34*	*36*	*38*	*40*	*42*	*44*	*46*	*48*	*50*	*52*	*54*	*56*	*58*	*60*
	0.0	kph	*2*	*4*	*6*	*8*	*10*	*12*	*14*	*16*	*18*	*20*	*22*	*24*	*26*	*28*	*30*

5. MOTION PLANNING AND CONTROL ALGORITHMS

In this study, a lane change and overtake maneuver assistive system is implemented. The quintic polynomial method is selected for trajectory planning. Dynamic re-planning of the trajectory added the possibility of application in flowing traffic conditions. The inclusion of the Frenet frame method extended the applicability to the curved road scenarios. A single-track bicycle model is selected for vehicle dynamics to represent the tire-road interaction which included real-world problems such as lateral stability and tire forces and slip. The MPC is employed for path following. The controller weights are adjusted for accurate path tracking that ensures the driver's safety and for realistic responses that consider the driver's comfort and actuator health.

5.1.Trajectory Generation with Re-planning in a Realistic Environment

The trajectory generation process has the following properties.

3. A quintic polynomial is used to express the trajectory, which results in a continuous motion profile for the subject vehicle.
4. A Frenet frame method is used to describe the trajectory in the road with curvature.
5. Dynamic re-planning of the trajectory is implemented in flowing traffic conditions to respond to unexpected situations.

Following corrective maneuvers are executed as a result of event triggers.

- Obstacle avoidance maneuver
- Lane change maneuver
- Overtake maneuver

In this study, the obstacle avoidance maneuver is achieved by lane change maneuver, where the terminal state is located at the adjacent lane. If an obstacle blocks the path of the subject vehicle, then the subject vehicle starts to evaluate a possible way to perform a lane change maneuver to avoid not only the obstacle but also the whole blocked lane.

Overtake maneuver is triggered when the adjacent lane is used only for overtaking. Then the vehicle performs two consecutive lane changes to overtake the leading vehicle and return to the original lane.

The trajectory generation is triggered when:

1. If the relative distance front is smaller than convenient and the leading vehicle's relative velocity is negative (Figure 5-1)

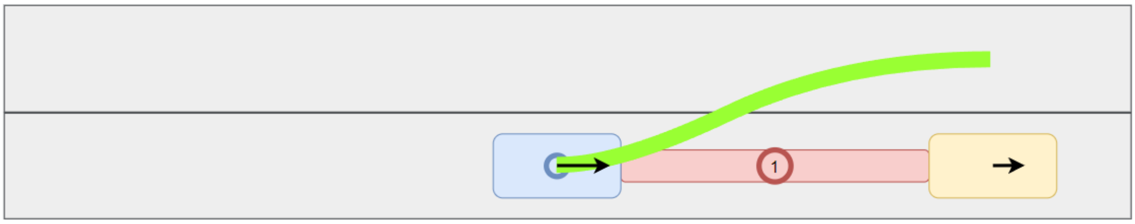


Figure 5-1 Front Trigger Case: Shortening of the Front Relative Distance

2. If the relative distance behind is smaller than convenient and trailing vehicle's relative velocity is positive (Figure 5-2)

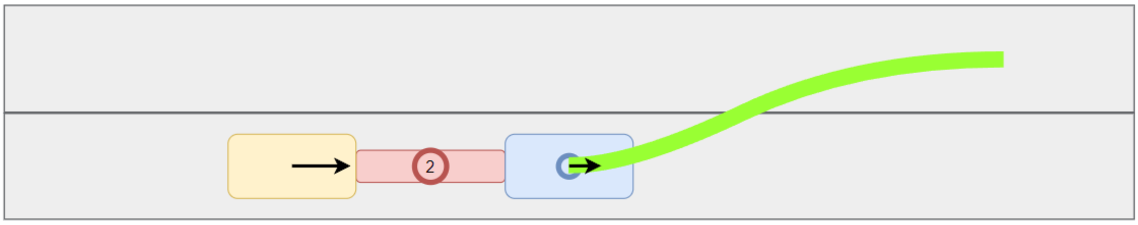


Figure 5-2 Rear Trigger Case: Shortening of the Rear Relative Distance

3. If the current lane is used only for overtaking (Figure 5-3)

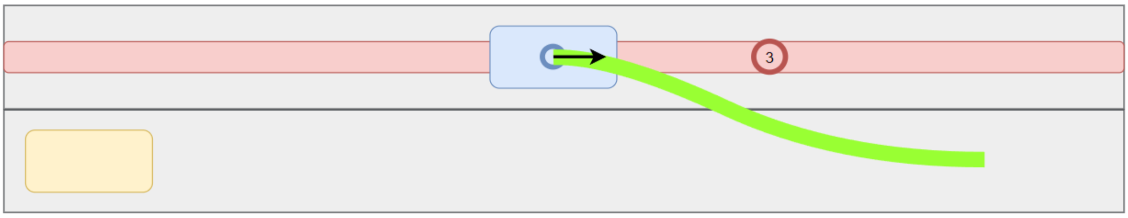


Figure 5-3 Passing Lane Trigger Case

The clearance as the convenient distance can be explained as:

$$Clearance = V_x * TG + DS \qquad \text{Equation 5.1}$$

An example triggered situation is presented in Figure 5-4 where the trajectory generation successfully completed within the available trajectory region.

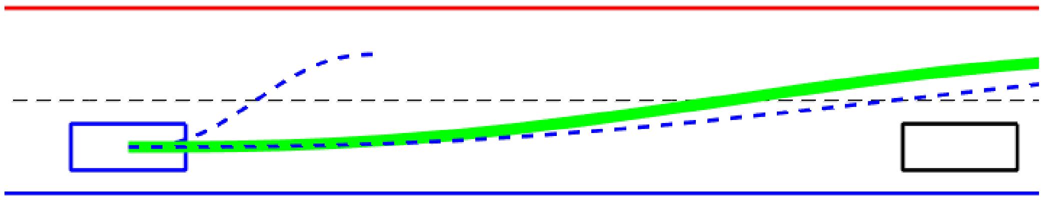


Figure 5-4 Example Trajectory Generation

The processed information for the available trajectory region from the traffic conditions in the Figure 5-5 is calculated by:

$$d_1 = -RD_{rear} + V_{x\,rear} * TG + DS \qquad \text{Equation 5.2a}$$

$$d_2 = DS \qquad \text{Equation 5.2b}$$

$$d_3 = V_x * TG + DS \qquad \text{Equation 5.2c}$$

$$d_4 = RD_{front} + V_{x\,front} * TG \qquad \text{Equation 5.2d}$$

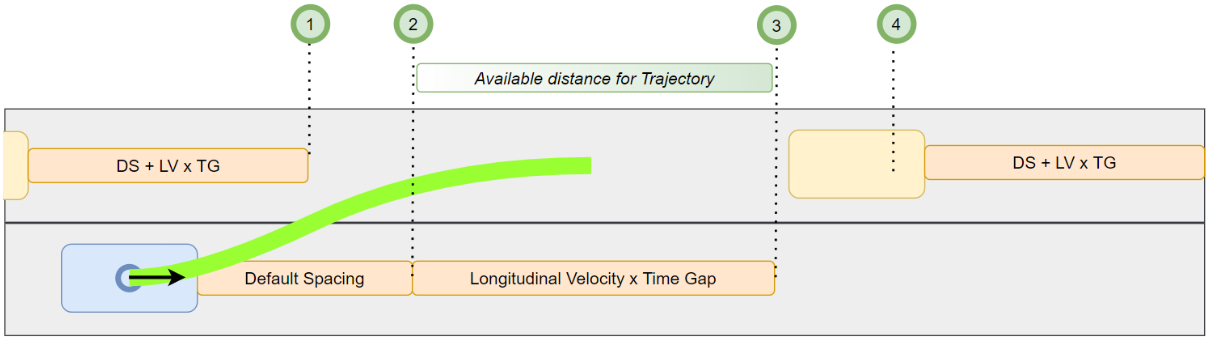


Figure 5-5 Available Trajectory Region

The available trajectory region in Figure 5-5 can be explained with the beginning and end of the region.

$$beginning\ of\ the\ region = \max(d_1, d_2) \qquad \text{Equation 5.3a}$$

$$end\ of\ the\ region = \min(d_3, d_4) \qquad \text{Equation 5.3b}$$

Then trajectory generation algorithm starts to create trajectories with 0,5 meters of intervals in the available trajectory region (Figure 5-6). The first trajectory that satisfies the comfort or critical limits is selected and is fed through to the decision mechanism.

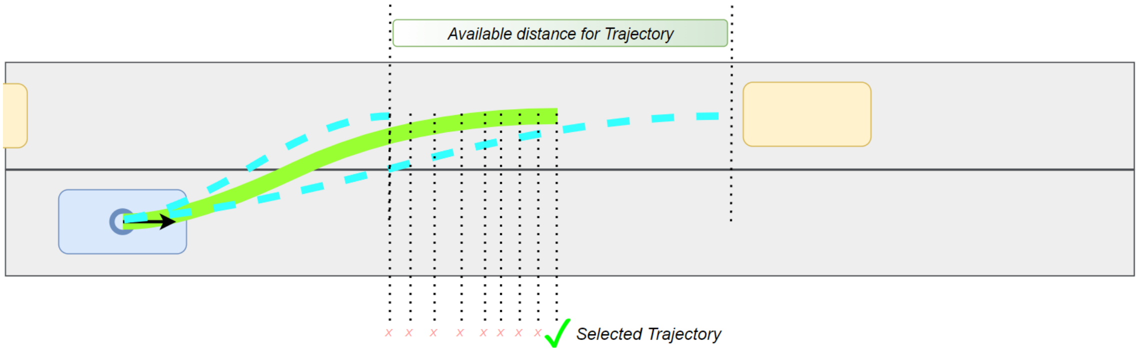


Figure 5-6 Trajectory Selection Procedure

The selected trajectory is both safe and comfortable with a continuous motion profile. The continuous motion profile term includes the velocity profiles, acceleration profiles and jerk profiles.

A quintic polynomial can be written as follows.

$$y(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 \qquad \text{Equation 5.4}$$

To obtain this quantic polynomial's unknown coefficients a_0 to a_5, a 6x6 matrix must be solved.

$$A = \begin{bmatrix} {x_0}^5 & {x_0}^4 & {x_0}^3 & {x_0}^2 & {x_0}^1 & 1 \\ 5{x_0}^4 & 4{x_0}^3 & 3{x_0}^2 & 2{x_0}^1 & 1 & 0 \\ 20{x_0}^3 & 12{x_0}^2 & 6{x_0}^1 & 1 & 0 & 0 \\ {x_f}^5 & {x_f}^4 & {x_f}^3 & {x_f}^2 & {x_f}^1 & 1 \\ 5{x_f}^4 & 4{x_f}^3 & 3{x_f}^2 & 2{x_f}^1 & 1 & 0 \\ 20{x_f}^3 & 12{x_f}^2 & 6{x_f}^1 & 1 & 0 & 0 \end{bmatrix} \qquad \text{Equation 5.5a}$$

$$B' = [a_5 \quad a_4 \quad a_3 \quad a_2 \quad a_1 \quad a_0] \qquad \text{Equation 5.5b}$$

$$C' = [y_0 \quad v_0 \quad a_0 \quad y_f \quad v_f \quad a_f] \qquad \text{Equation 5.5c}$$

$$A * B = C \qquad \text{Equation 5.5d}$$

$$B = A^{-1}C \qquad \text{Equation 5.5e}$$

To solve this matrix, parameters for the initial and final conditions must be expressed.

Cartesian parameters are:

$$Cartesian\ States = [x \quad y \quad v_y \quad a_y] \qquad \text{Equation 5.6a}$$

Initial conditions are:

$$IC = [x_0 \quad y_0 \quad v_{y0} \quad a_{y0}] \qquad \text{Equation 5.6b}$$

Final conditions are:

$$FC = [x_f \quad y_f \quad v_{yf} \quad a_{yf}] \qquad \text{Equation 5.6c}$$

The simple straight road case can be explained in the Cartesian frame. Then, this polynomial expressed the following trajectory for the subject vehicle.

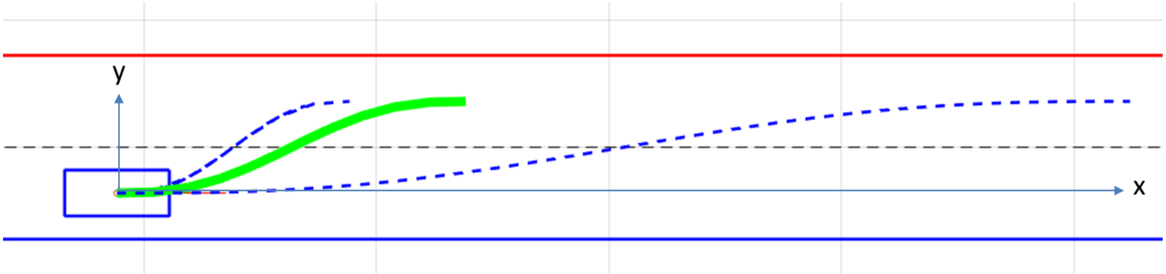


Figure 5-7 Trajectory Generation on Straight Road Case

The maximum distance and minimum distance available in blue dashed lines are the main input of the trajectory generation algorithm. The trajectory generation algorithm then evaluates the available region for suitable trajectory generation.

Initial conditions for this straight road example are:

$$IC = [0\,m \quad 0\,m \quad 0\,m/s \quad 0\,m/s^2] \qquad \text{Equation 5.7a}$$

Final conditions for this straight road example are:

$$FC = [20\,m \quad 3.60\,m \quad 0\,m/s \quad 0\,m/s^2] \qquad \text{Equation 5.7b}$$

The Cartesian frame method works on straight roads, As previously mentioned, there are statements about it is not recommended to perform lane changes or overtake maneuvers on a curved road. However, the requirement persists since there is an urgent reaction needed on the curved road such as avoiding an obstacle. Thus, to create a global solution on the roads with curvature, it is required to utilize the Frenet frame method.

The Frenet frame from MathWorks can be expressed as the following [34].

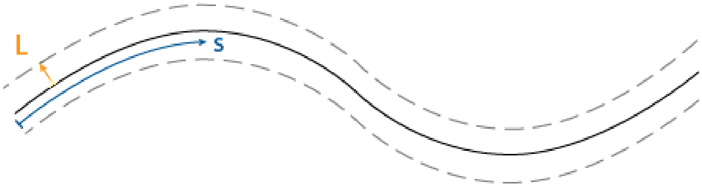


Figure 5-8 Frenet frame on the center of the road with a curvature

Similarly, the Frenet parameters are:

$$Frenet\ States = [x \quad v_x \quad a_x \quad y \quad v_y \quad a_y] \qquad \text{Equation 5.8a}$$

The frame is attached to the road center along the travel path of the vehicle. To solve the same matrix in Frenet frames, the same parameters for the initial and final conditions must be expressed.

Initial conditions are:

$$IC = [x_0 \quad v_{x0} \quad a_{x0} \quad y_0 \quad v_{y0} \quad a_{y0}] \qquad \text{Equation 5.8b}$$

Final conditions are:

$$FC = [x_f \quad v_{xf} \quad a_{xf} \quad y_f \quad v_{yf} \quad a_{yf}] \qquad \text{Equation 5.8c}$$

After the straight road case, the curved road situation is explained in the Frenet frame method. Then, the quintic polynomial is used to express the following trajectory to be followed by the Subject Vehicle.

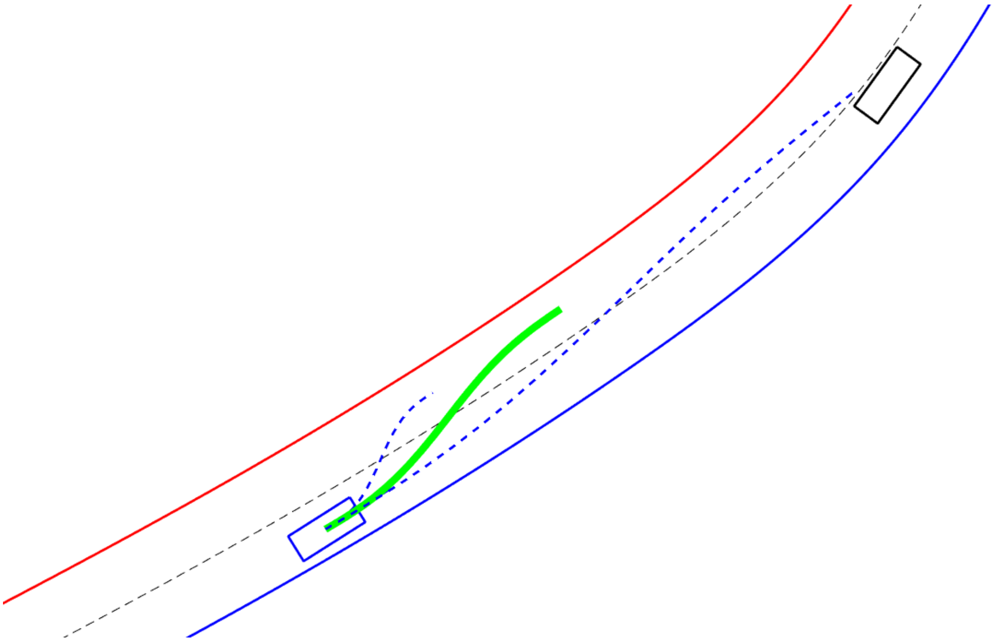


Figure 5-9 Trajectory generation on road with curvature case

First, the vehicle obtains the information for the relative distance and relative velocity of the leading vehicle. Then the available trajectory region is evaluated for the trajectory generation. The green line is the found solution for this example situation (Figure 5-9).

Initial conditions for this curved road example are:

$$IC = [0\,m \quad 60\,kph \quad 0\,m/s^2 \quad 0\,m \quad 0\,kph \quad 0\,m/s^2] \qquad \text{Equation 5.9a}$$

Final conditions for this curved road example are:

$$FC = [25\,m \quad 60\,kph \quad 0\,m/s^2 \quad 3.60m \quad 0\,kph \quad 0\,m/s^2] \qquad \text{Equation 5.9b}$$

It is important to note that, the lateral states can be utilized to create a trajectory that involves a lateral movement. This can be utilized especially on curved roads since the vehicle has already a lateral motion. Also, the path following errors such as lateral deviation and yaw angle are not always zero.

Thus, the improved solution can be expressed as:

$$Frenet\ States = [x \quad v_x \quad a_x \quad y \quad v_y \quad a_y] \qquad \text{Equation 5.10a}$$

Initial conditions are:

$$IC = [x_0 \quad v_{x0\,sens} \quad a_{x0\,sens} \quad l_{d0\,sens} \quad v_{y0\,sens} \quad a_{y0\,sens}] \qquad \text{Equation 5.10b}$$

Final conditions are:

$$FC = [x_f \quad v_{xf} \quad a_{xf} \quad y_f \quad v_{yf} \quad a_{yf}] \qquad \text{Equation 5.10c}$$

In the proposed solution, the measured parameters are:

$$[v_{x0\,sens} \quad a_{x0\,sens} \quad l_{d0\,sens} \quad v_{y0\,sens} \quad a_{y0\,sens}] \qquad \text{Equation 5.10d}$$

The calculated states are:

$$[x_0 \quad x_f] \qquad \text{Equation 5.10e}$$

The v_{xf} might be set to the v_{x0} for comfort:

$$[v_{x0}] = [v_{xf}] \qquad \text{Equation 5.10f}$$

Then, the following parameters might set to zero for comfort:

$$[a_{xf} \quad v_{yf} \quad a_{yf}] = 0 \qquad \text{Equation 5.10g}$$

The decision scheme for the trajectory generation is available in the Figure 5-10.

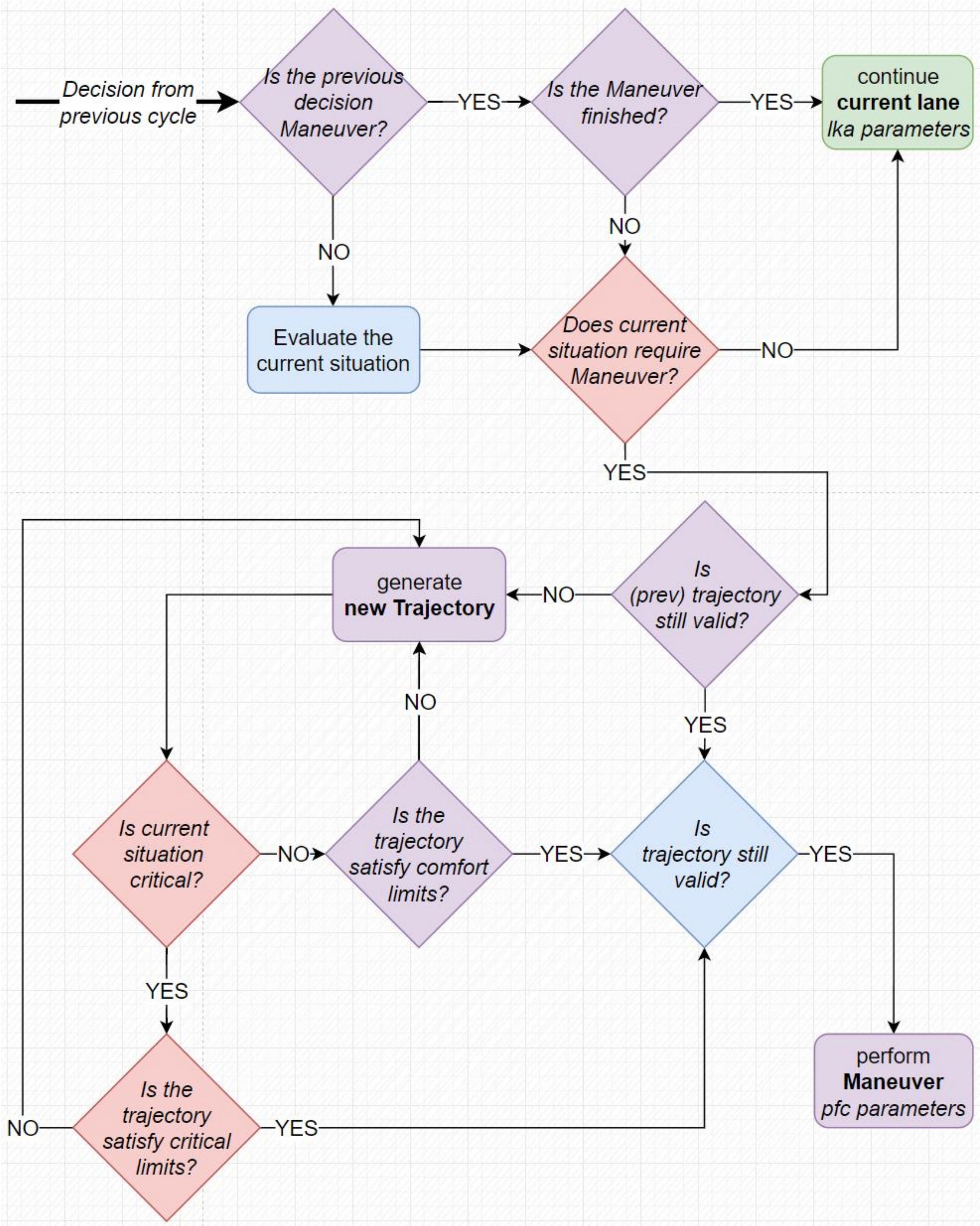


Figure 5-10 A Complete Decision Scheme for Trajectory Generation Procedure

5.2.Path Following MPC for Advanced Driver Assistance Systems

Model predictive control is a well-known and widely used control strategy, especially for multiple constrained systems. The primary action of MPC is to control the system by solving an optimal control problem online. The optimal controller inputs are decided by tunning the weights and minimizing costs for the actuators and errors in the system.

The costs are calculated over the prediction horizon where the MPC estimates the outputs of the system. Then the solution to this optimization problem yields a sequence of control inputs over a control horizon. The solution is expected to utilize the multiple inputs related to multiple output estimates. As a result, in theory, the cost is minimized and the actuator utilization is maximized.

The prediction horizon is the number of estimated future states of the model. At every discrete instant, the model of the system is used to estimate the total cost by the weights and limits. Then the cost minimization is calculated for the different actuator inputs over the control horizon. It is expected to improve the solution quality by increasing the prediction horizon. However, the computational costs also increase, which delays the response of the MPC. Therefore, in this study, a relatively sufficient control horizon and prediction horizon ratio were tried to be implemented.

The control horizon is the length of the sequence of control inputs that are calculated and expected to apply to the model. The input sequence is calculated at each cycle, but only the first value is applied as the control input. The advantage of applying the control inputs by sequence is that it utilizes the actuator capacity without exceeding the limits while maintaining high responsiveness. In addition, the rate of change for an actuator input can be limited or weighted to have more control over the actuators' performance.

Therefore, the MPC is one of the few methods that have highly responsive actuator utilization and an adaptable control strategy.

The Path Following MPC has the following properties:

- Vehicle mode selector with a controller decision mechanism for Longitudinal and Lateral driver assistance systems,
- A path following MPC that has highly responsive actuator utilization with safety and comfort tailored controller weights.

In this study, ADAS such as:

Automated Emergency Braking	(AEB)
Adaptive Cruise Control	(ACC)
Lane-Keeping Assist	(LKA)

are considered.

In addition to these, the lane change and overtake maneuver assistance system are implemented.

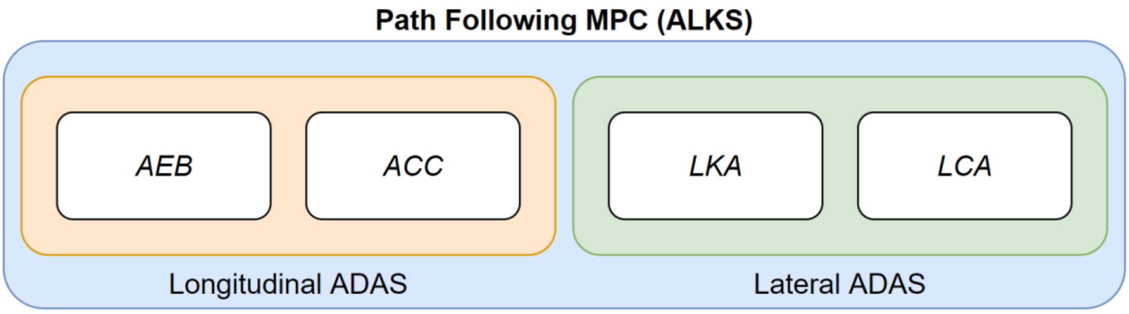


Figure 5-11 Overview of the Path Following MPC

This combined assistance system can be defined as an ALKS system where the AEB, ACC, LKA and lane change and overtake maneuver assistance systems are combined (Figure 5-11). In this study, the transition between the driving modes is governed by a Vehicle Mode Selector system which is explained in 5.2.5.

5.2.1. Automated Emergency Braking (AEB)

AEB is a braking-based safety system for emergency situations that are predicted to result in an accident. According to UN regulation 152 [36], the system should detect a possible forward collision automatically. Then it is expected to provide a suitable warning to the driver. The main goal is to prevent or weaken the potential collision by activating the braking system of the vehicle. Therefore, in this study, the AEB is automatically enabled when a trigger of the system related to front collision warning is activated.

In normal driving conditions, ACC and LKA are activated. ACC operates the longitudinal motion of the subject vehicle, where the relative distance and relative velocity are the main measurements used by the controller. However, if ACC cannot ensure a safe relative distance, then the trigger for the AEB is activated.

The trigger for the AEB is as:

$$Relative\ Distance \leq DS - SD \qquad \text{Equation 5.11}$$

In this study, the desired maximum deceleration for automated emergency braking is taken as 8 m/s^2.

An example case for AEB is given in what follows (Table 5-1 and Figure 5-12):

Table 5-1 Example Case for AEB

Initial Ego Velocity [V_{e0}]	60 kph
Initial Relative Distance [d_{x0}]	50 m
Roadway Condition	0.8

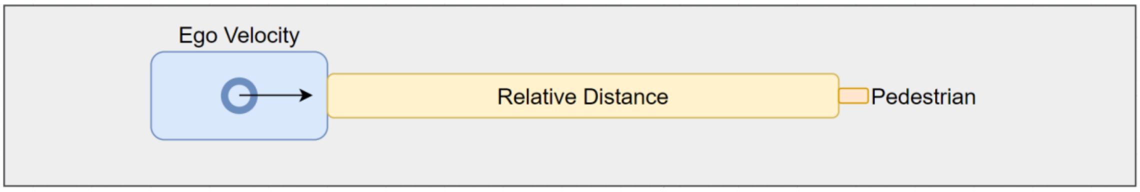


Figure 5-12 Example Case for AEB

In the example case, first, the normal driving conditions apply. ACC governs the vehicle's longitudinal motion and LKA keeps the vehicle in the road center (Figure 5-13).

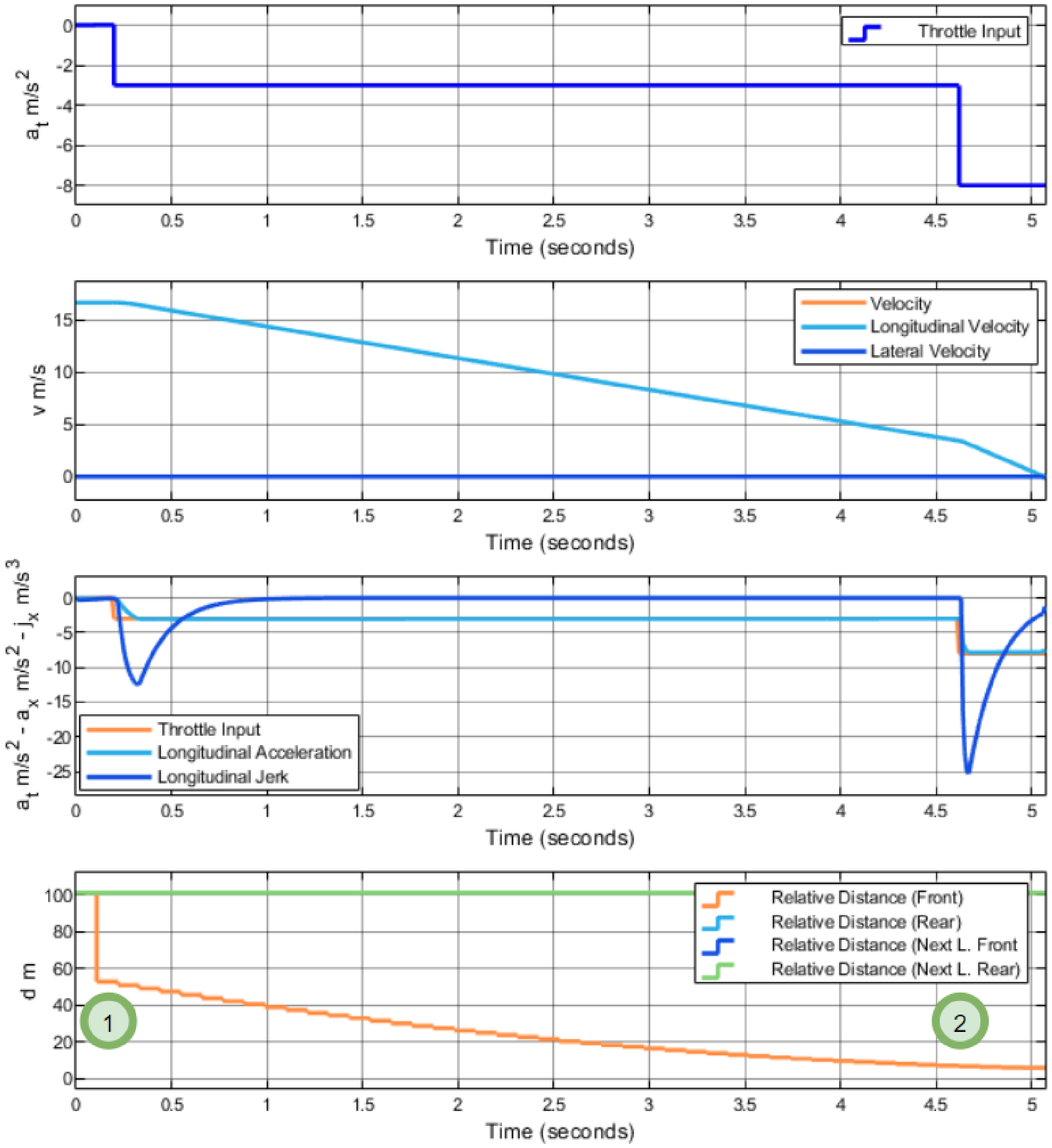


Figure 5-13 Result of the Example Case for AEB

At Point 1, Pedestrian gets detected. One cycle later, the vehicle starts to slow down due to decreasing relative distance. The initial slow-down phase from Point 1 to 2 is governed by ACC. Although the initial slowing down, the relative distance keeps getting smaller. The trigger for AEB gets activated at Point 2 at which point the hard braking phase starts. The hard braking phase successfully stops the car.

The example case was in dry road conditions where road adhesion coefficient is 0.8. The following case represents a low friction situation (Table 5-2).

Table 5-2 Low Friction Example Case for AEB

Initial Ego Velocity [V_{e0}]	60 kph
Initial Relative Distance [d_{x0}]	50 m
Roadway Condition	0.2

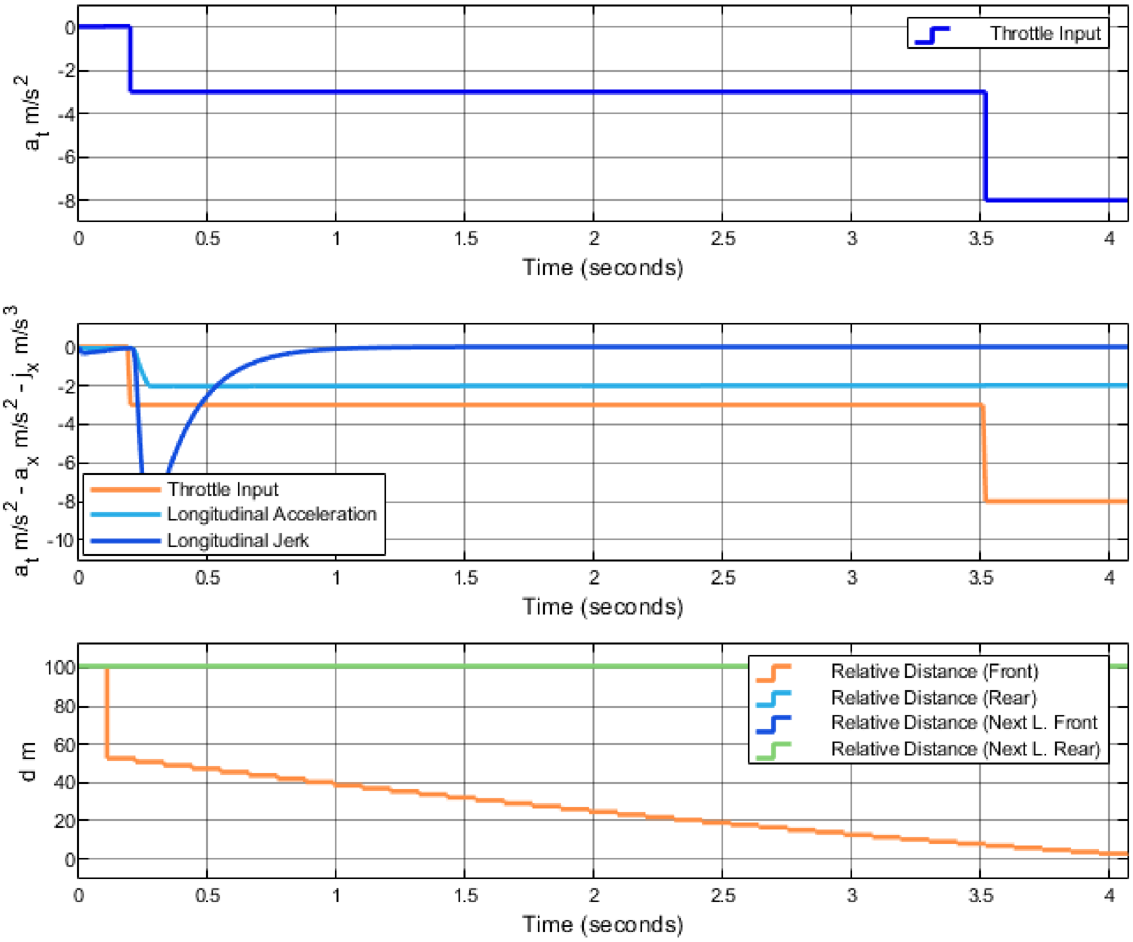


Figure 5-14 Result of the Example Case for AEB with Low Friction

In the second example, the same actions were taken by ACC and AEB (Figure 5-14). However, the low friction reduced the vehicle's ability to brake. In high friction case, the vehicle was able to brake with a deceleration up to 8 m/s^2, but in the low friction case the vehicle could not reach a deceleration above than 2 m/s^2. Therefore, this low friction case resulted in a collision.

5.2.2. Adaptive Cruise Control (ACC)

ACC controls the vehicle's longitudinal motion and adapts its velocity and distance to the lead vehicle's dynamic longitudinal behaviors. The desired safe distance and desired velocity can be adjusted by the driver. The ACC utilizes the vehicle's velocity along with the lead vehicle's velocity and the relative distance between them. The relative distance between the lead vehicle is maintained at a predefined safe level by matching the lead vehicle's longitudinal velocity.

$$Set\ Longitudinal\ Velocity = V_{lead} \quad \text{Equation 5.12a}$$

$$Clearance\ Distance = V_x * TG + DS \quad \text{Equation 5.12b}$$

The ACC limits velocity tracking if the lead vehicle's velocity exceeds the predefined set longitudinal velocity.

An example case for ACC is presented in Table 5-3, Figure 5-15 and Figure 5-16:

Table 5-3 Example Case for ACC

Initial Ego Velocity [V_{e0}]	50 kph
Initial Lead Velocity [Vo0]	40 kph
Initial Relative Distance [dx0]	50 m
Roadway Condition	0.8

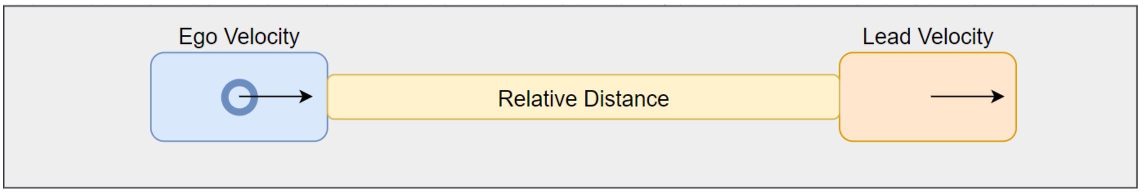


Figure 5-15 Example Case for ACC

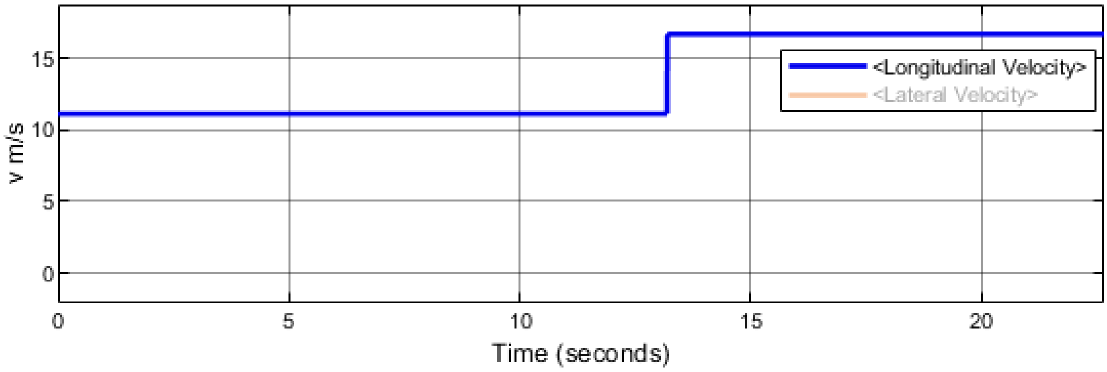


Figure 5-16 Velocity Profile of the Lead Vehicle in Example Case for ACC

In the example case, first 8 seconds, normal driving conditions apply. ACC governs the vehicle's longitudinal motion and LKA keeps the vehicle in the road center (Figure 5-17).

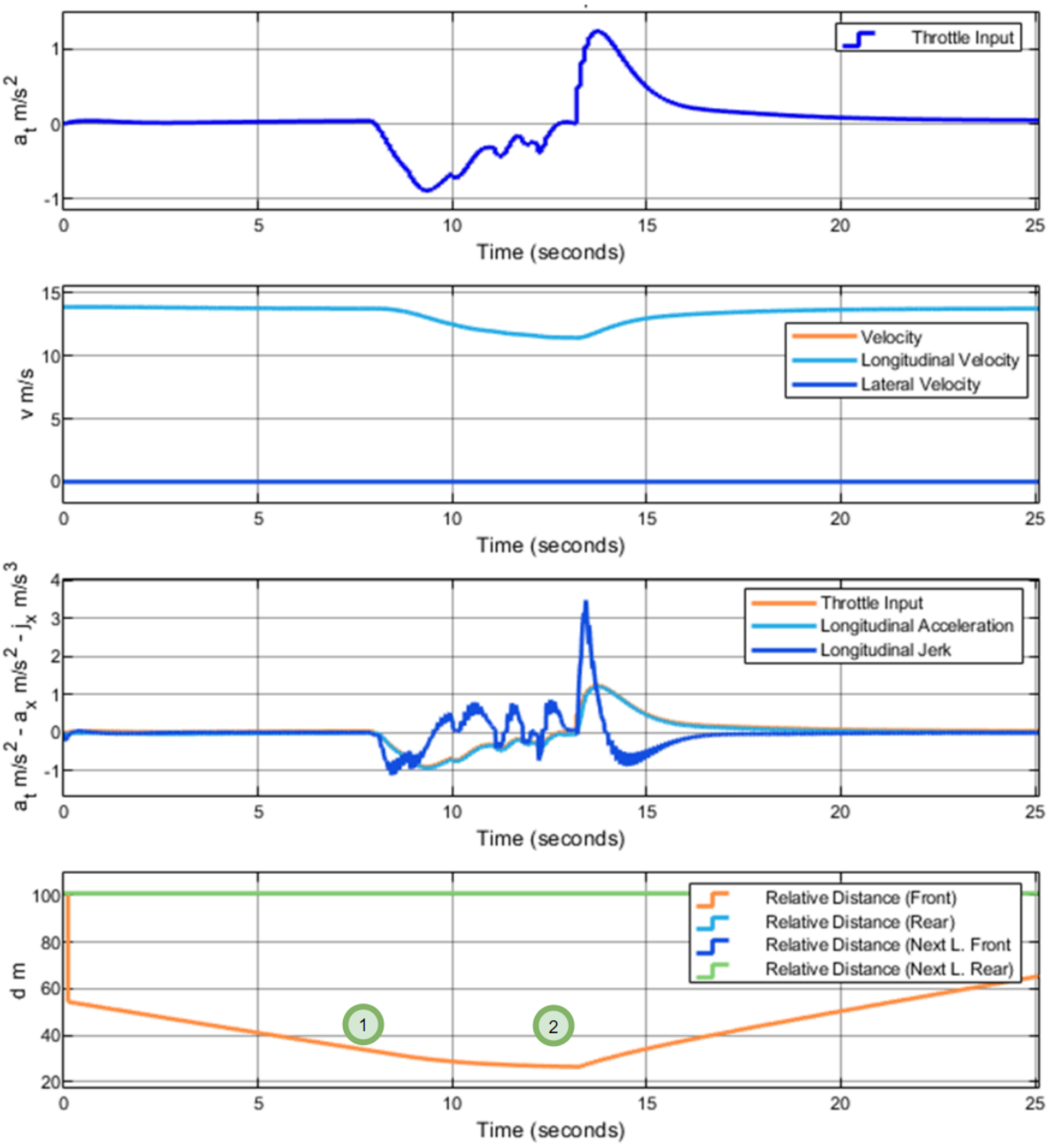


Figure 5-17 Result of the Example Case for ACC

At Point 1, the lead vehicle gets detected. One cycle later the vehicle starts to slow down due to decreasing relative distance. The initial slow-down phase through Point 1 and 2 is governed by ACC. At Point 2, the lead vehicle starts to accelerate and exceeds the initial set longitudinal velocity of the subject vehicle. The relative distance increases, therefore, ACC starts to increase the subject vehicle's velocity. However, after the velocity reaches the desired velocity, the acceleration stops and the vehicle starts to cruise normally as in normal driving conditions.

5.2.3. Lane Keeping Assist (LKA)

LKA is a lateral motion assistance system. The primary objective is to keep the vehicle between the lines and on the road center. By controlling the steering wheel, LKA aims to prevent possible accidents with road borders or other vehicles by departing front the lane guidance lines. The lateral motion dynamics are mainly dependent on the road adhesion coefficient. In conditions where the friction value is low, the lane keeping capability can suffer significantly, especially with at velocities.

An example case for LKA is presented in Table 5-4 and Figure 5-18:

Table 5-4 Example Case for LKA

Initial Ego Velocity [V_{e0}]	60 kph
Roadway Condition	0.8

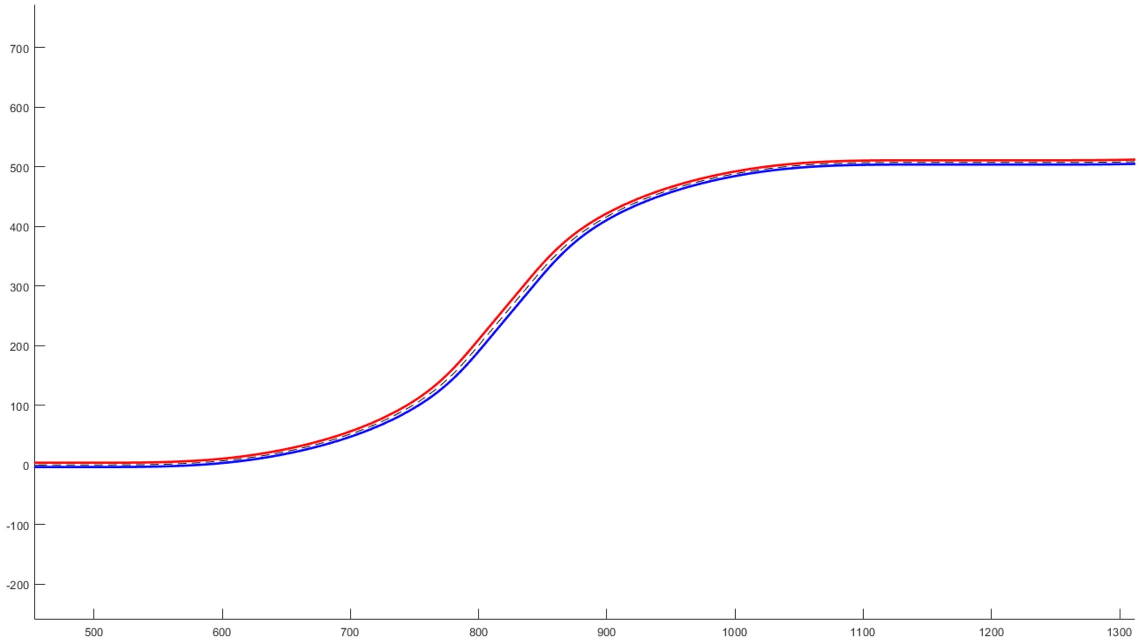


Figure 5-18 Example Case for LKA (~800x500 meters)

The map is an ALKS scenario map with different curvatures. The case contains 2 turns with different radiuses. The lateral performance of the LKA is presented in Figure 5-19. The lateral deviation levels are under 0.20 meters. The relative yaw angle between the road center and the vehicle's yaw is under 0.006 radians. For regular road adhesion coefficient, the lateral errors kept normal, and the vehicle is able to follow the road successfully.

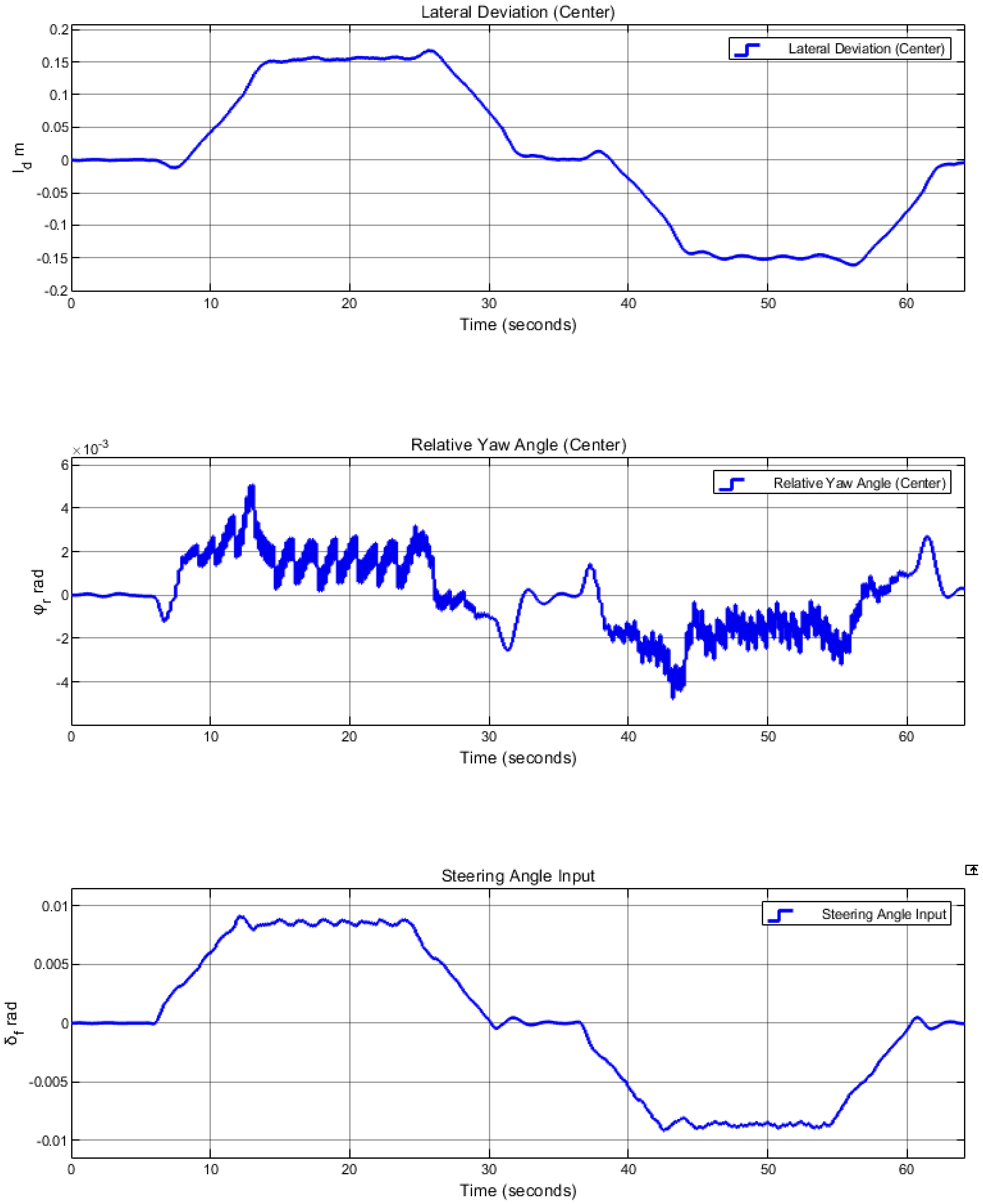


Figure 5-19 Results of the Example Case for LKA

Then, the same scenario is simulated again with a low road adhesion coefficient, to explore the lateral performance further (Table 5-5).

Table 5-5 Low Friction Example Case for LKA

Initial Ego Velocity [V_{e0}]	60 kph
Roadway Condition	0.2

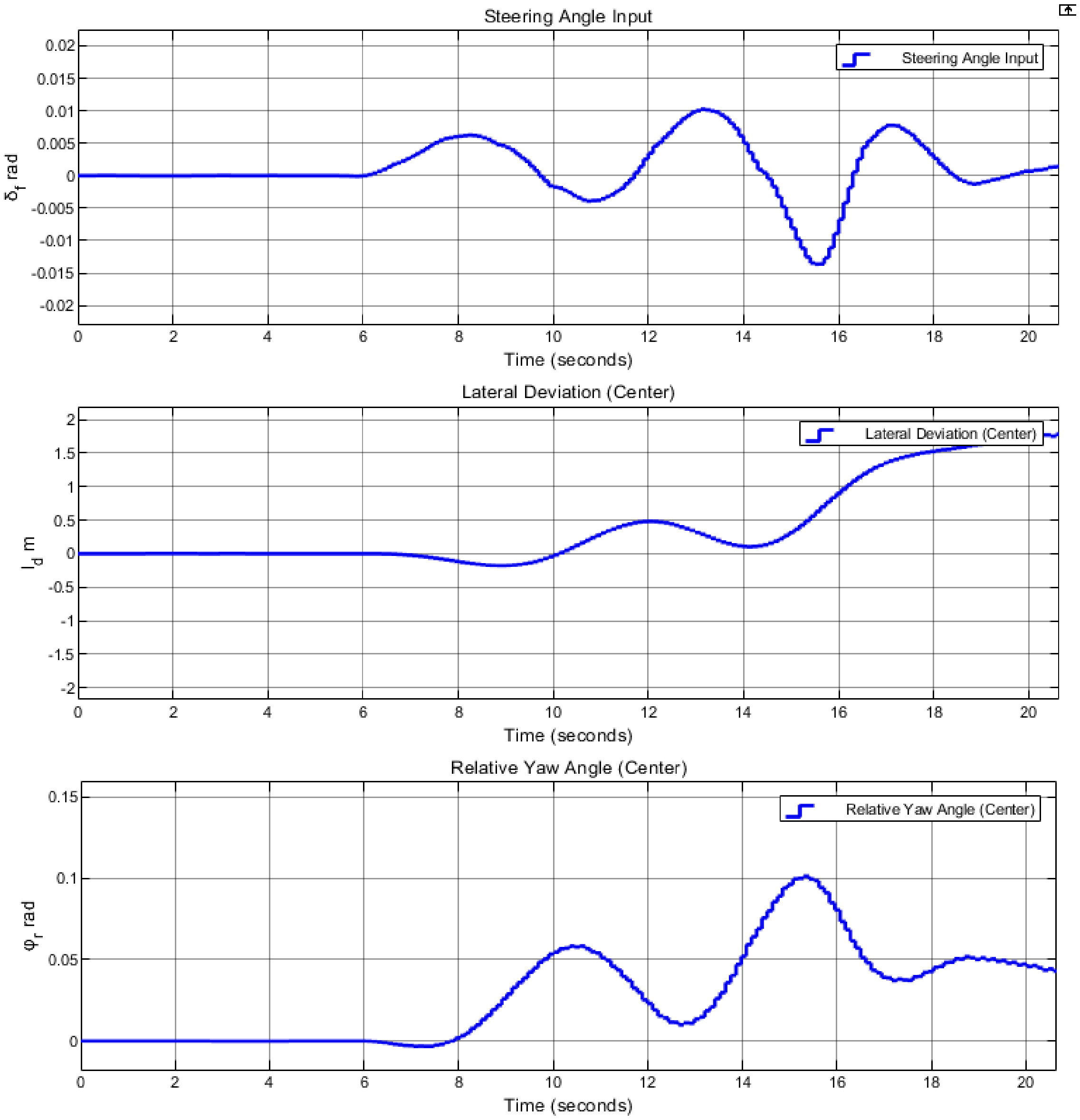


Figure 5-20 Results of the Example Case for LKA with Low Friction

In that case, the lateral deviation reaches 1.8 meters where the simulation is terminated (Figure 5-20). The relative yaw angle reached 0.1 radians. As a result, in the low friction coefficient case, the LKA has failed to hold the vehicle in the road center.

5.2.4. Lane Change Assist (LCA)

LCA is a lateral motion assistance system. The main objective of LCA is to perform a lane change maneuver by planning and following a suitable trajectory. The maneuver can be performed to change lane or during obstacle avoidance. After the Subject Vehicle completes a successful lane change, overtaking maneuver can be triggered if the new lane is defined as a passing lane. Then, overtaking maneuver can be completed by two consecutive lane change maneuvers. The trigger distances for LCA are given as:

$$Relative\ Distance\ Front \leq V_x * TG + DS * 2 \qquad \text{Equation 5.13a}$$

$$Relative\ Distance\ Rear \leq V_{rear} * TG \qquad \text{Equation 5.13b}$$

An example case for LCA is presented in Table 5-6, Figure 5-21:

Table 5-6 Example Case for LCA

Initial Ego Velocity [V_{e0}]	60 kph
Initial Lead Velocity [Vo0]	20 kph
Initial Relative Distance [dx0]	50 m
Roadway Condition	0.8

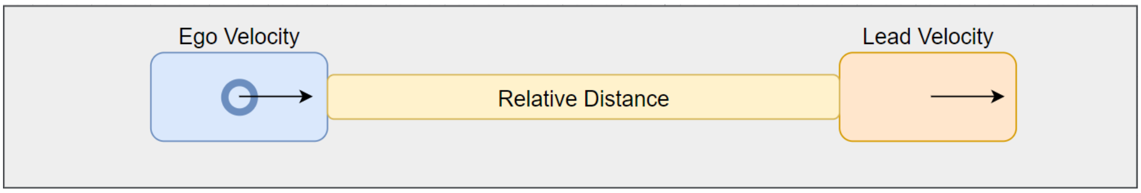


Figure 5-21 Example Case for LCA

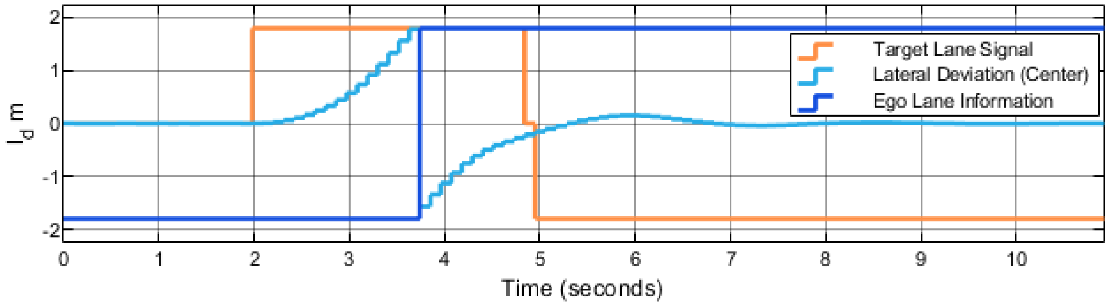


Figure 5-22 Results of the Example Case of the LCA

The maneuver signal was produced in 2.0 seconds (Figure 5-22). LCA planned a suitable trajectory and started to follow it. The lane change maneuver was completed in 2.8 seconds and the signal was set to zero. Then, an overtaking signal was produced in 5.0 s.

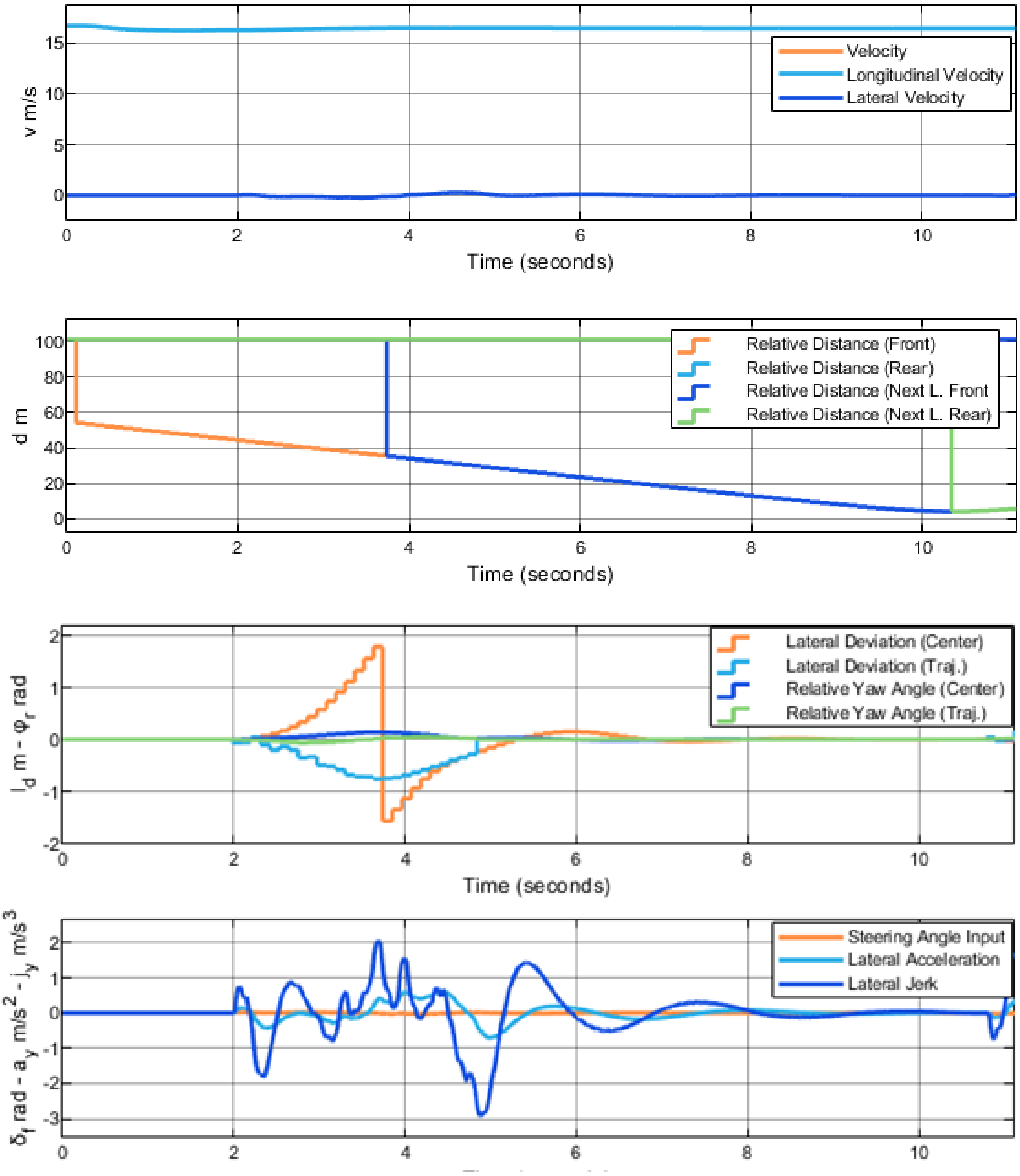


Figure 5-23 Results of the Example Case of the LCA

The velocity was kept at the set longitudinal velocity even though the relative distance was decreasing below the clearance (Figure 5-23). After the subject vehicle reached the next lane, the relative distance value changes.

The trajectory following weights were adjusted to ensure trajectory following while satisfying the lateral acceleration limits. The lateral acceleration value reached 0.5 m/s^2. However, the maximum lateral deviation from the trajectory has occurred in the lane crossing line, where the relative yaw angle was 0 radians at that instance.

Then, the same scenario is simulated again with a low road adhesion coefficient, to explore the lateral performance further (Table 5-7).

Table 5-7 Example Case for LCA with Low Friction

Initial Ego Velocity [V_{e0}]	60 kph
Initial Lead Velocity [Vo0]	20 kph
Initial Relative Distance [dx0]	50 m
Roadway Condition	0.2

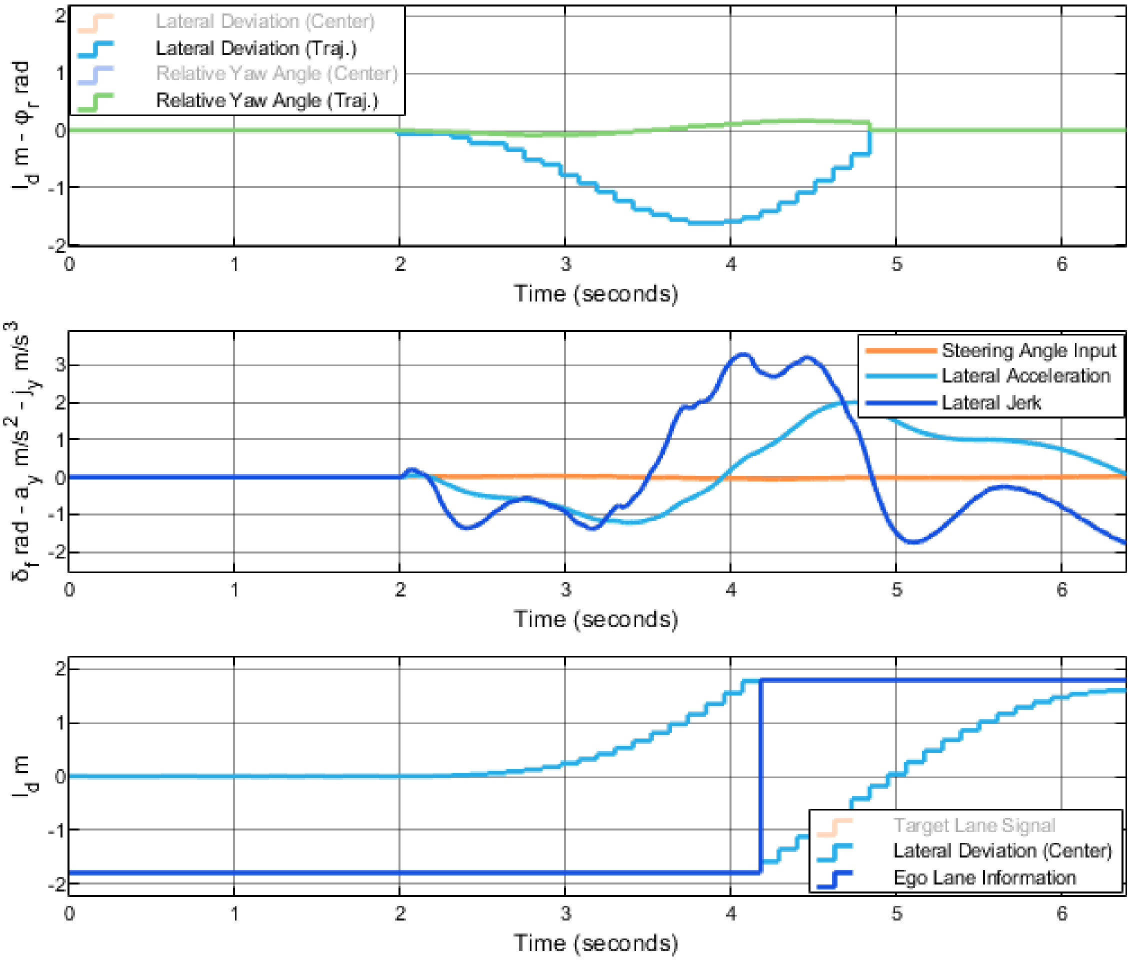


Figure 5-24 Results of the Example Case of the LCA with Low Friction

The lateral deviation reached to 1.8 meters where the simulation terminated (Figure 5-24). The lateral acceleration reached 2.0 m/s^2. As a result, in the low friction coefficient case, the LCA failed to follow the trajectory and hold the vehicle in the road center.

5.2.5. Vehicle Mode Selector

The decision scheme for the Vehicle mode selector is given in Figure 5-25 and Figure 5-26.

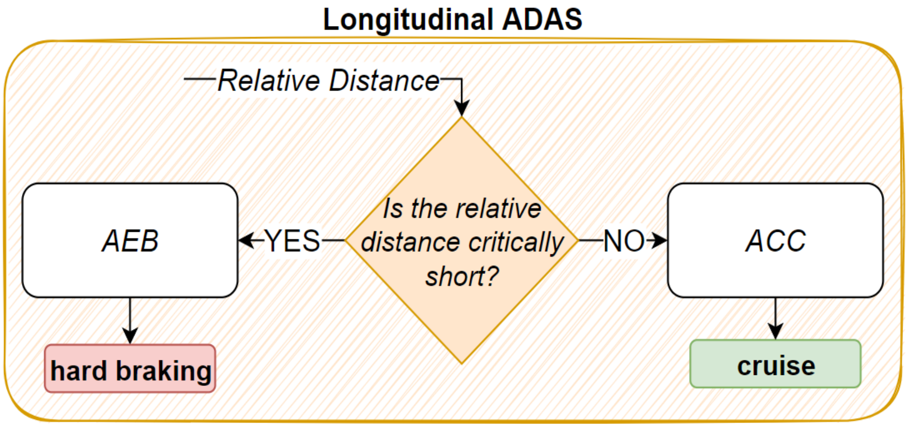


Figure 5-25 Decision Scheme of the Longitudinal ADAS

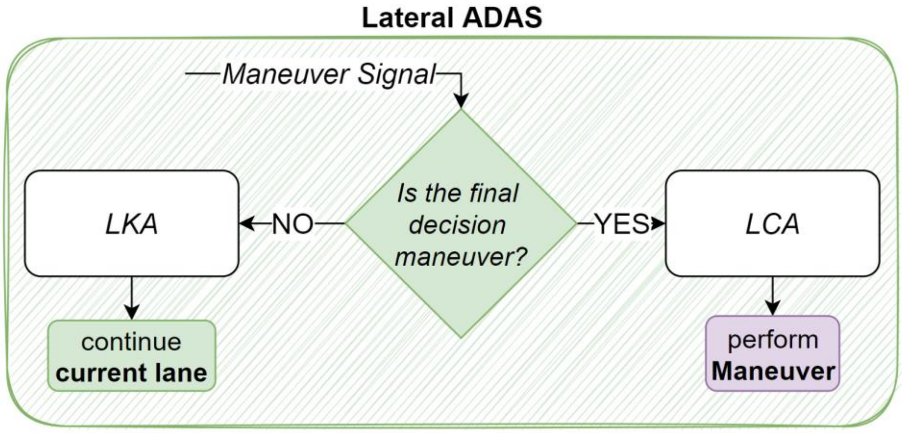


Figure 5-26 Decision Scheme of the Lateral ADAS

Critically short term is referred to a situation where distance is critically smaller than default spacing (Table 5-8). In this study, distance is explained as equation 5.11 in **Hata! Başvuru kaynağı bulunamadı.**:

$$Relative\ Distance \leq DS - SD \qquad \text{Equation 5.14}$$

Table 5-8 Vehicle Mode Selector Parameters

Vehicle Mode Selector Parameters		
Value	*Unit*	*Description*
10.0	m	Default spacing
1.5	s	Time Gap
3.0	m	Safe distance

The overview of the vehicle mode selector is given in Figure 5-27 and Figure 5-28.

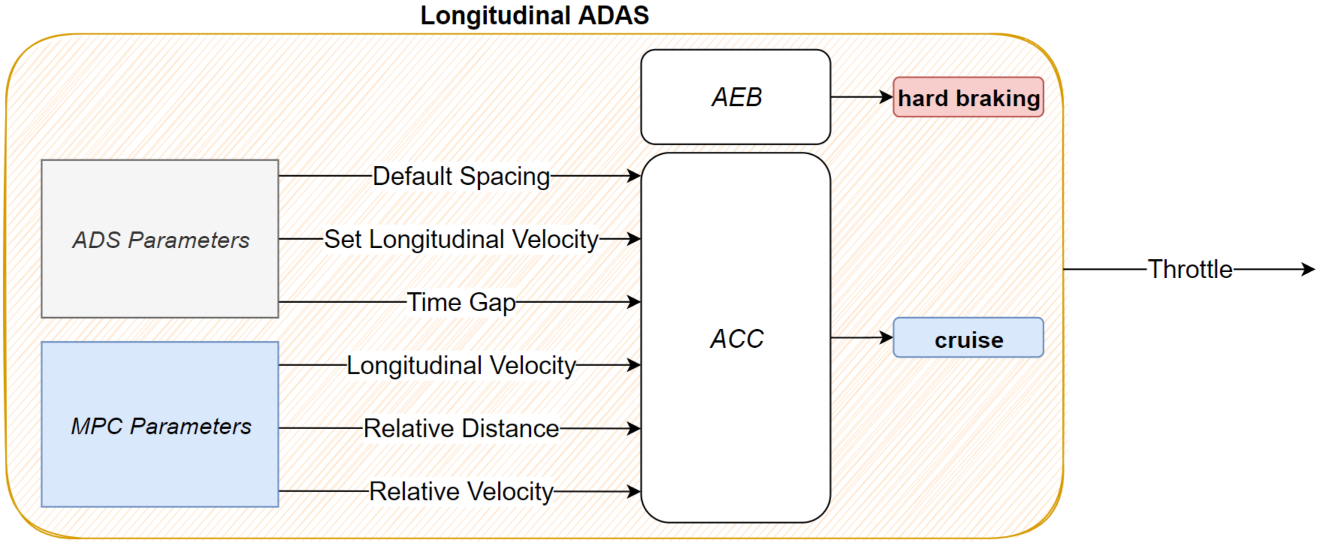


Figure 5-27 Overview of the Vehicle Mode Selector for Longitudinal ADAS

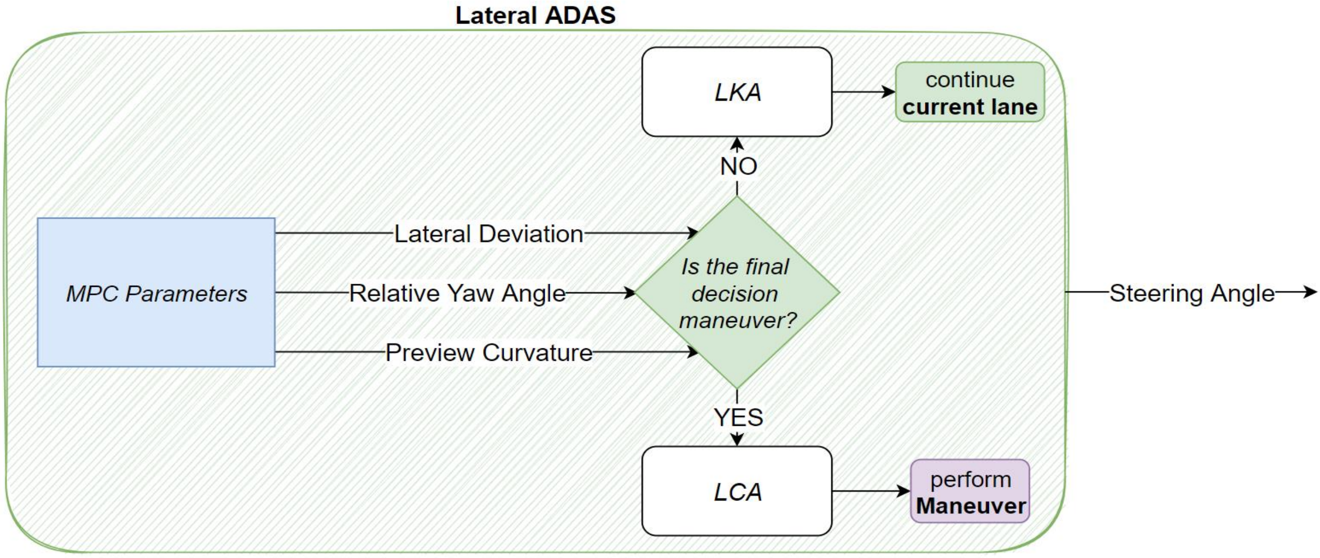


Figure 5-28 Overview of the Vehicle Mode Selector for Lateral ADAS

The vehicle can operate under ACC or trigger AEB while changing lanes. With the implementation of the combined ALKS, it is possible to evaluate the controller with mixed scenarios of AEB, ACC, LKS and LCA.

5.2.6. Path Following MPC

The Path following MPC has state-space representations for the longitudinal and lateral vehicle modes. The models are used to estimate the vehicle's states. Meanwhile this information is updated with the perception block.

The longitudinal states are defined as:

$$x = [a_x \quad v_x]' \qquad \text{Equation 5.15a}$$

The longitudinal throttle input is defined as:

$$u = [a_t]' \qquad \text{Equation 5.15b}$$

The Longitudinal Predictive Model state-space representation is as the following.

$$\dot{x} = Ax + Bu \qquad \text{Equation 5.15c}$$

$$A_{11} = \left[-\frac{1}{\tau}\right] \qquad \text{Equation 5.15d}$$

$$B_{11} = \left[\frac{1}{\tau}\right] \qquad \text{Equation 5.15e}$$

$$\dot{x} = \begin{bmatrix} A_{11} & 0 \\ 1 & 0 \end{bmatrix} x + \begin{bmatrix} B_{11} \\ 0 \end{bmatrix} u \qquad \text{Equation 5.15f}$$

The lateral states are defined as:

$$x = [v_y \quad \dot{\psi}]' \qquad \text{Equation 5.15g}$$

The lateral input steering angle is defined as:

$$u = [\delta_f]' \qquad \text{Equation 5.15h}$$

The Lateral Predictive Model state-space representation is as the following.

$$A_{11} = \left[-\frac{2(C_f + C_r)}{mU}\right] \qquad \text{Equation 5.15i}$$

$$A_{12} = \left[-U - \frac{2(aC_f - l_r C_r)}{mU}\right] \qquad \text{Equation 5.15j}$$

$$A_{21} = \left[-\frac{2(aC_f - l_r C_r)}{I_{zz}U}\right] \qquad \text{Equation 5.15k}$$

$$A_{22} = \left[-\frac{2({l_f}^2 C_f + {l_r}^2 C_r)}{I_{zz} U} \right]$$ Equation 5.15l

$$B_{11} = \left[-\frac{2C_f}{m} \right]$$ Equation 5.15m

$$B_{21} = \left[\frac{2 l_f C_f}{I_{zz}} \right]$$ Equation 5.15n

$$\dot{x} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} x + \begin{bmatrix} B_{11} \\ B_{12} \end{bmatrix} u$$ Equation 5.15o

As a result, the whole Automated Lane Keeping Assist Predictive Model can be represented. The state-space representation is as the following.

$$x = [a_x \quad v_x \quad v_y \quad \dot{\psi}]'$$ Equation 5.15p

$$u = [a_t \quad \delta_f]'$$ Equation 5.15q

$$A_{11} = \left[-\frac{1}{\tau} \right]$$ Equation 5.15r

$$A_{33} = \left[-\frac{2(C_f + C_r)}{mU} \right]$$ Equation 5.15s

$$A_{34} = \left[-U - \frac{2(l_f C_f - l_r C_r)}{mU} \right]$$ Equation 5.15t

$$A_{43} = \left[-\frac{2(l_f C_f - l_r C_r)}{I_{zz} U} \right]$$ Equation 5.15u

$$A_{44} = \left[-\frac{2({l_f}^2 C_f + {l_r}^2 C_r)}{I_{zz} U} \right]$$ Equation 5.15v

$$B_{11} = \left[\frac{1}{\tau} \right]$$ Equation 5.15w

$$B_{31} = \left[-\frac{2C_f}{m} \right]$$ Equation 5.15x

$$B_{41} = \left[\frac{2 l_f C_f}{I_{zz}} \right]$$ Equation 5.15y

$$\dot{x} = \begin{bmatrix} A_{11} & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & A_{33} & A_{34} \\ 0 & 0 & A_{43} & A_{44} \end{bmatrix} x + \begin{bmatrix} B_{11} \\ 0 \\ B_{31} \\ B_{41} \end{bmatrix} u$$ Equation 5.15z

The parameters of the path following MPC are given in Table 5-9.

Table 5-9 Path Following MPC Parameters

Path Following MPC Parameters

Value	*Unit*	*Description*
0.01	s	Transport lag between model inputs and outputs
10.00	m	Default spacing
1.50	s	Time Gap
1670	kg	Total mass
2100	kgm^2	Yaw moment of inertia
0.99	m	Longitudinal distance from CG to front tires
1.70	m	Longitudinal distance from CG to rear tires
61595	N/rad	Cornering stiffness of front tires
52095	N/rad	Cornering stiffness of rear tires
0.50	s	Longitudinal acceleration tracking time constant
-0.26	rad	Minimum steering angle
0.26	rad	Maximum steering angle
-3.00	m/s^2	Minimum longitudinal acceleration
2.00	m/s^2	Maximum longitudinal acceleration
10.00	Hz	Sampling Frequency
30.00	-	Prediction Horizon
10.00	-	Control Horizon
≈1	-	Weight on velocity tracking
≈1	-	Weight on change of longitudinal acceleration
≈10	-	Weight on lateral error
≈400	-	Weight on change of steering angle

The controller weights and limits were adjusted for accurate path tracking that ensures the driver's safety and for realistic responses that consider the driver's comfort and actuator health. In addition, the weights of the MPC can be adjusted to adapt to different kinds of operating conditions in various driving environments.

6. TEST RESULTS AND DISCUSSION

In this section, the ADAS are first inspected separately. First, AEB and LCA were inspected as critical situation systems. Then, ACC and LKA were inspected under normal situation systems.

6.1. AEB Testing

This system can identify a possible forward collision and trigger the vehicle braking system to slow down the vehicle to avoid or prevent a collision. In this study, the desired maximum deceleration for automated emergency braking is taken as 8 m/s^2. The scenario for AEB contains an Actor lead vehicle (Figure 6-1). The relative distance, the initial velocities are predefined.

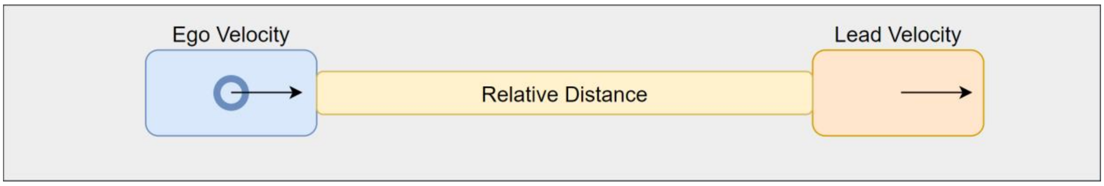


Figure 6-1 Test Scenario Scheme for AEB Testing

It is aimed to explore the ODD and detect the failure cases' borders. The pass and fail results for the cases are shown in Table 6-1.

Table 6-1 Color Legend for Pass and Fail Results of the Test Cases

FAIL	PASS	
Collision	Full Stop	Non-Stop
🟥	🟨	🟩

6.1.1. 1st Case for AEB Testing: Low Velocity and Low Relative Distance

The 1st case is a simple case to explore and inspect the ODD of AEB (Table 6-2).

Table 6-2 Result Matrix of the 1st Case for AEB Testing

Initial Ego Velocity [V_{e0}]	20	kph	Relative Distance m [d_{x0}]				
Roadway Condition	0.8		2	4	6	8	10
Lead Velocity [V_{o0}]	10.0	kph	*6*	*7*	*8*	*9*	*10*
	0.0	kph	*1*	*2*	*3*	*4*	*5*

Time to collision values for the 1st case is as follows (Table 6-3).

Table 6-3 Time to Collision Matrix of the 1st Case for AEB Testing

Time to Collision [TTC]				
0.20	*0.40*	*0.60*	*0.80*	*1.00*
0.10	*0.20*	*0.30*	*0.40*	*0.50*

After inspecting the 1st results, the operating domain was inspected further by decreasing the time to collision parameter.

6.1.2. 2nd Case for AEB Testing: Medium Velocity and Low Relative Distance

The 2nd case increases the relative velocity parameter range (Table 6-4).

Table 6-4 Result Matrix of the 2nd Case for AEB Testing

Initial Ego Velocity [V_{e0}]	40	kph	Relative Distance m [d_{x0}]				
Roadway Condition	0.8		2	4	6	8	10
Lead Velocity [V_{o0}]	30.0	kph	*16*	*17*	*18*	*19*	*20*
	20.0	kph	*11*	*12*	*13*	*14*	*15*
	10.0	kph	*6*	*7*	*8*	*9*	*10*
	0.0	kph	*1*	*2*	*3*	*4*	*5*

Time to collision values for the 2nd case is as the following (Table 6-5).

Table 6-5 Time to Collision Matrix of the 2nd Case for AEB Testing

Time to Collision [TTC]				
0.20	*0.40*	*0.60*	*0.80*	*1.00*
0.10	*0.20*	*0.30*	*0.40*	*0.50*
0.07	*0.13*	*0.20*	*0.27*	*0.33*
0.05	*0.10*	*0.15*	*0.20*	*0.25*

After inspecting the 2nd results, the operating domain was inspected further by also increasing the relative distance parameter.

6.1.3. 3rd case for AEB Testing: High Road Friction in ODD

The 3rd case increases the relative velocity and relative distance parameter range in high road friction environment (Table 6-6).

Table 6-6 Result Matrix of the 3rd Case for AEB Testing

Initial Ego Velocity [V_{e0}]	60	kph	Relative Distance m [d_{x0}]														
Roadway Condition	0.8		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
Lead Velocity [V_{o0}]	50.0	kph	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
	40.0	kph	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
	30.0	kph	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
	20.0	kph	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
	10.0	kph	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
	0.0	kph	2	4	6	8	#	#	#	#	#	#	#	#	#	#	#

Time to collision values for the 3rd case is as the following (Table 6-7).

Table 6-7 Time to Collision Matrix for the 3rd Case for AEB Testing

Time to Collision [TTC]														
0.20	*0.40*	*0.60*	*0.80*	*1.00*	*1.20*	*1.40*	*1.60*	*1.80*	*2.00*	*2.20*	*2.40*	*2.60*	*2.80*	*3.00*
0.10	*0.20*	*0.30*	*0.40*	*0.50*	*0.60*	*0.70*	*0.80*	*0.90*	*1.00*	*1.10*	*1.20*	*1.30*	*1.40*	*1.50*
0.07	*0.13*	*0.20*	*0.27*	*0.33*	*0.40*	*0.47*	*0.53*	*0.60*	*0.67*	*0.73*	*0.80*	*0.87*	*0.93*	*1.00*
0.05	*0.10*	*0.15*	*0.20*	*0.25*	*0.30*	*0.35*	*0.40*	*0.45*	*0.50*	*0.55*	*0.60*	*0.65*	*0.70*	*0.75*
0.04	*0.08*	*0.12*	*0.16*	*0.20*	*0.24*	*0.28*	*0.32*	*0.36*	*0.40*	*0.44*	*0.48*	*0.52*	*0.56*	*0.60*
0.03	*0.07*	*0.10*	*0.13*	*0.17*	*0.20*	*0.23*	*0.27*	*0.30*	*0.33*	*0.37*	*0.40*	*0.43*	*0.47*	*0.50*

After inspecting the 3rd result, the operating domain was inspected further by adjusting the roadway condition parameter for the road adhesion coefficient.

6.1.4. 4th case for AEB Testing: Low Road Friction in ODD

The 4th case changes the roadway condition to explore the friction values effect (Table 6-8).

Table 6-8 Result Matrix of the 4th Case for AEB Testing

Initial Ego Velocity [V_{e0}]	60	kph	Relative Distance m [d_{x0}]														
Roadway Condition	0.2		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
Lead Velocity [V_{o0}]	50.0	kph	🟥 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #
	40.0	kph	🟥 #	🟥 #	🟥 #	🟥 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #
	30.0	kph	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #	🟩 #
	20.0	kph	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #
	10.0	kph	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #
	0.0	kph	🟥 1	🟥 3	🟥 5	🟥 7	🟥 9	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #	🟥 #

Time to collision values for the 4th case is as the following (Table 6-9).

Table 6-9 Time to Collision Matrix of the 4th Case for AEB Testing

Time to Collision [TTC]														
0.20	*0.40*	*0.60*	*0.80*	*1.00*	*1.20*	*1.40*	*1.60*	*1.80*	*2.00*	*2.20*	*2.40*	*2.60*	*2.80*	*3.00*
0.10	*0.20*	*0.30*	*0.40*	*0.50*	*0.60*	*0.70*	*0.80*	*0.90*	*1.00*	*1.10*	*1.20*	*1.30*	*1.40*	*1.50*
0.07	*0.13*	*0.20*	*0.27*	*0.33*	*0.40*	*0.47*	*0.53*	*0.60*	*0.67*	*0.73*	*0.80*	*0.87*	*0.93*	*1.00*
0.05	*0.10*	*0.15*	*0.20*	*0.25*	*0.30*	*0.35*	*0.40*	*0.45*	*0.50*	*0.55*	*0.60*	*0.65*	*0.70*	*0.75*
0.04	*0.08*	*0.12*	*0.16*	*0.20*	*0.24*	*0.28*	*0.32*	*0.36*	*0.40*	*0.44*	*0.48*	*0.52*	*0.56*	*0.60*
0.03	*0.07*	*0.10*	*0.13*	*0.17*	*0.20*	*0.23*	*0.27*	*0.30*	*0.33*	*0.37*	*0.40*	*0.43*	*0.47*	*0.50*

After evaluating all the results, it can be seen that the roadway condition affected the results. The minimum safe TTC value increased in the low friction cases. TTC is directly related to initial conditions. However, after the inspection of the results, it has appeared that TTC is not the only parameter that governs the results. Therefore, the initial velocity of the subject vehicle is also considered in evaluations.

In the previous cases, the subject vehicle failed to stop when there is 28 meters of distance between a static obstacle. This is a dangerous situation where AEB could not prevent the collision. Therefore, the situation further was inspected with LCA assist.

6.2. LCA Testing

Lane change and overtake assist performs lane change maneuvers for overtake or obstacle avoidance. In the following scenario the effect of the lane change maneuver for obstacle avoidance is inspected.

6.2.1. 1st Case for LCA Testing: Comparison with 3rd AEB Testing Case

From the results, it can be seen that the critical situation at 28.0 meters relative distance has been successfully avoided (Table 6-10). Normally, without maneuver, the AEB alone was not enough to prevent collision in the previous results in 3rd AEB Testing Case.

Table 6-10 Result Matrix of the 1st Case for LCA Testing

Initial Ego Velocity [V_{e0}]	60.0 kph		Initial Distance m [d_{x0}]		
Roadway Condition	0.8		26	28	30
Lead Velocity [V_{o0}]	50.0	kph	🟩	🟩	🟩
	40.0	kph	🟩	🟩	🟩
	30.0	kph	🟩	🟩	🟩
	20.0	kph	🟩	🟩	🟩
	10.0	kph	🟩	🟩	🟩
	0.0	kph	🟥	🟩	🟩

The breakdown of the situation is presented as the following.

1. The subject vehicle observes the lead vehicle.
2. Decision has been made to perform the maneuver.
3. Trajectory generated for a lane change maneuver which avoids the obstacle (Figure 6-2).

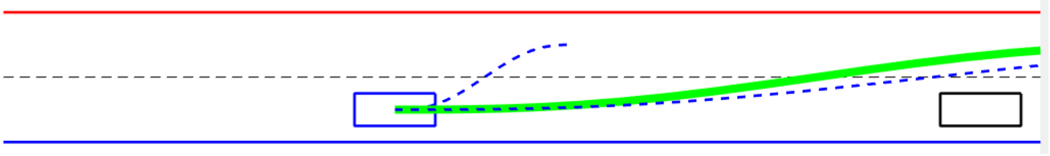


Figure 6-2 Beginning of the 1st Case for the LCA Testing

4. Trajectory is being followed by the vehicle.
5. Near pass of the static object. This situation has resulted in a collision with AEB previously (Figure 6-3 and Figure 6-4).

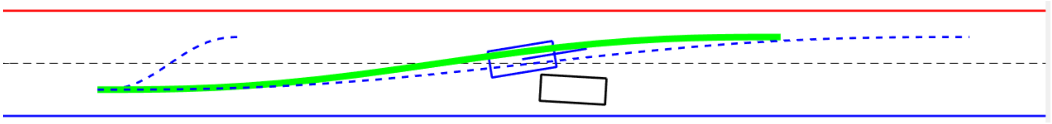


Figure 6-3 Trajectory Tracking in the 1st Case for LCA Testing (near pass frame 1)

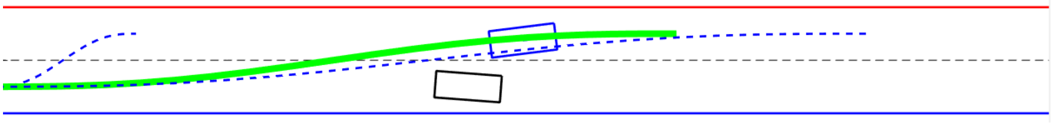


Figure 6-4 Trajectory Tracking in the 1st Case for LCA Testing (near pass frame 2)

6. The vehicle continues to follow the lane center in the new lane (Figure 6-5).

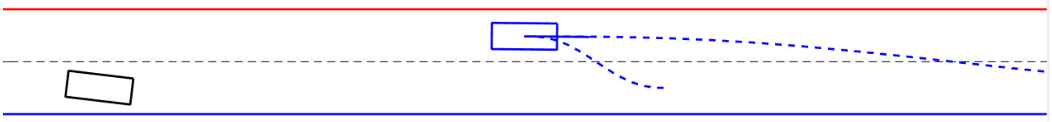


Figure 6-5 Lane Center Following in the 1st Case for LCA Testing

It can be seen that the subject vehicle starts to evaluate another lane change to the original lane after completing maneuver (Figure 6-6). This is triggered because the current new lane is a passing lane. After the next lane change maneuver, the total maneuver can be considered an overtaking. First, the situation while performing obstacle avoidance will be inspected.

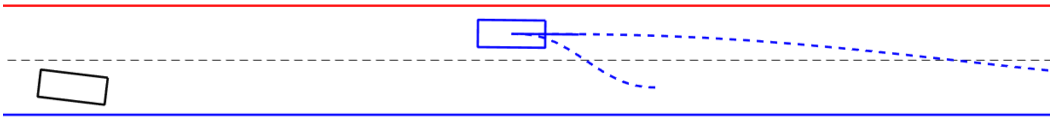


Figure 6-6 Overview of the Situation After Lane Change Maneuver in the 1st Case for LCA Testing

The path history can be inspected for the overall performance of trajectory tracking (Figure 6-7).

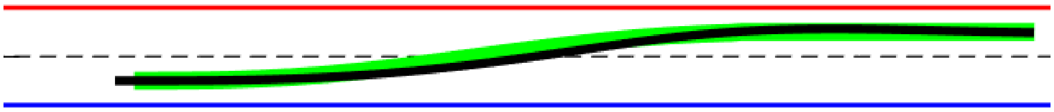


Figure 6-7 Path history of the situation after lane change maneuver in the 1st case for LCA

It appears that the vehicle reached the final position; however, there is a slight offset in the middle of the trajectory. This may be caused by the lateral dynamics of the vehicle or the low weights of the controller.

At 0.1 s after the simulation started, a maneuver signal was produced. The maneuver took 2.5 s and after that, another maneuver signal was produced for completing the overtaking maneuver.

The testing and evaluation phase makes it available to find the critical design points and the ability to improve the motion planning and control algorithms. In the longitudinal direction, the controller performed well. The velocity control had little error on the set longitudinal velocity. The vehicle performed a successful lane change maneuver.

However, there was a lateral deviation from the trajectory, especially in the middle region as suspected in the path history plot evaluation. Nevertheless, the vehicle safely performed an avoidance maneuver. In addition, the driver's comfort is also a consideration in this study. In the longitudinal motion profiles, the values were low and comfortable. The throttle command was changed little during the maneuver. In the lateral motion profiles, the values were limited under 3.0 m/s^3, m/s^2 and m/s, since trajectory is accepted only when these limits were satisfied. However, the maximum jerk value is close to the 3.0 m/s^3.

This situation was further inspected as the subject vehicle performs another lane change maneuver and completes the overtaking maneuver (Figure 6-8).

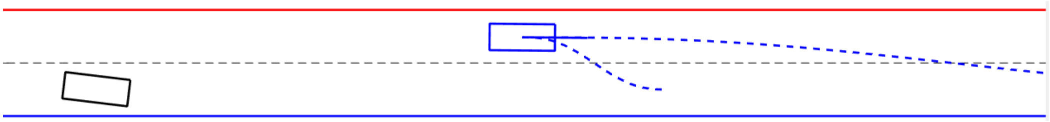


Figure 6-8 Beginning of the Overtake Phase in the 1st Case for the LCA Testing

The breakdown of the consecutive situation is presented as the following.

7. Decision has been made to perform the maneuver.
8. Trajectory generated for an overtaking maneuver (Figure 6-9).

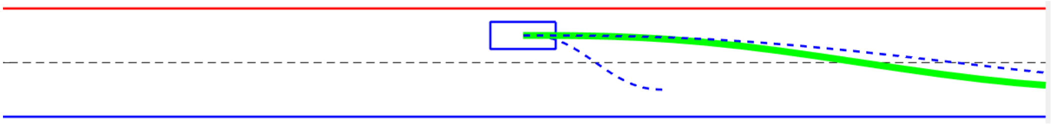


Figure 6-9 Trajectory Generation Overtake Maneuver in the 1st Case for the LCA Testing

9. Trajectory is being followed by the vehicle (Figure 6-10).

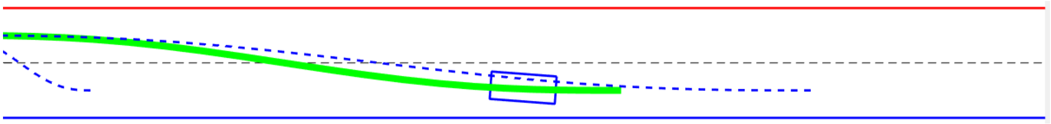


Figure 6-10 Trajectory Tracking for Overtake Maneuver in the 1st Case for the LCA Testing

10. The vehicle continues to follow the lane center in the original lane.

The path history can be inspected for the overall performance of trajectory tracking (Figure 6-11).

Figure 6-11 Path History of the Situation After Overtake Maneuver in the 1st Case for LCA Testing

It appears that the vehicle reaches the final position and safely follows the new road center in its original lane.

After 2.6 s after the simulation started, another maneuver signal was produced for the consecutive lane change. The maneuver started at 7.7 seconds and finished at 10.4 seconds. The maneuver was completed in 2.7 s.

The velocity control had little error on the set longitudinal velocity. In the longitudinal direction, the controller performed well. The effect of other factors such as road adhesion coefficient will be presented later in the following testing case in 6.2.2. The vehicle performed two consecutive lane change maneuvers successfully.

However, there is a lateral deviation from the trajectory, especially in the middle regions of the trajectory as suspected in the path history plot evaluation. Nevertheless, the vehicle safely performed an overtaking maneuver. In the longitudinal motion profiles, the values are low and comfortable. The throttle command was changed little during the maneuver. In the lateral motion profiles, the values for both maneuvers are limited under 3.0 $m/s^3, m/s^2\ and\ m/s$, since trajectory is accepted only when these limits were satisfied.

6.2.2. 2nd Case for LCA Testing: Low Road Friction

The operating domain was inspected further by adjusting the roadway condition parameter for the road adhesion coefficient. The friction value is the main concern when performing maneuvers due to real-life problems such as lateral stability.

Thus, in the following, this effect of road adhesion coefficient was inspected (Table 6-11).

Table 6-11 Result Matrix of the 2nd case for LCA Testing

Initial Ego Velocity [V_{e0}]					
kph	60		Initial Distance m [d_{x0}]		
Roadway Condition	0.2				
			26	28	30
	Lead Velocity kph [V_{o0}]	50.0	🟥	🟥	🟥
		40.0	🟥	🟥	🟥
		30.0	🟥	🟥	🟥
		20.0	🟥	🟥	🟥
		10.0	🟥	🟥	🟥
		0.0	🟥	🟥	🟥

In the cases with 0.2 roadway conditions, the vehicle failed to perform the maneuver. It is evident that there is a requirement to inspect the effect of the friction values.

Recall the 3rd AEB Testing Case with 28.0 meters of relative distance where the AEB alone resulted in a collision. In the 1st LCA Testing Case, an assist from LCA performed a successful maneuver to avoid a collision. However, in the low-friction conditions, the maneuvers can result in a collision.

Therefore, there must be a mechanism to evaluate roadway conditions. Evidently, in low-friction conditions, the vehicle must decide whether it is safe and stable to perform a maneuver or not.

6.3. ACC Testing

Adaptive cruise control is a sophisticated driver-assistance technology that automatically controls the vehicle speed to maintain a stable safe distance from vehicles ahead.

The 1st case for ACC is as the following (Figure 6-12).

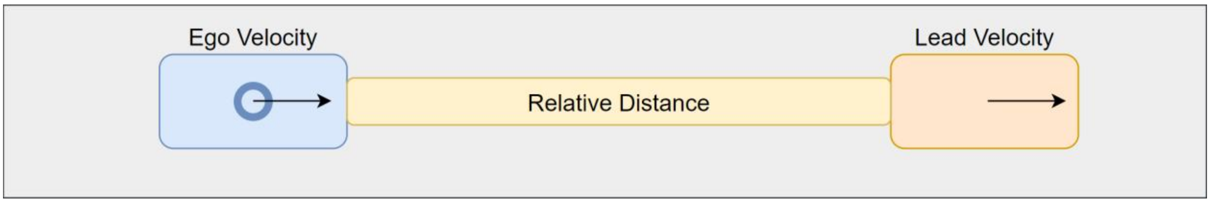


Figure 6-12 Test Scenario Scheme for ACC Testing

6.3.1. 1st Case of ACC: High Road Friction

The 1st test case for ACC is presented in Table 6-12:

Table 6-12 Simplified ODD for the 1st Scenario of ACC Testing

Initial Ego Velocity [V_{e0}]	60 kph
Lead Velocity [Vo0]	50 kph
Initial Relative Distance [d_{x0}]	50 m
Roadway Condition	0.8

It can be seen that the subject vehicle's velocity matched the lead vehicle's velocity in Figure 6-13. The vehicle applies brakes to match the leading vehicle's velocity.

The longitudinal motion values are around -1.0 m/s^2 for the acceleration and -1.0 m/s^3 for the jerk.

The relative distance between the subject vehicle and the leading vehicle started at 50.0 meters. After the subject vehicle adapted its velocity to the leading vehicle's velocity, the relative distance value is adjusted to 30.82 meters.

This clearance is calculated by:

$$13.88\ m/s \times 1.50\ s + 10\ m = 30.82\ m$$

Equation 6.1

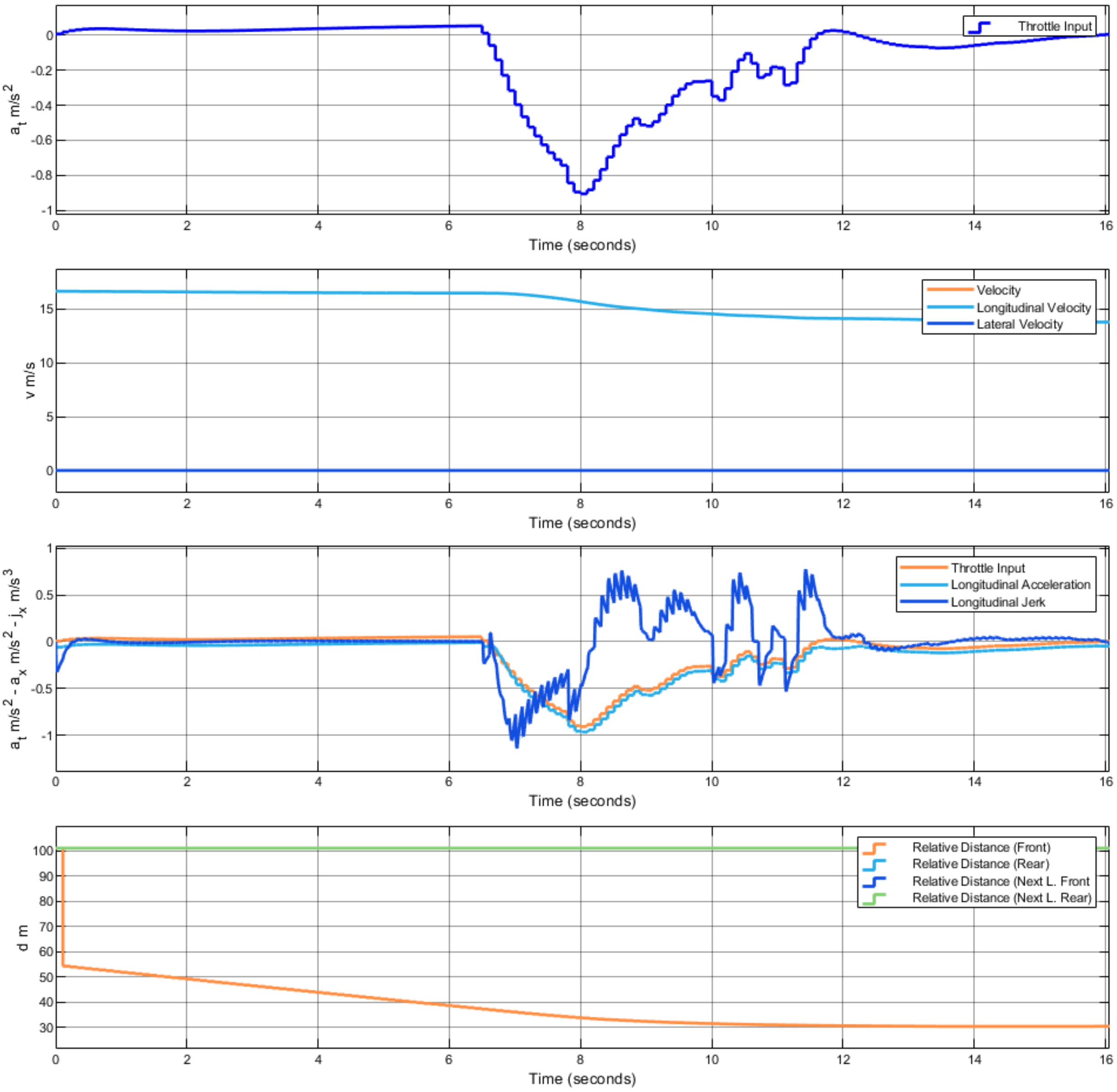


Figure 6-13 Result of the 1st Case of ACC Testing

6.3.2. 2nd Case of ACC Testing: Low Road Friction

In the second case, the ACC performance is evaluated with Lane Keeping Assist in degraded roadway conditions. The subject vehicle adapts to the velocity for the target vehicle, meanwhile, while the lane keeping assist keeps the subject vehicle on the road center. This case takes place in an ALKS scenario map. The map is given in Figure 6-14.

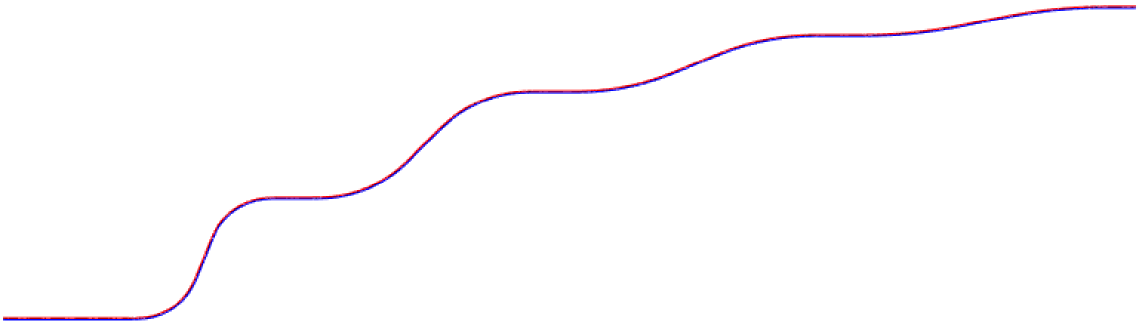


Figure 6-14 Overview of the Map (ALKS: Road with Different Curvatures)

The 2nd test case for ACC is presented in Table 6-13 and Figure 6-15:

Table 6-13 Simplified ODD of the 2nd Case for ACC Testing

Initial Ego Velocity [V_{e0}]	60 kph
Initial Lead Velocity [Vo0]	50 kph
Initial Relative Distance [dx0]	50 m
Roadway Condition	0.4

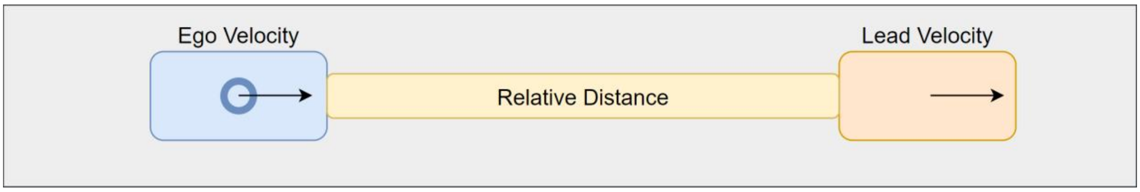


Figure 6-15 Test Scenario for ACC Testing

The velocity matches the lead vehicle’s velocity, then continues to stay at 50 kph. The longitudinal acceleration and longitudinal jerk levels reached around -1.0 ms^{-3} in the slowing down section. After that, the values stayed low and normal.

The ACC was inspected while the LKA system kept the vehicle oriented at the road center. Since in normal operation conditions the maneuver is not required, LKA and ACC systems are always active. For further inspection, Figure 6-16 is presented in the following.

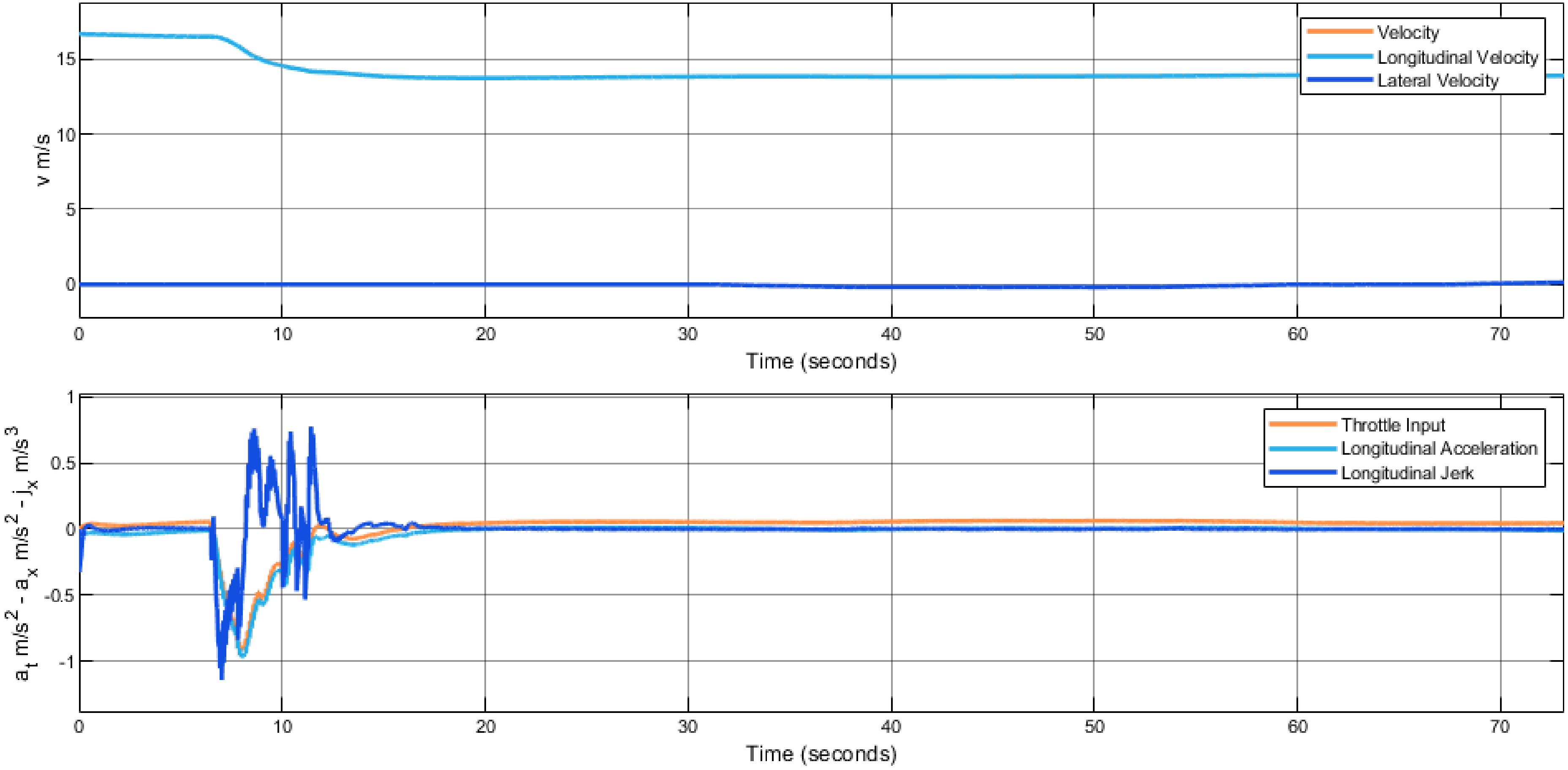


Figure 6-16 Longitudinal Dynamics of the 2nd Case for ACC Testing

6.4. LKA Testing

The Lane Keeping Assist system aims to keep the vehicle in the center of the lane. As inspected in LCA, the roadway condition has a significant effect on the performance of lateral motions.

Therefore, the scenarios take place in an ALKS scenario map with different for the road adhesion coefficient values (Table 6-14 and Figure 6-17).

Table 6-14 Result Matrix of the LKA Testing

ALKS: Road with Different Curvatures		Roadway Condition		
		0.2	0.4	0.8
Initial Ego Velocity [Ve0]	10.0	🟩	🟩	🟩
	20.0	🟩	🟩	🟩
	30.0	🟩	🟩	🟩
	40.0	🟩	🟩	🟩
	50.0	🟥	🟩	🟩
	60.0	🟥	🟩	🟩

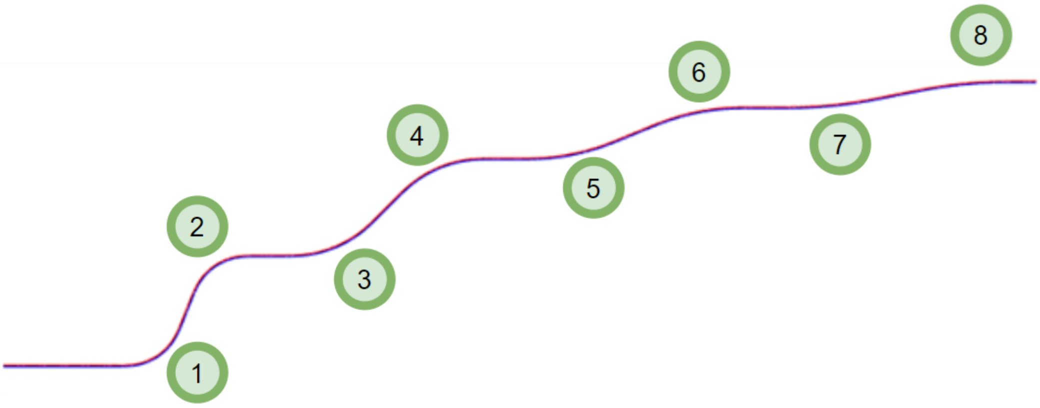


Figure 6-17 Overview of the Map (ALKS: Road with Different Curvatures)

The map in Figure 6-17 contains eight turns with different radii. The lateral assist was successful in cases where the roadway condition is 0.4 or 0.8. The assist mechanism also successfully led the vehicle in cases with roadway conditions of 0.2 where the vehicle’s velocity is 40 kph and lower. However, there seems to be a critical situation in cases where the roadway condition is 0.2 and the velocity is 50 kph and higher.

6.4.1. 1st Case for LKA Testing: High Velocity and Medium Road Friction

The case where the roadway condition is 0.4 and the subject vehicle's velocity is 60 kph is inspected as follows (Table 6-15).

Table 6-15 Simplified ODD of the 1st Case for LKA Testing

Initial Ego Velocity [V_{e0}]	60 kph
Roadway Condition	0.4

The results are presented in Figure 6-18.

The controller successfully held the velocity at the desired set longitudinal velocity. The longitudinal dynamics were stable and motion profiles were relatively low throughout the case.

The controller has lateral error levels around 0.3 meters which are higher than in cases with normal operating conditions, but it is expected since the road adhesion coefficient value is lower than convenient and the velocity is at the upper limit of the operating domain.

6.4.2. 2nd Case for LKA Testing: Medium Velocity and Low Road Friction

The case where the roadway condition is 0.2 and the subject vehicle's velocity is 40 kph is inspected as follows (Table 6-16).

Table 6-16 Simplified ODD of the 2nd case for LKA Testing

Initial Ego Velocity [V_{e0}]	40 kph
Roadway Condition	0.2

The results are presented in Figure 6-18.

Similarly, the controller held the velocity to the set longitudinal velocity successfully. The longitudinal dynamics were stable and motion profiles were relatively low throughout the case.

Similarly, the controller has lateral error levels around 0.3 meters which are higher than in cases with normal operating conditions, but this situation is expected since the road adhesion coefficient value is lower than convenient and the velocity is high for that roadway condition.

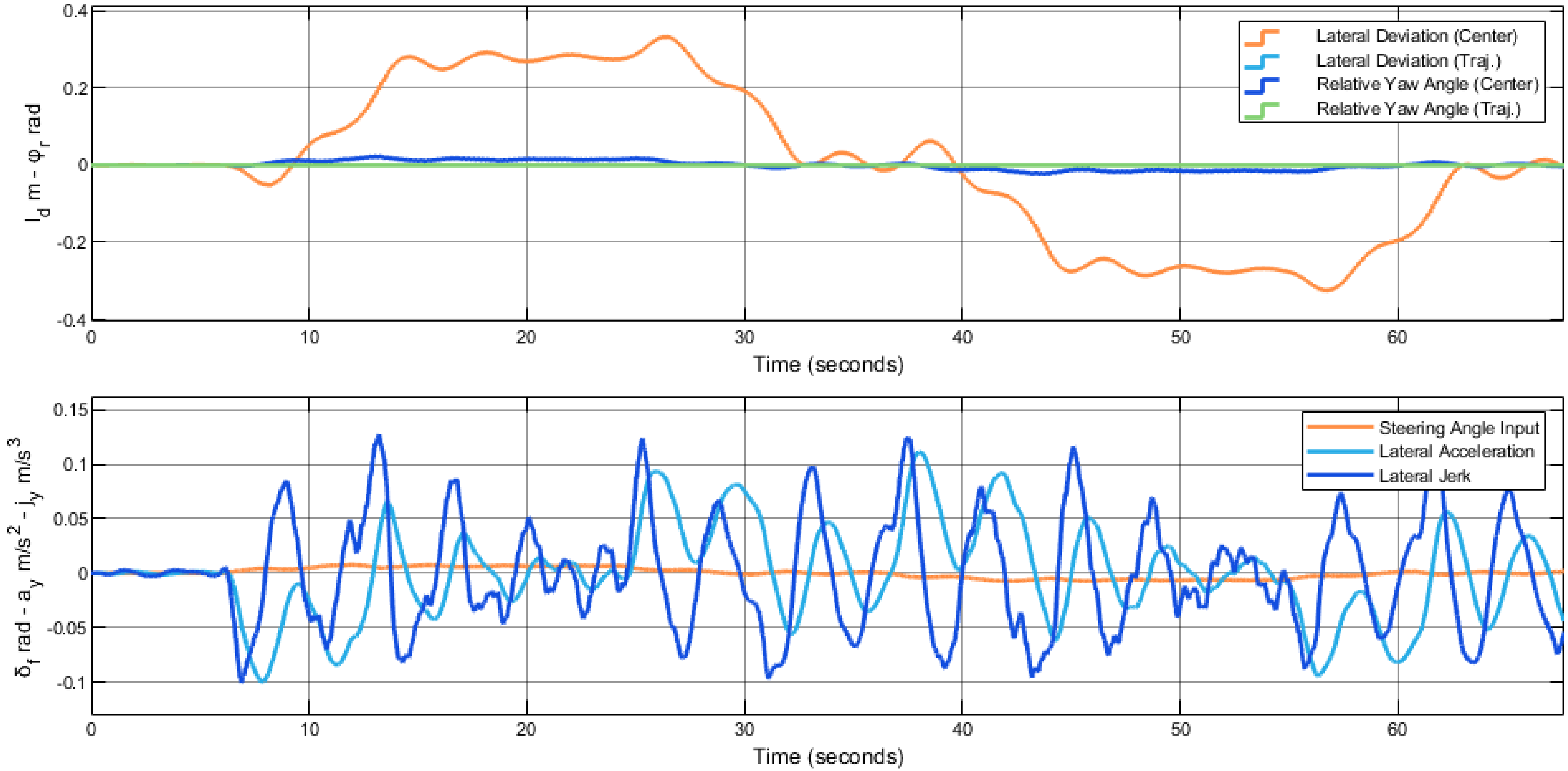


Figure 6-18 Lateral dynamics of the 1st case for LKA Testing

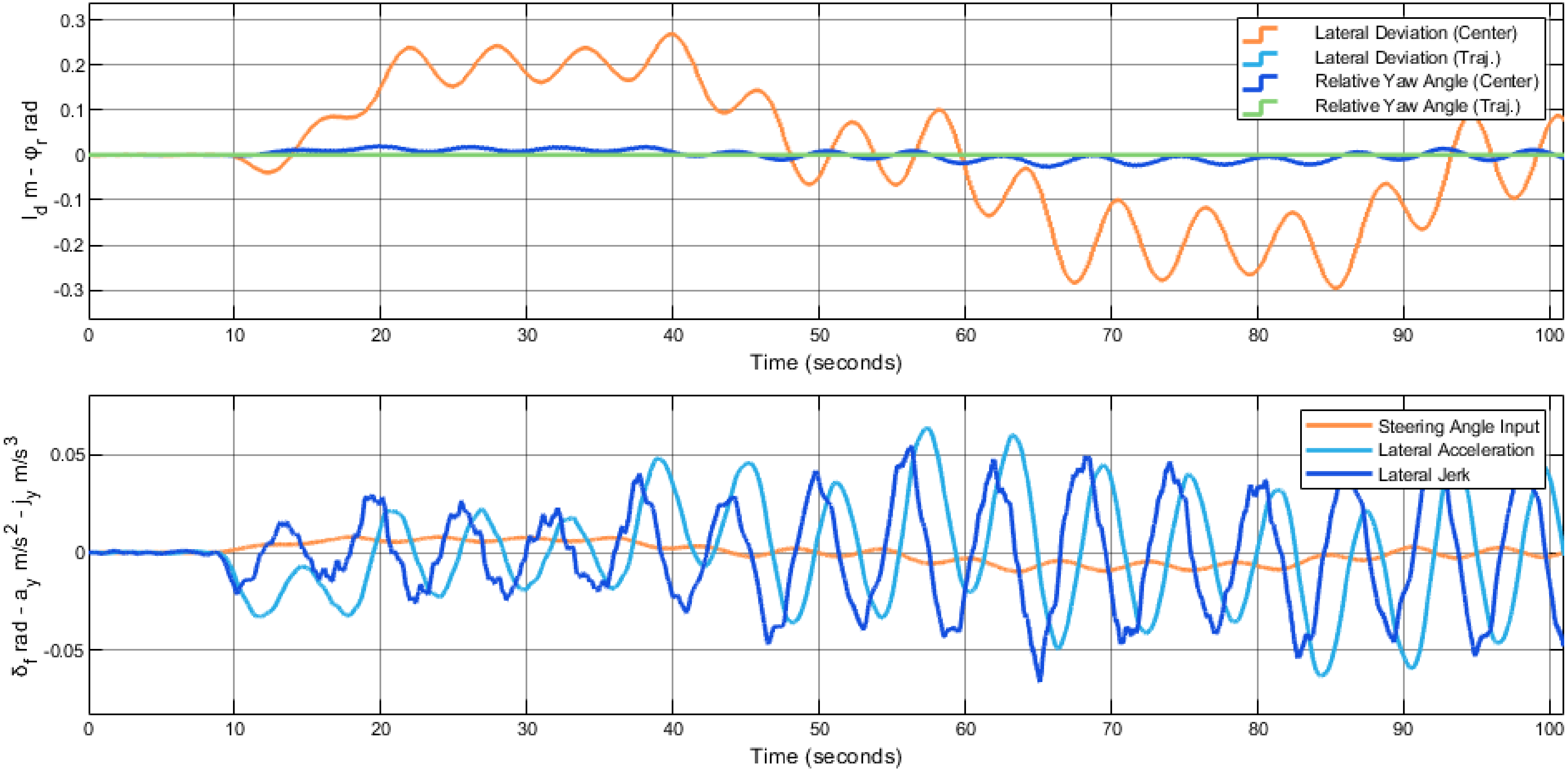


Figure 6-19 Lateral Dynamics of the 2nd Case for LKA Testing

After inspecting the results, it appears that in the cases with 0.2 roadway conditions, the LKA fails to control the vehicle when the velocity is 50 kph and 60 kph. In the previous section where LCA were inspected, in the cases with 0.4 roadway conditions, the vehicle failed to perform the maneuver. Similarly, the vehicle can operate normally in 0.4 and 0.8 roadway conditions with ACC and LKA, however, in low friction values the lateral assistance systems tend to fail in the lateral control.

6.5.ALKS Case Study: Lane Crossing Pedestrian

In the previous section, several scenarios for the advanced driver assistance systems were tested, evaluated and inspected. The combined assistance system which is defined as an ALKS was previously described in the Section 5.2. ALKS was defined as the combination of the AEB, ACC, LKA and LCA. It was also mentioned that the transition between the driving modes is governed by a Vehicle mode selector system.

Therefore, the Lane Crossing Pedestrian scenario was selected to evaluate the combined performances of the ADAS (Figure 6-20).

Figure 6-20 Test Scenario for Lane Crossing Pedestrian

In this situation, the subject vehicle has multiple options:

1. Slow down with ACC and AEB to prevent collision to slow down or full stop, then continue on the original lane (Figure 6-21),

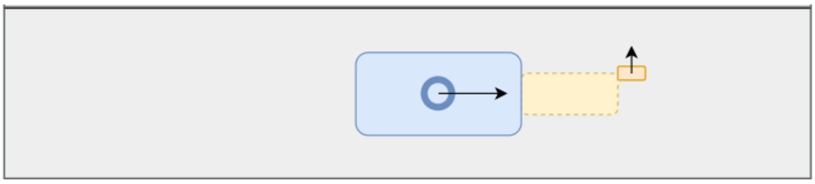


Figure 6-21 First Option: Slowing Down

2. Perform lane change maneuver with LCA to prevent collision, then continue on the new lane or lane change again to continue on the original lane (Figure 6-22).

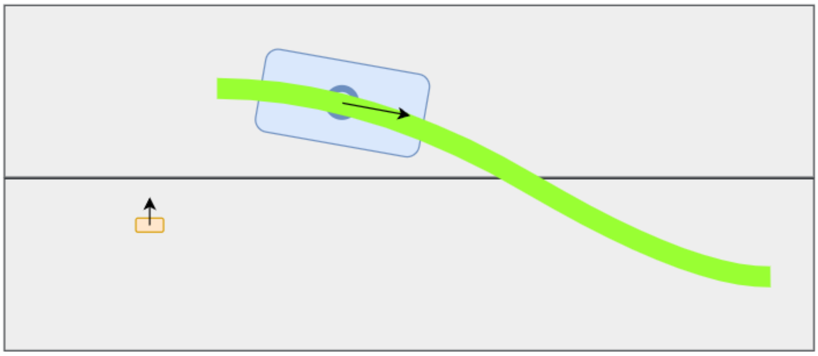


Figure 6-22 Second Option: Lane Changing

The failure criteria consider the following:

1. Collision with the pedestrian while slowing down or while performing maneuver (Figure 6-23),
2. Collision with the road borders while performing maneuver (Figure 6-24).

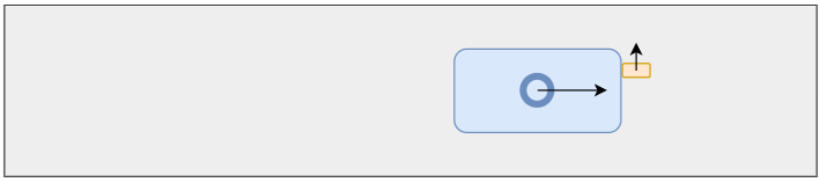


Figure 6-23 Collision with pedestrian while slowing down

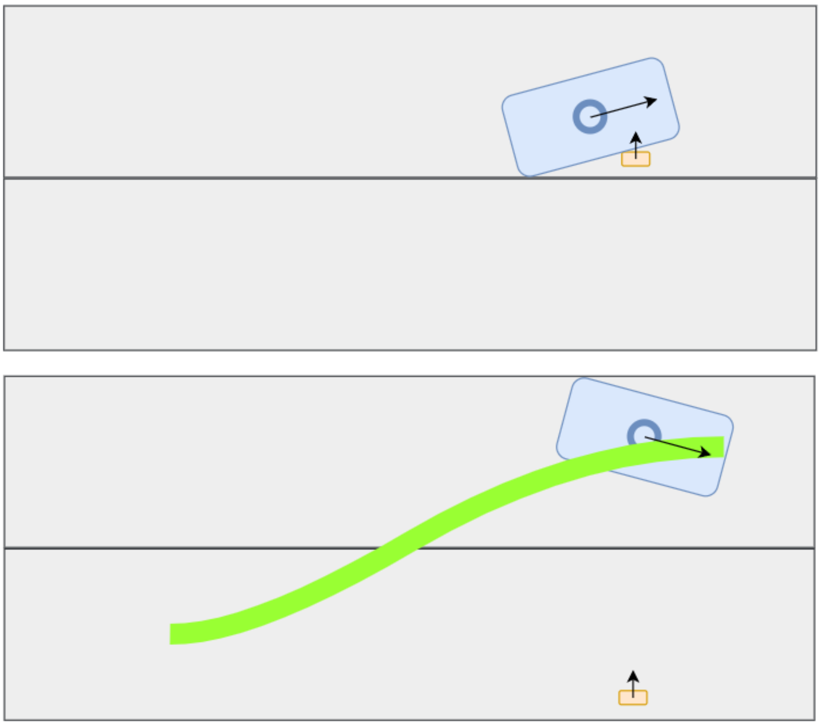


Figure 6-24 Collision with pedestrian or road border while lane changing

The ODD was inspired by the ALKS regulation by the UN (UN ECE Regulation No.157 [29]. This regulation defined some important aspects of the test and evaluation phase.

In these statements, the following were selected for defining the ODD of the ALKS for performance evaluation on the Lane Crossing Pedestrian scenario.

- The roadway conditions can vary to represent dry, wet, icy, snow, new, worn roads by changing the road adhesion coefficient values
- The subject vehicle velocity can vary up to 60 kph
- The pedestrian’s lateral velocity for lane crossing can vary up to 5 kph.
- The pedestrian’s detection distance can vary up to 100.0 m

Therefore, the following parameters were selected for scenario generation (Table 6-18).

Table 6-17 Selected Scenario Parameters for Lane Crossing Pedestrian Scenario

Selected Scenario Parameters				
Operating conditions	Roadway	Number of lanes	2	*the number of adjacent lanes in the same direction*
		Lane Width	3.6 m	*the width of each lane*
		Roadway grade	x	*grade of the roadway*
		Roadway condition	✓	*tire-road coefficient of friction*
		Lane markings	x	*the type, color, width, visibility*
Initial condition	Initial velocity	V_{e0}	✓	*Subject vehicle (ego) longitudinal velocity*
		V_{y}	✓	*Pedestrian's crossing velocity*
		V_{f0}	x	*Vehicle in front of the pedestrian*
	Initial distance	d_{x0}	✓	*distance in the longitudinal direction between pedestrian*
		d_{y0}	x	*distance in the lateral direction between pedestrian*
		d_{y0_f}	x	*distance in the longitudinal direction between the vehicle in front of the pedestrian*
		d_{x0_f}	x	*distance in the lateral direction between the vehicle in front of the pedestrian*
		d_{fy}	x	*width of the vehicle in front of the pedestrian*
		d_{oy}	x	*width of the pedestrian*
		d_{ox}	x	*length of the pedestrian*

Then range and resolution values for the selected parameters are defined as the following.

6. Roadway adhesion coefficient

$$0.2 - 0.8 - 1.0$$

7. Vo0: Leading vehicle’s initial velocity

$$10\ kph\ \leq\ V_{o0} \leq 60\ kph \qquad with\ 10\ kph\ resolution$$

8. Vy: Pedestrian’s crossing velocity

$$0.1\ m/s\ \leq\ V_y \leq 1.4\ m/s\ \ (5\ kph) \qquad with\ 0.1\ m/s\ resolution$$

9. dx0: Pedestrian’s relative distance to the subject vehicle

$$2\ m\ \leq d_{x0}\ \leq 100\ m \qquad with\ 2\ m\ resolution$$

After the evaluation of the results, a new set of cases were executed with updated Path Following MPC weights.

There were two different configurations for ALKS Testing. The test results were first given for the 1st Configuration, then 2nd Configuration. Each configuration’s results were given in descending order with respect to road adhesion coefficient values of the test cases. Then, results sharing the same configuration and road adhesion coefficient values were presented in ascending order with respect to initial ego velocity values. In results, fails with red is on 1.0, brown is on 0.8 and sand color is on 0.2 roadway conditions.

Results for 1st Configuration MPC were presented in Table 6-19 in the following order.

- 1.0 Road Adhesion Coefficient
    - 10 to 60 kph Initial Ego Velocity
- 0.8 Road Adhesion Coefficient
    - 10 to 60 kph Initial Ego Velocity
- 0.2 Road Adhesion Coefficient
    - 10 to 60 kph Initial Ego Velocity

Results for 2nd Configuration MPC were presented in Table 6-20 in the following order.

- 0.8 Road Adhesion Coefficient
    - 10 to 60 kph Initial Ego Velocity
- 0.2 Road Adhesion Coefficient
    - 10 to 60 kph Initial Ego Velocity

In combined results table for 1st and 2nd configuration results:

- 2nd configuration fails are shown with red is on 1.0, brown is on 0.8 and sand color is on 0.2 roadway conditions.
- 1st configuration's fails are shown with light is on 1.0, blue is on 0.8 and dark blue is on 0.2 roadway conditions.

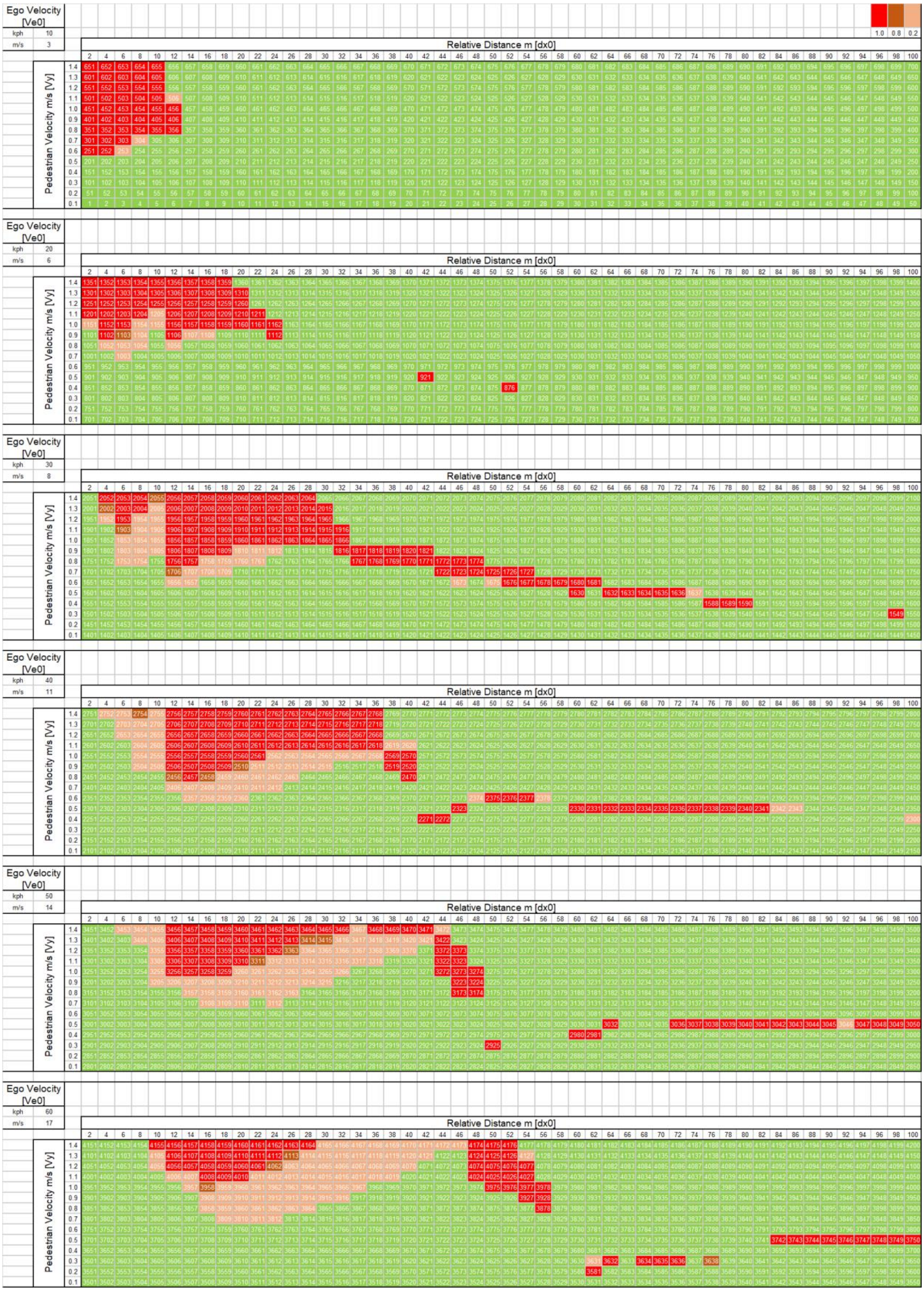
In order to evaluate the algorithm accurately, the results were plotted on top of each other. In the color legend, the green color indicates "a successful pass", where no collision has occurred with a pedestrian or road whatsoever (Table 6-18).

Table 6-18 Color Legend for Pass and Fail Results of the Cases

FAIL			PASS
1.0	0.8	0.2	🟩
1.0	0.8	0.20	🟩

Green color indicates a successful test case which resulted in Pass. The other colors indicate "a failure" in different roadway conditions.

Table 6-19 Combined Results Table of the Lane Crossing Pedestrian Scenario for 1st Configuration with Different Roadway Conditions



1.0	0.8	0.2

Ego Velocity [Ve0]
kph 10
m/s 3

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700
1.3	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650
1.2	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600
1.1	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550
1.0	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500
0.9	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450
0.8	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
0.7	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350
0.6	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300
0.5	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250
0.4	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
0.3	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
0.2	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
0.1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

Ego Velocity [Ve0]
kph 20
m/s 6

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	1351	1352	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362	1363	1364	1365	1366	1367	1368	1369	1370	1371	1372	1373	1374	1375	1376	1377	1378	1379	1380	1381	1382	1383	1384	1385	1386	1387	1388	1389	1390	1391	1392	1393	1394	1395	1396	1397	1398	1399	1400
1.3	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343	1344	1345	1346	1347	1348	1349	1350
1.2	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296	1297	1298	1299	1300
1.1	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250
1.0	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200
0.9	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150
0.8	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100
0.7	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050
0.6	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000
0.5	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950
0.4	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900
0.3	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850
0.2	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800
0.1	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750

Ego Velocity [Ve0]
kph 30
m/s 8

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
1.3	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1.2	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1.1	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
1.0	1851	1852	1853	1854	1855	1856	1857	1858	1859	1860	1861	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900
0.9	1801	1802	1803	1804	1805	1806	1807	1808	1809	1810	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826	1827	1828	1829	1830	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840	1841	1842	1843	1844	1845	1846	1847	1848	1849	1850
0.8	1751	1752	1753	1754	1755	1756	1757	1758	1759	1760	1761	1762	1763	1764	1765	1766	1767	1768	1769	1770	1771	1772	1773	1774	1775	1776	1777	1778	1779	1780	1781	1782	1783	1784	1785	1786	1787	1788	1789	1790	1791	1792	1793	1794	1795	1796	1797	1798	1799	1800
0.7	1701	1702	1703	1704	1705	1706	1707	1708	1709	1710	1711	1712	1713	1714	1715	1716	1717	1718	1719	1720	1721	1722	1723	1724	1725	1726	1727	1728	1729	1730	1731	1732	1733	1734	1735	1736	1737	1738	1739	1740	1741	1742	1743	1744	1745	1746	1747	1748	1749	1750
0.6	1651	1652	1653	1654	1655	1656	1657	1658	1659	1660	1661	1662	1663	1664	1665	1666	1667	1668	1669	1670	1671	1672	1673	1674	1675	1676	1677	1678	1679	1680	1681	1682	1683	1684	1685	1686	1687	1688	1689	1690	1691	1692	1693	1694	1695	1696	1697	1698	1699	1700
0.5	1601	1602	1603	1604	1605	1606	1607	1608	1609	1610	1611	1612	1613	1614	1615	1616	1617	1618	1619	1620	1621	1622	1623	1624	1625	1626	1627	1628	1629	1630	1631	1632	1633	1634	1635	1636	1637	1638	1639	1640	1641	1642	1643	1644	1645	1646	1647	1648	1649	1650
0.4	1551	1552	1553	1554	1555	1556	1557	1558	1559	1560	1561	1562	1563	1564	1565	1566	1567	1568	1569	1570	1571	1572	1573	1574	1575	1576	1577	1578	1579	1580	1581	1582	1583	1584	1585	1586	1587	1588	1589	1590	1591	1592	1593	1594	1595	1596	1597	1598	1599	1600
0.3	1501	1502	1503	1504	1505	1506	1507	1508	1509	1510	1511	1512	1513	1514	1515	1516	1517	1518	1519	1520	1521	1522	1523	1524	1525	1526	1527	1528	1529	1530	1531	1532	1533	1534	1535	1536	1537	1538	1539	1540	1541	1542	1543	1544	1545	1546	1547	1548	1549	1550
0.2	1451	1452	1453	1454	1455	1456	1457	1458	1459	1460	1461	1462	1463	1464	1465	1466	1467	1468	1469	1470	1471	1472	1473	1474	1475	1476	1477	1478	1479	1480	1481	1482	1483	1484	1485	1486	1487	1488	1489	1490	1491	1492	1493	1494	1495	1496	1497	1498	1499	1500
0.1	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423	1424	1425	1426	1427	1428	1429	1430	1431	1432	1433	1434	1435	1436	1437	1438	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448	1449	1450

Ego Velocity [Ve0]
kph 40
m/s 11

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	2751	2752	2753	2754	2755	2756	2757	2758	2759	2760	2761	2762	2763	2764	2765	2766	2767	2768	2769	2770	2771	2772	2773	2774	2775	2776	2777	2778	2779	2780	2781	2782	2783	2784	2785	2786	2787	2788	2789	2790	2791	2792	2793	2794	2795	2796	2797	2798	2799	2800
1.3	2701	2702	2703	2704	2705	2706	2707	2708	2709	2710	2711	2712	2713	2714	2715	2716	2717	2718	2719	2720	2721	2722	2723	2724	2725	2726	2727	2728	2729	2730	2731	2732	2733	2734	2735	2736	2737	2738	2739	2740	2741	2742	2743	2744	2745	2746	2747	2748	2749	2750
1.2	2651	2652	2653	2654	2655	2656	2657	2658	2659	2660	2661	2662	2663	2664	2665	2666	2667	2668	2669	2670	2671	2672	2673	2674	2675	2676	2677	2678	2679	2680	2681	2682	2683	2684	2685	2686	2687	2688	2689	2690	2691	2692	2693	2694	2695	2696	2697	2698	2699	2700
1.1	2601	2602	2603	2604	2605	2606	2607	2608	2609	2610	2611	2612	2613	2614	2615	2616	2617	2618	2619	2620	2621	2622	2623	2624	2625	2626	2627	2628	2629	2630	2631	2632	2633	2634	2635	2636	2637	2638	2639	2640	2641	2642	2643	2644	2645	2646	2647	2648	2649	2650
1.0	2551	2552	2553	2554	2555	2556	2557	2558	2559	2560	2561	2562	2563	2564	2565	2566	2567	2568	2569	2570	2571	2572	2573	2574	2575	2576	2577	2578	2579	2580	2581	2582	2583	2584	2585	2586	2587	2588	2589	2590	2591	2592	2593	2594	2595	2596	2597	2598	2599	2600
0.9	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534	2535	2536	2537	2538	2539	2540	2541	2542	2543	2544	2545	2546	2547	2548	2549	2550
0.8	2451	2452	2453	2454	2455	2456	2457	2458	2459	2460	2461	2462	2463	2464	2465	2466	2467	2468	2469	2470	2471	2472	2473	2474	2475	2476	2477	2478	2479	2480	2481	2482	2483	2484	2485	2486	2487	2488	2489	2490	2491	2492	2493	2494	2495	2496	2497	2498	2499	2500
0.7	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450
0.6	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400
0.5	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350
0.4	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300
0.3	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250
0.2	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200
0.1	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150

Ego Velocity [Ve0]
kph 50
m/s 14

Relative Distance m [dx0]

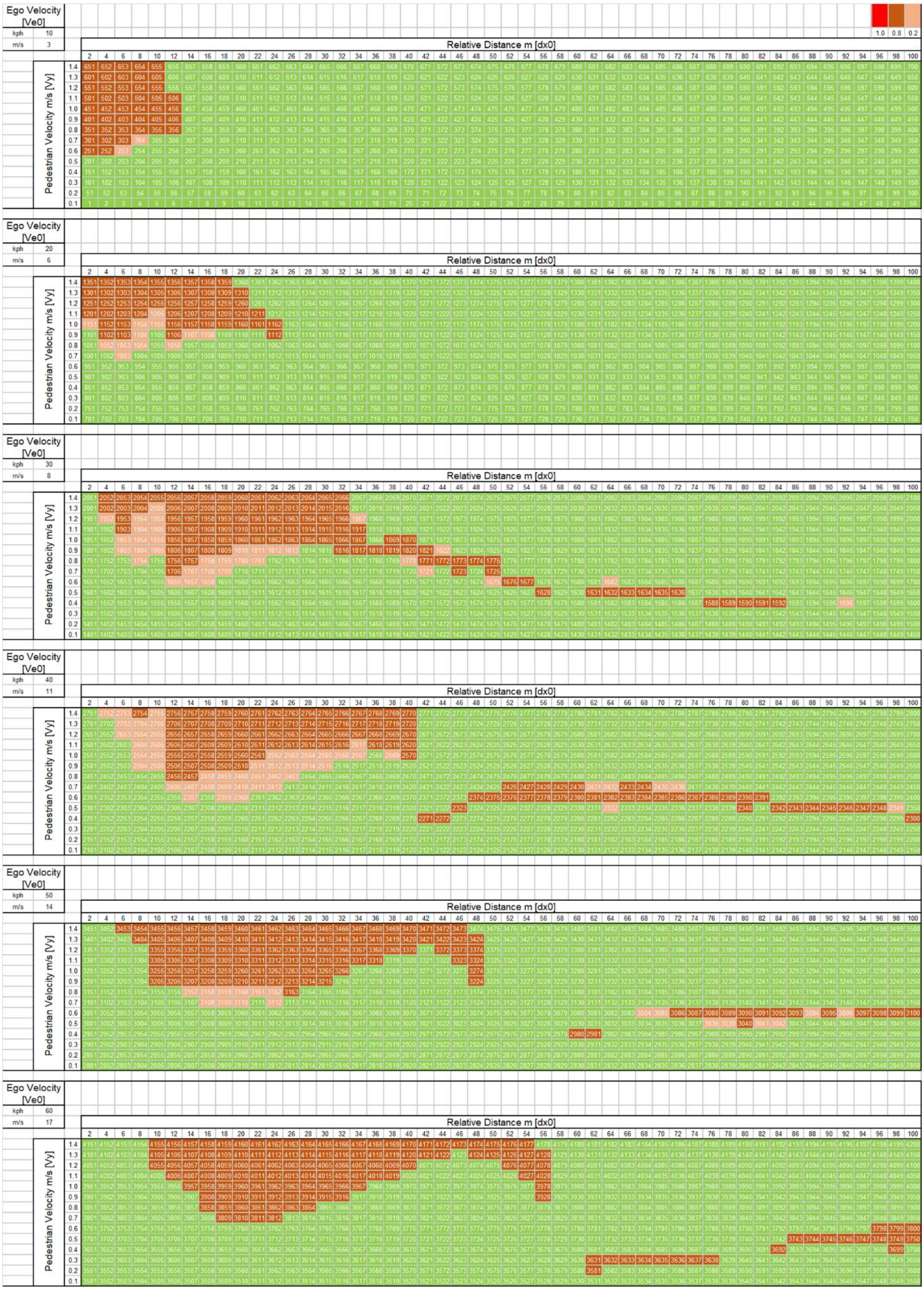
Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	3451	3452	3453	3454	3455	3456	3457	3458	3459	3460	3461	3462	3463	3464	3465	3466	3467	3468	3469	3470	3471	3472	3473	3474	3475	3476	3477	3478	3479	3480	3481	3482	3483	3484	3485	3486	3487	3488	3489	3490	3491	3492	3493	3494	3495	3496	3497	3498	3499	3500
1.3	3401	3402	3403	3404	3405	3406	3407	3408	3409	3410	3411	3412	3413	3414	3415	3416	3417	3418	3419	3420	3421	3422	3423	3424	3425	3426	3427	3428	3429	3430	3431	3432	3433	3434	3435	3436	3437	3438	3439	3440	3441	3442	3443	3444	3445	3446	3447	3448	3449	3450
1.2	3351	3352	3353	3354	3355	3356	3357	3358	3359	3360	3361	3362	3363	3364	3365	3366	3367	3368	3369	3370	3371	3372	3373	3374	3375	3376	3377	3378	3379	3380	3381	3382	3383	3384	3385	3386	3387	3388	3389	3390	3391	3392	3393	3394	3395	3396	3397	3398	3399	3400
1.1	3301	3302	3303	3304	3305	3306	3307	3308	3309	3310	3311	3312	3313	3314	3315	3316	3317	3318	3319	3320	3321	3322	3323	3324	3325	3326	3327	3328	3329	3330	3331	3332	3333	3334	3335	3336	3337	3338	3339	3340	3341	3342	3343	3344	3345	3346	3347	3348	3349	3350
1.0	3251	3252	3253	3254	3255	3256	3257	3258	3259	3260	3261	3262	3263	3264	3265	3266	3267	3268	3269	3270	3271	3272	3273	3274	3275	3276	3277	3278	3279	3280	3281	3282	3283	3284	3285	3286	3287	3288	3289	3290	3291	3292	3293	3294	3295	3296	3297	3298	3299	3300
0.9	3201	3202	3203	3204	3205	3206	3207	3208	3209	3210	3211	3212	3213	3214	3215	3216	3217	3218	3219	3220	3221	3222	3223	3224	3225	3226	3227	3228	3229	3230	3231	3232	3233	3234	3235	3236	3237	3238	3239	3240	3241	3242	3243	3244	3245	3246	3247	3248	3249	3250
0.8	3151	3152	3153	3154	3155	3156	3157	3158	3159	3160	3161	3162	3163	3164	3165	3166	3167	3168	3169	3170	3171	3172	3173	3174	3175	3176	3177	3178	3179	3180	3181	3182	3183	3184	3185	3186	3187	3188	3189	3190	3191	3192	3193	3194	3195	3196	3197	3198	3199	3200
0.7	3101	3102	3103	3104	3105	3106	3107	3108	3109	3110	3111	3112	3113	3114	3115	3116	3117	3118	3119	3120	3121	3122	3123	3124	3125	3126	3127	3128	3129	3130	3131	3132	3133	3134	3135	3136	3137	3138	3139	3140	3141	3142	3143	3144	3145	3146	3147	3148	3149	3150
0.6	3051	3052	3053	3054	3055	3056	3057	3058	3059	3060	3061	3062	3063	3064	3065	3066	3067	3068	3069	3070	3071	3072	3073	3074	3075	3076	3077	3078	3079	3080	3081	3082	3083	3084	3085	3086	3087	3088	3089	3090	3091	3092	3093	3094	3095	3096	3097	3098	3099	3100
0.5	3001	3002	3003	3004	3005	3006	3007	3008	3009	3010	3011	3012	3013	3014	3015	3016	3017	3018	3019	3020	3021	3022	3023	3024	3025	3026	3027	3028	3029	3030	3031	3032	3033	3034	3035	3036	3037	3038	3039	3040	3041	3042	3043	3044	3045	3046	3047	3048	3049	3050
0.4	2951	2952	2953	2954	2955	2956	2957	2958	2959	2960	2961	2962	2963	2964	2965	2966	2967	2968	2969	2970	2971	2972	2973	2974	2975	2976	2977	2978	2979	2980	2981	2982	2983	2984	2985	2986	2987	2988	2989	2990	2991	2992	2993	2994	2995	2996	2997	2998	2999	3000
0.3	2901	2902	2903	2904	2905	2906	2907	2908	2909	2910	2911	2912	2913	2914	2915	2916	2917	2918	2919	2920	2921	2922	2923	2924	2925	2926	2927	2928	2929	2930	2931	2932	2933	2934	2935	2936	2937	2938	2939	2940	2941	2942	2943	2944	2945	2946	2947	2948	2949	2950
0.2	2851	2852	2853	2854	2855	2856	2857	2858	2859	2860	2861	2862	2863	2864	2865	2866	2867	2868	2869	2870	2871	2872	2873	2874	2875	2876	2877	2878	2879	2880	2881	2882	2883	2884	2885	2886	2887	2888	2889	2890	2891	2892	2893	2894	2895	2896	2897	2898	2899	2900
0.1	2801	2802	2803	2804	2805	2806	2807	2808	2809	2810	2811	2812	2813	2814	2815	2816	2817	2818	2819	2820	2821	2822	2823	2824	2825	2826	2827	2828	2829	2830	2831	2832	2833	2834	2835	2836	2837	2838	2839	2840	2841	2842	2843	2844	2845	2846	2847	2848	2849	2850

Ego Velocity [Ve0]
kph 60
m/s 17

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	4151	4152	4153	4154	4155	4156	4157	4158	4159	4160	4161	4162	4163	4164	4165	4166	4167	4168	4169	4170	4171	4172	4173	4174	4175	4176	4177	4178	4179	4180	4181	4182	4183	4184	4185	4186	4187	4188	4189	4190	4191	4192	4193	4194	4195	4196	4197	4198	4199	4200
1.3	4101	4102	4103	4104	4105	4106	4107	4108	4109	4110	4111	4112	4113	4114	4115	4116	4117	4118	4119	4120	4121	4122	4123	4124	4125	4126	4127	4128	4129	4130	4131	4132	4133	4134	4135	4136	4137	4138	4139	4140	4141	4142	4143	4144	4145	4146	4147	4148	4149	4150
1.2	4051	4052	4053	4054	4055	4056	4057	4058	4059	4060	4061	4062	4063	4064	4065	4066	4067	4068	4069	4070	4071	4072	4073	4074	4075	4076	4077	4078	4079	4080	4081	4082	4083	4084	4085	4086	4087	4088	4089	4090	4091	4092	4093	4094	4095	4096	4097	4098	4099	4100
1.1	4001	4002	4003	4004	4005	4006	4007	4008	4009	4010	4011	4012	4013	4014	4015	4016	4017	4018	4019	4020	4021	4022	4023	4024	4025	4026	4027	4028	4029	4030	4031	4032	4033	4034	4035	4036	4037	4038	4039	4040	4041	4042	4043	4044	4045	4046	4047	4048	4049	4050
1.0	3951	3952	3953	3954	3955	3956	3957	3958	3959	3960	3961	3962	3963	3964	3965	3966	3967	3968	3969	3970	3971	3972	3973	3974	3975	3976	3977	3978	3979	3980	3981	3982	3983	3984	3985	3986	3987	3988	3989	3990	3991	3992	3993	3994	3995	3996	3997	3998	3999	4000
0.9	3901	3902	3903	3904	3905	3906	3907	3908	3909	3910	3911	3912	3913	3914	3915	3916	3917	3918	3919	3920	3921	3922	3923	3924	3925	3926	3927	3928	3929	3930	3931	3932	3933	3934	3935	3936	3937	3938	3939	3940	3941	3942	3943	3944	3945	3946	3947	3948	3949	3950
0.8	3851	3852	3853	3854	3855	3856	3857	3858	3859	3860	3861	3862	3863	3864	3865	3866	3867	3868	3869	3870	3871	3872	3873	3874	3875	3876	3877	3878	3879	3880	3881	3882	3883	3884	3885	3886	3887	3888	3889	3890	3891	3892	3893	3894	3895	3896	3897	3898	3899	3900
0.7	3801	3802	3803	3804	3805	3806	3807	3808	3809	3810	3811	3812	3813	3814	3815	3816	3817	3818	3819	3820	3821	3822	3823	3824	3825	3826	3827	3828	3829	3830	3831	3832	3833	3834	3835	3836	3837	3838	3839	3840	3841	3842	3843	3844	3845	3846	3847	3848	3849	3850
0.6	3751	3752	3753	3754	3755	3756	3757	3758	3759	3760	3761	3762	3763	3764	3765	3766	3767	3768	3769	3770	3771	3772	3773	3774	3775	3776	3777	3778	3779	3780	3781	3782	3783	3784	3785	3786	3787	3788	3789	3790	3791	3792	3793	3794	3795	3796	3797	3798	3799	3800
0.5	3701	3702	3703	3704	3705	3706	3707	3708	3709	3710	3711	3712	3713	3714	3715	3716	3717	3718	3719	3720	3721	3722	3723	3724	3725	3726	3727	3728	3729	3730	3731	3732	3733	3734	3735	3736	3737	3738	3739	3740	3741	3742	3743	3744	3745	3746	3747	3748	3749	3750
0.4	3651	3652	3653	3654	3655	3656	3657	3658	3659	3660	3661	3662	3663	3664	3665	3666	3667	3668	3669	3670	3671	3672	3673	3674	3675	3676	3677	3678	3679	3680	3681	3682	3683	3684	3685	3686	3687	3688	3689	3690	3691	3692	3693	3694	3695	3696	3697	3698	3699	3700
0.3	3601	3602	3603	3604	3605	3606	3607	3608	3609	3610	3611	3612	3613	3614	3615	3616	3617	3618	3619	3620	3621	3622	3623	3624	3625	3626	3627	3628	3629	3630	3631	3632	3633	3634	3635	3636	3637	3638	3639	3640	3641	3642	3643	3644	3645	3646	3647	3648	3649	3650
0.2	3551	3552	3553	3554	3555	3556	3557	3558	3559	3560	3561	3562	3563	3564	3565	3566	3567	3568	3569	3570	3571	3572	3573	3574	3575	3576	3577	3578	3579	3580	3581	3582	3583	3584	3585	3586	3587	3588	3589	3590	3591	3592	3593	3594	3595	3596	3597	3598	3599	3600
0.1	3501	3502	3503	3504	3505	3506	3507	3508	3509	3510	3511	3512	3513	3514	3515	3516	3517	3518	3519	3520	3521	3522	3523	3524	3525	3526	3527	3528	3529	3530	3531	3532	3533	3534	3535	3536	3537	3538	3539	3540	3541	3542	3543	3544	3545	3546	3547	3548	3549	3550

Table 6-20 Combined Results Table of the Lane Crossing Pedestrian Scenario for 2nd Configuration with Different Roadway Conditions



🟥 1.0 | 🟧 0.8 | ▨ 0.2

Ego Velocity [Ve0]
kph 10
m/s 3

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700
1.3	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650
1.2	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600
1.1	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550
1.0	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500
0.9	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450
0.8	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
0.7	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350
0.6	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300
0.5	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250
0.4	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
0.3	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
0.2	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
0.1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

Ego Velocity [Ve0]
kph 20
m/s 6

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	1351	1352	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362	1363	1364	1365	1366	1367	1368	1369	1370	1371	1372	1373	1374	1375	1376	1377	1378	1379	1380	1381	1382	1383	1384	1385	1386	1387	1388	1389	1390	1391	1392	1393	1394	1395	1396	1397	1398	1399	1400
1.3	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343	1344	1345	1346	1347	1348	1349	1350
1.2	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296	1297	1298	1299	1300
1.1	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250
1.0	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200
0.9	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150
0.8	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100
0.7	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050
0.6	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000
0.5	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950
0.4	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900
0.3	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850
0.2	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800
0.1	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750

Ego Velocity [Ve0]
kph 30
m/s 8

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
1.3	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1.2	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1.1	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
1.0	1851	1852	1853	1854	1855	1856	1857	1858	1859	1860	1861	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900
0.9	1801	1802	1803	1804	1805	1806	1807	1808	1809	1810	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826	1827	1828	1829	1830	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840	1841	1842	1843	1844	1845	1846	1847	1848	1849	1850
0.8	1751	1752	1753	1754	1755	1756	1757	1758	1759	1760	1761	1762	1763	1764	1765	1766	1767	1768	1769	1770	1771	1772	1773	1774	1775	1776	1777	1778	1779	1780	1781	1782	1783	1784	1785	1786	1787	1788	1789	1790	1791	1792	1793	1794	1795	1796	1797	1798	1799	1800
0.7	1701	1702	1703	1704	1705	1706	1707	1708	1709	1710	1711	1712	1713	1714	1715	1716	1717	1718	1719	1720	1721	1722	1723	1724	1725	1726	1727	1728	1729	1730	1731	1732	1733	1734	1735	1736	1737	1738	1739	1740	1741	1742	1743	1744	1745	1746	1747	1748	1749	1750
0.6	1651	1652	1653	1654	1655	1656	1657	1658	1659	1660	1661	1662	1663	1664	1665	1666	1667	1668	1669	1670	1671	1672	1673	1674	1675	1676	1677	1678	1679	1680	1681	1682	1683	1684	1685	1686	1687	1688	1689	1690	1691	1692	1693	1694	1695	1696	1697	1698	1699	1700
0.5	1601	1602	1603	1604	1605	1606	1607	1608	1609	1610	1611	1612	1613	1614	1615	1616	1617	1618	1619	1620	1621	1622	1623	1624	1625	1626	1627	1628	1629	1630	1631	1632	1633	1634	1635	1636	1637	1638	1639	1640	1641	1642	1643	1644	1645	1646	1647	1648	1649	1650
0.4	1551	1552	1553	1554	1555	1556	1557	1558	1559	1560	1561	1562	1563	1564	1565	1566	1567	1568	1569	1570	1571	1572	1573	1574	1575	1576	1577	1578	1579	1580	1581	1582	1583	1584	1585	1586	1587	1588	1589	1590	1591	1592	1593	1594	1595	1596	1597	1598	1599	1600
0.3	1501	1502	1503	1504	1505	1506	1507	1508	1509	1510	1511	1512	1513	1514	1515	1516	1517	1518	1519	1520	1521	1522	1523	1524	1525	1526	1527	1528	1529	1530	1531	1532	1533	1534	1535	1536	1537	1538	1539	1540	1541	1542	1543	1544	1545	1546	1547	1548	1549	1550
0.2	1451	1452	1453	1454	1455	1456	1457	1458	1459	1460	1461	1462	1463	1464	1465	1466	1467	1468	1469	1470	1471	1472	1473	1474	1475	1476	1477	1478	1479	1480	1481	1482	1483	1484	1485	1486	1487	1488	1489	1490	1491	1492	1493	1494	1495	1496	1497	1498	1499	1500
0.1	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423	1424	1425	1426	1427	1428	1429	1430	1431	1432	1433	1434	1435	1436	1437	1438	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448	1449	1450

Ego Velocity [Ve0]
kph 40
m/s 11

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	2751	2752	2753	2754	2755	2756	2757	2758	2759	2760	2761	2762	2763	2764	2765	2766	2767	2768	2769	2770	2771	2772	2773	2774	2775	2776	2777	2778	2779	2780	2781	2782	2783	2784	2785	2786	2787	2788	2789	2790	2791	2792	2793	2794	2795	2796	2797	2798	2799	2800
1.3	2701	2702	2703	2704	2705	2706	2707	2708	2709	2710	2711	2712	2713	2714	2715	2716	2717	2718	2719	2720	2721	2722	2723	2724	2725	2726	2727	2728	2729	2730	2731	2732	2733	2734	2735	2736	2737	2738	2739	2740	2741	2742	2743	2744	2745	2746	2747	2748	2749	2750
1.2	2651	2652	2653	2654	2655	2656	2657	2658	2659	2660	2661	2662	2663	2664	2665	2666	2667	2668	2669	2670	2671	2672	2673	2674	2675	2676	2677	2678	2679	2680	2681	2682	2683	2684	2685	2686	2687	2688	2689	2690	2691	2692	2693	2694	2695	2696	2697	2698	2699	2700
1.1	2601	2602	2603	2604	2605	2606	2607	2608	2609	2610	2611	2612	2613	2614	2615	2616	2617	2618	2619	2620	2621	2622	2623	2624	2625	2626	2627	2628	2629	2630	2631	2632	2633	2634	2635	2636	2637	2638	2639	2640	2641	2642	2643	2644	2645	2646	2647	2648	2649	2650
1.0	2551	2552	2553	2554	2555	2556	2557	2558	2559	2560	2561	2562	2563	2564	2565	2566	2567	2568	2569	2570	2571	2572	2573	2574	2575	2576	2577	2578	2579	2580	2581	2582	2583	2584	2585	2586	2587	2588	2589	2590	2591	2592	2593	2594	2595	2596	2597	2598	2599	2600
0.9	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534	2535	2536	2537	2538	2539	2540	2541	2542	2543	2544	2545	2546	2547	2548	2549	2550
0.8	2451	2452	2453	2454	2455	2456	2457	2458	2459	2460	2461	2462	2463	2464	2465	2466	2467	2468	2469	2470	2471	2472	2473	2474	2475	2476	2477	2478	2479	2480	2481	2482	2483	2484	2485	2486	2487	2488	2489	2490	2491	2492	2493	2494	2495	2496	2497	2498	2499	2500
0.7	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450
0.6	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400
0.5	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350
0.4	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300
0.3	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250
0.2	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200
0.1	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150

Ego Velocity [Ve0]
kph 50
m/s 14

Relative Distance m [dx0]

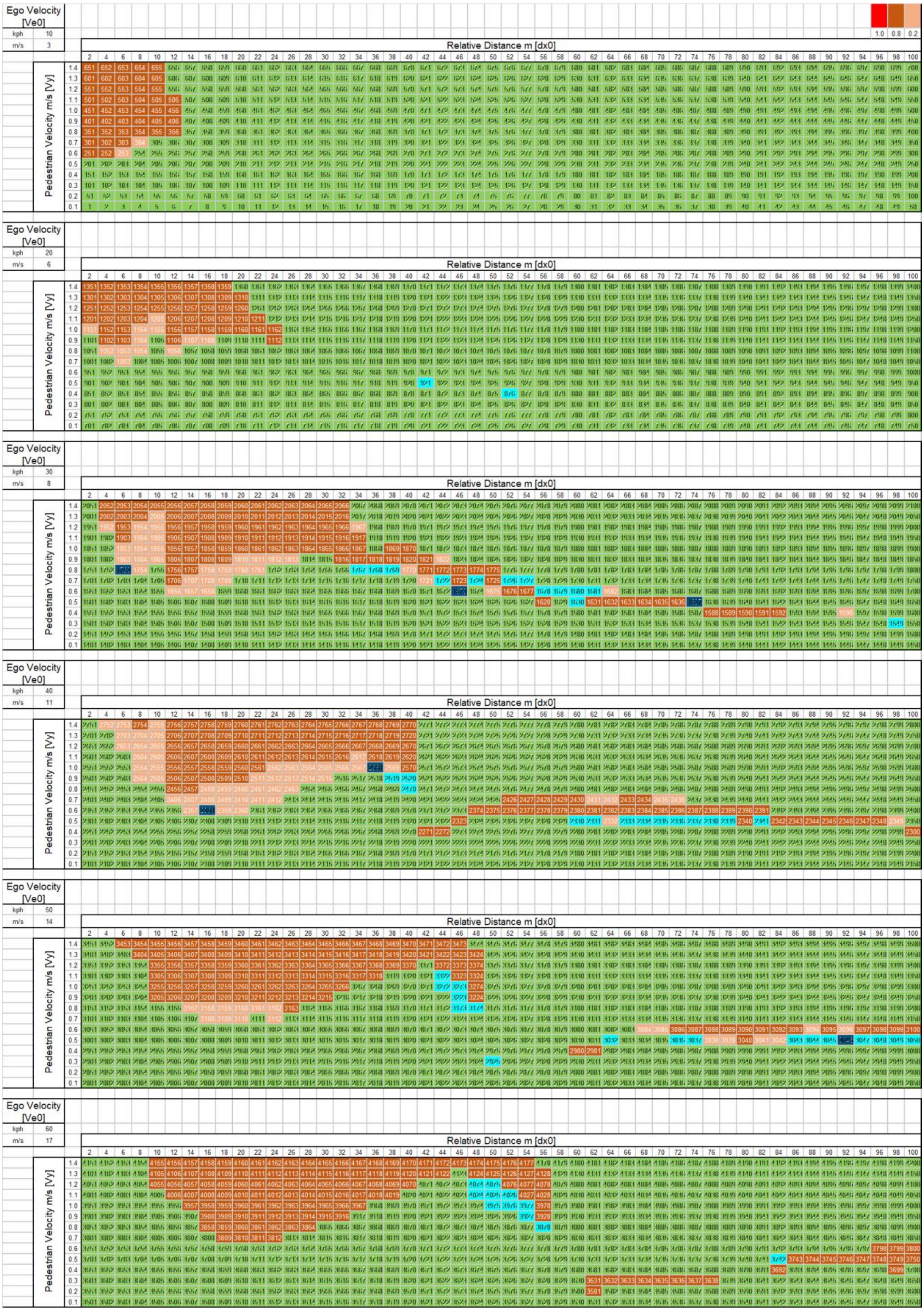
Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	3451	3452	3453	3454	3455	3456	3457	3458	3459	3460	3461	3462	3463	3464	3465	3466	3467	3468	3469	3470	3471	3472	3473	3474	3475	3476	3477	3478	3479	3480	3481	3482	3483	3484	3485	3486	3487	3488	3489	3490	3491	3492	3493	3494	3495	3496	3497	3498	3499	3500
1.3	3401	3402	3403	3404	3405	3406	3407	3408	3409	3410	3411	3412	3413	3414	3415	3416	3417	3418	3419	3420	3421	3422	3423	3424	3425	3426	3427	3428	3429	3430	3431	3432	3433	3434	3435	3436	3437	3438	3439	3440	3441	3442	3443	3444	3445	3446	3447	3448	3449	3450
1.2	3351	3352	3353	3354	3355	3356	3357	3358	3359	3360	3361	3362	3363	3364	3365	3366	3367	3368	3369	3370	3371	3372	3373	3374	3375	3376	3377	3378	3379	3380	3381	3382	3383	3384	3385	3386	3387	3388	3389	3390	3391	3392	3393	3394	3395	3396	3397	3398	3399	3400
1.1	3301	3302	3303	3304	3305	3306	3307	3308	3309	3310	3311	3312	3313	3314	3315	3316	3317	3318	3319	3320	3321	3322	3323	3324	3325	3326	3327	3328	3329	3330	3331	3332	3333	3334	3335	3336	3337	3338	3339	3340	3341	3342	3343	3344	3345	3346	3347	3348	3349	3350
1.0	3251	3252	3253	3254	3255	3256	3257	3258	3259	3260	3261	3262	3263	3264	3265	3266	3267	3268	3269	3270	3271	3272	3273	3274	3275	3276	3277	3278	3279	3280	3281	3282	3283	3284	3285	3286	3287	3288	3289	3290	3291	3292	3293	3294	3295	3296	3297	3298	3299	3300
0.9	3201	3202	3203	3204	3205	3206	3207	3208	3209	3210	3211	3212	3213	3214	3215	3216	3217	3218	3219	3220	3221	3222	3223	3224	3225	3226	3227	3228	3229	3230	3231	3232	3233	3234	3235	3236	3237	3238	3239	3240	3241	3242	3243	3244	3245	3246	3247	3248	3249	3250
0.8	3151	3152	3153	3154	3155	3156	3157	3158	3159	3160	3161	3162	3163	3164	3165	3166	3167	3168	3169	3170	3171	3172	3173	3174	3175	3176	3177	3178	3179	3180	3181	3182	3183	3184	3185	3186	3187	3188	3189	3190	3191	3192	3193	3194	3195	3196	3197	3198	3199	3200
0.7	3101	3102	3103	3104	3105	3106	3107	3108	3109	3110	3111	3112	3113	3114	3115	3116	3117	3118	3119	3120	3121	3122	3123	3124	3125	3126	3127	3128	3129	3130	3131	3132	3133	3134	3135	3136	3137	3138	3139	3140	3141	3142	3143	3144	3145	3146	3147	3148	3149	3150
0.6	3051	3052	3053	3054	3055	3056	3057	3058	3059	3060	3061	3062	3063	3064	3065	3066	3067	3068	3069	3070	3071	3072	3073	3074	3075	3076	3077	3078	3079	3080	3081	3082	3083	3084	3085	3086	3087	3088	3089	3090	3091	3092	3093	3094	3095	3096	3097	3098	3099	3100
0.5	3001	3002	3003	3004	3005	3006	3007	3008	3009	3010	3011	3012	3013	3014	3015	3016	3017	3018	3019	3020	3021	3022	3023	3024	3025	3026	3027	3028	3029	3030	3031	3032	3033	3034	3035	3036	3037	3038	3039	3040	3041	3042	3043	3044	3045	3046	3047	3048	3049	3050
0.4	2951	2952	2953	2954	2955	2956	2957	2958	2959	2960	2961	2962	2963	2964	2965	2966	2967	2968	2969	2970	2971	2972	2973	2974	2975	2976	2977	2978	2979	2980	2981	2982	2983	2984	2985	2986	2987	2988	2989	2990	2991	2992	2993	2994	2995	2996	2997	2998	2999	3000
0.3	2901	2902	2903	2904	2905	2906	2907	2908	2909	2910	2911	2912	2913	2914	2915	2916	2917	2918	2919	2920	2921	2922	2923	2924	2925	2926	2927	2928	2929	2930	2931	2932	2933	2934	2935	2936	2937	2938	2939	2940	2941	2942	2943	2944	2945	2946	2947	2948	2949	2950
0.2	2851	2852	2853	2854	2855	2856	2857	2858	2859	2860	2861	2862	2863	2864	2865	2866	2867	2868	2869	2870	2871	2872	2873	2874	2875	2876	2877	2878	2879	2880	2881	2882	2883	2884	2885	2886	2887	2888	2889	2890	2891	2892	2893	2894	2895	2896	2897	2898	2899	2900
0.1	2801	2802	2803	2804	2805	2806	2807	2808	2809	2810	2811	2812	2813	2814	2815	2816	2817	2818	2819	2820	2821	2822	2823	2824	2825	2826	2827	2828	2829	2830	2831	2832	2833	2834	2835	2836	2837	2838	2839	2840	2841	2842	2843	2844	2845	2846	2847	2848	2849	2850

Ego Velocity [Ve0]
kph 60
m/s 17

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	4151	4152	4153	4154	4155	4156	4157	4158	4159	4160	4161	4162	4163	4164	4165	4166	4167	4168	4169	4170	4171	4172	4173	4174	4175	4176	4177	4178	4179	4180	4181	4182	4183	4184	4185	4186	4187	4188	4189	4190	4191	4192	4193	4194	4195	4196	4197	4198	4199	4200
1.3	4101	4102	4103	4104	4105	4106	4107	4108	4109	4110	4111	4112	4113	4114	4115	4116	4117	4118	4119	4120	4121	4122	4123	4124	4125	4126	4127	4128	4129	4130	4131	4132	4133	4134	4135	4136	4137	4138	4139	4140	4141	4142	4143	4144	4145	4146	4147	4148	4149	4150
1.2	4051	4052	4053	4054	4055	4056	4057	4058	4059	4060	4061	4062	4063	4064	4065	4066	4067	4068	4069	4070	4071	4072	4073	4074	4075	4076	4077	4078	4079	4080	4081	4082	4083	4084	4085	4086	4087	4088	4089	4090	4091	4092	4093	4094	4095	4096	4097	4098	4099	4100
1.1	4001	4002	4003	4004	4005	4006	4007	4008	4009	4010	4011	4012	4013	4014	4015	4016	4017	4018	4019	4020	4021	4022	4023	4024	4025	4026	4027	4028	4029	4030	4031	4032	4033	4034	4035	4036	4037	4038	4039	4040	4041	4042	4043	4044	4045	4046	4047	4048	4049	4050
1.0	3951	3952	3953	3954	3955	3956	3957	3958	3959	3960	3961	3962	3963	3964	3965	3966	3967	3968	3969	3970	3971	3972	3973	3974	3975	3976	3977	3978	3979	3980	3981	3982	3983	3984	3985	3986	3987	3988	3989	3990	3991	3992	3993	3994	3995	3996	3997	3998	3999	4000
0.9	3901	3902	3903	3904	3905	3906	3907	3908	3909	3910	3911	3912	3913	3914	3915	3916	3917	3918	3919	3920	3921	3922	3923	3924	3925	3926	3927	3928	3929	3930	3931	3932	3933	3934	3935	3936	3937	3938	3939	3940	3941	3942	3943	3944	3945	3946	3947	3948	3949	3950
0.8	3851	3852	3853	3854	3855	3856	3857	3858	3859	3860	3861	3862	3863	3864	3865	3866	3867	3868	3869	3870	3871	3872	3873	3874	3875	3876	3877	3878	3879	3880	3881	3882	3883	3884	3885	3886	3887	3888	3889	3890	3891	3892	3893	3894	3895	3896	3897	3898	3899	3900
0.7	3801	3802	3803	3804	3805	3806	3807	3808	3809	3810	3811	3812	3813	3814	3815	3816	3817	3818	3819	3820	3821	3822	3823	3824	3825	3826	3827	3828	3829	3830	3831	3832	3833	3834	3835	3836	3837	3838	3839	3840	3841	3842	3843	3844	3845	3846	3847	3848	3849	3850
0.6	3751	3752	3753	3754	3755	3756	3757	3758	3759	3760	3761	3762	3763	3764	3765	3766	3767	3768	3769	3770	3771	3772	3773	3774	3775	3776	3777	3778	3779	3780	3781	3782	3783	3784	3785	3786	3787	3788	3789	3790	3791	3792	3793	3794	3795	3796	3797	3798	3799	3800
0.5	3701	3702	3703	3704	3705	3706	3707	3708	3709	3710	3711	3712	3713	3714	3715	3716	3717	3718	3719	3720	3721	3722	3723	3724	3725	3726	3727	3728	3729	3730	3731	3732	3733	3734	3735	3736	3737	3738	3739	3740	3741	3742	3743	3744	3745	3746	3747	3748	3749	3750
0.4	3651	3652	3653	3654	3655	3656	3657	3658	3659	3660	3661	3662	3663	3664	3665	3666	3667	3668	3669	3670	3671	3672	3673	3674	3675	3676	3677	3678	3679	3680	3681	3682	3683	3684	3685	3686	3687	3688	3689	3690	3691	3692	3693	3694	3695	3696	3697	3698	3699	3700
0.3	3601	3602	3603	3604	3605	3606	3607	3608	3609	3610	3611	3612	3613	3614	3615	3616	3617	3618	3619	3620	3621	3622	3623	3624	3625	3626	3627	3628	3629	3630	3631	3632	3633	3634	3635	3636	3637	3638	3639	3640	3641	3642	3643	3644	3645	3646	3647	3648	3649	3650
0.2	3551	3552	3553	3554	3555	3556	3557	3558	3559	3560	3561	3562	3563	3564	3565	3566	3567	3568	3569	3570	3571	3572	3573	3574	3575	3576	3577	3578	3579	3580	3581	3582	3583	3584	3585	3586	3587	3588	3589	3590	3591	3592	3593	3594	3595	3596	3597	3598	3599	3600
0.1	3501	3502	3503	3504	3505	3506	3507	3508	3509	3510	3511	3512	3513	3514	3515	3516	3517	3518	3519	3520	3521	3522	3523	3524	3525	3526	3527	3528	3529	3530	3531	3532	3533	3534	3535	3536	3537	3538	3539	3540	3541	3542	3543	3544	3545	3546	3547	3548	3549	3550

Table 6-21 Combined Results Table of the Lane Crossing Pedestrian Scenario for 1st and 2nd Configuration with Different Roadway Conditions



🟥	🟧	🟧
1.0	0.8	0.2

Ego Velocity [Ve0]
kph 10
m/s 3

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700
1.3	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650
1.2	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600
1.1	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550
1.0	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500
0.9	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450
0.8	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
0.7	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350
0.6	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300
0.5	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250
0.4	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
0.3	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
0.2	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
0.1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

Ego Velocity [Ve0]
kph 20
m/s 6

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	1351	1352	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362	1363	1364	1365	1366	1367	1368	1369	1370	1371	1372	1373	1374	1375	1376	1377	1378	1379	1380	1381	1382	1383	1384	1385	1386	1387	1388	1389	1390	1391	1392	1393	1394	1395	1396	1397	1398	1399	1400
1.3	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343	1344	1345	1346	1347	1348	1349	1350
1.2	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296	1297	1298	1299	1300
1.1	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250
1.0	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200
0.9	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150
0.8	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100
0.7	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050
0.6	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000
0.5	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950
0.4	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900
0.3	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850
0.2	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800
0.1	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750

Ego Velocity [Ve0]
kph 30
m/s 8

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
1.3	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1.2	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1.1	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
1.0	1851	1852	1853	1854	1855	1856	1857	1858	1859	1860	1861	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900
0.9	1801	1802	1803	1804	1805	1806	1807	1808	1809	1810	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826	1827	1828	1829	1830	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840	1841	1842	1843	1844	1845	1846	1847	1848	1849	1850
0.8	1751	1752	1753	1754	1755	1756	1757	1758	1759	1760	1761	1762	1763	1764	1765	1766	1767	1768	1769	1770	1771	1772	1773	1774	1775	1776	1777	1778	1779	1780	1781	1782	1783	1784	1785	1786	1787	1788	1789	1790	1791	1792	1793	1794	1795	1796	1797	1798	1799	1800
0.7	1701	1702	1703	1704	1705	1706	1707	1708	1709	1710	1711	1712	1713	1714	1715	1716	1717	1718	1719	1720	1721	1722	1723	1724	1725	1726	1727	1728	1729	1730	1731	1732	1733	1734	1735	1736	1737	1738	1739	1740	1741	1742	1743	1744	1745	1746	1747	1748	1749	1750
0.6	1651	1652	1653	1654	1655	1656	1657	1658	1659	1660	1661	1662	1663	1664	1665	1666	1667	1668	1669	1670	1671	1672	1673	1674	1675	1676	1677	1678	1679	1680	1681	1682	1683	1684	1685	1686	1687	1688	1689	1690	1691	1692	1693	1694	1695	1696	1697	1698	1699	1700
0.5	1601	1602	1603	1604	1605	1606	1607	1608	1609	1610	1611	1612	1613	1614	1615	1616	1617	1618	1619	1620	1621	1622	1623	1624	1625	1626	1627	1628	1629	1630	1631	1632	1633	1634	1635	1636	1637	1638	1639	1640	1641	1642	1643	1644	1645	1646	1647	1648	1649	1650
0.4	1551	1552	1553	1554	1555	1556	1557	1558	1559	1560	1561	1562	1563	1564	1565	1566	1567	1568	1569	1570	1571	1572	1573	1574	1575	1576	1577	1578	1579	1580	1581	1582	1583	1584	1585	1586	1587	1588	1589	1590	1591	1592	1593	1594	1595	1596	1597	1598	1599	1600
0.3	1501	1502	1503	1504	1505	1506	1507	1508	1509	1510	1511	1512	1513	1514	1515	1516	1517	1518	1519	1520	1521	1522	1523	1524	1525	1526	1527	1528	1529	1530	1531	1532	1533	1534	1535	1536	1537	1538	1539	1540	1541	1542	1543	1544	1545	1546	1547	1548	1549	1550
0.2	1451	1452	1453	1454	1455	1456	1457	1458	1459	1460	1461	1462	1463	1464	1465	1466	1467	1468	1469	1470	1471	1472	1473	1474	1475	1476	1477	1478	1479	1480	1481	1482	1483	1484	1485	1486	1487	1488	1489	1490	1491	1492	1493	1494	1495	1496	1497	1498	1499	1500
0.1	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423	1424	1425	1426	1427	1428	1429	1430	1431	1432	1433	1434	1435	1436	1437	1438	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448	1449	1450

Ego Velocity [Ve0]
kph 40
m/s 11

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	2751	2752	2753	2754	2755	2756	2757	2758	2759	2760	2761	2762	2763	2764	2765	2766	2767	2768	2769	2770	2771	2772	2773	2774	2775	2776	2777	2778	2779	2780	2781	2782	2783	2784	2785	2786	2787	2788	2789	2790	2791	2792	2793	2794	2795	2796	2797	2798	2799	2800
1.3	2701	2702	2703	2704	2705	2706	2707	2708	2709	2710	2711	2712	2713	2714	2715	2716	2717	2718	2719	2720	2721	2722	2723	2724	2725	2726	2727	2728	2729	2730	2731	2732	2733	2734	2735	2736	2737	2738	2739	2740	2741	2742	2743	2744	2745	2746	2747	2748	2749	2750
1.2	2651	2652	2653	2654	2655	2656	2657	2658	2659	2660	2661	2662	2663	2664	2665	2666	2667	2668	2669	2670	2671	2672	2673	2674	2675	2676	2677	2678	2679	2680	2681	2682	2683	2684	2685	2686	2687	2688	2689	2690	2691	2692	2693	2694	2695	2696	2697	2698	2699	2700
1.1	2601	2602	2603	2604	2605	2606	2607	2608	2609	2610	2611	2612	2613	2614	2615	2616	2617	2618	2619	2620	2621	2622	2623	2624	2625	2626	2627	2628	2629	2630	2631	2632	2633	2634	2635	2636	2637	2638	2639	2640	2641	2642	2643	2644	2645	2646	2647	2648	2649	2650
1.0	2551	2552	2553	2554	2555	2556	2557	2558	2559	2560	2561	2562	2563	2564	2565	2566	2567	2568	2569	2570	2571	2572	2573	2574	2575	2576	2577	2578	2579	2580	2581	2582	2583	2584	2585	2586	2587	2588	2589	2590	2591	2592	2593	2594	2595	2596	2597	2598	2599	2600
0.9	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534	2535	2536	2537	2538	2539	2540	2541	2542	2543	2544	2545	2546	2547	2548	2549	2550
0.8	2451	2452	2453	2454	2455	2456	2457	2458	2459	2460	2461	2462	2463	2464	2465	2466	2467	2468	2469	2470	2471	2472	2473	2474	2475	2476	2477	2478	2479	2480	2481	2482	2483	2484	2485	2486	2487	2488	2489	2490	2491	2492	2493	2494	2495	2496	2497	2498	2499	2500
0.7	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450
0.6	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400
0.5	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350
0.4	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300
0.3	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250
0.2	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200
0.1	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150

Ego Velocity [Ve0]
kph 50
m/s 14

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	3451	3452	3453	3454	3455	3456	3457	3458	3459	3460	3461	3462	3463	3464	3465	3466	3467	3468	3469	3470	3471	3472	3473	3474	3475	3476	3477	3478	3479	3480	3481	3482	3483	3484	3485	3486	3487	3488	3489	3490	3491	3492	3493	3494	3495	3496	3497	3498	3499	3500
1.3	3401	3402	3403	3404	3405	3406	3407	3408	3409	3410	3411	3412	3413	3414	3415	3416	3417	3418	3419	3420	3421	3422	3423	3424	3425	3426	3427	3428	3429	3430	3431	3432	3433	3434	3435	3436	3437	3438	3439	3440	3441	3442	3443	3444	3445	3446	3447	3448	3449	3450
1.2	3351	3352	3353	3354	3355	3356	3357	3358	3359	3360	3361	3362	3363	3364	3365	3366	3367	3368	3369	3370	3371	3372	3373	3374	3375	3376	3377	3378	3379	3380	3381	3382	3383	3384	3385	3386	3387	3388	3389	3390	3391	3392	3393	3394	3395	3396	3397	3398	3399	3400
1.1	3301	3302	3303	3304	3305	3306	3307	3308	3309	3310	3311	3312	3313	3314	3315	3316	3317	3318	3319	3320	3321	3322	3323	3324	3325	3326	3327	3328	3329	3330	3331	3332	3333	3334	3335	3336	3337	3338	3339	3340	3341	3342	3343	3344	3345	3346	3347	3348	3349	3350
1.0	3251	3252	3253	3254	3255	3256	3257	3258	3259	3260	3261	3262	3263	3264	3265	3266	3267	3268	3269	3270	3271	3272	3273	3274	3275	3276	3277	3278	3279	3280	3281	3282	3283	3284	3285	3286	3287	3288	3289	3290	3291	3292	3293	3294	3295	3296	3297	3298	3299	3300
0.9	3201	3202	3203	3204	3205	3206	3207	3208	3209	3210	3211	3212	3213	3214	3215	3216	3217	3218	3219	3220	3221	3222	3223	3224	3225	3226	3227	3228	3229	3230	3231	3232	3233	3234	3235	3236	3237	3238	3239	3240	3241	3242	3243	3244	3245	3246	3247	3248	3249	3250
0.8	3151	3152	3153	3154	3155	3156	3157	3158	3159	3160	3161	3162	3163	3164	3165	3166	3167	3168	3169	3170	3171	3172	3173	3174	3175	3176	3177	3178	3179	3180	3181	3182	3183	3184	3185	3186	3187	3188	3189	3190	3191	3192	3193	3194	3195	3196	3197	3198	3199	3200
0.7	3101	3102	3103	3104	3105	3106	3107	3108	3109	3110	3111	3112	3113	3114	3115	3116	3117	3118	3119	3120	3121	3122	3123	3124	3125	3126	3127	3128	3129	3130	3131	3132	3133	3134	3135	3136	3137	3138	3139	3140	3141	3142	3143	3144	3145	3146	3147	3148	3149	3150
0.6	3051	3052	3053	3054	3055	3056	3057	3058	3059	3060	3061	3062	3063	3064	3065	3066	3067	3068	3069	3070	3071	3072	3073	3074	3075	3076	3077	3078	3079	3080	3081	3082	3083	3084	3085	3086	3087	3088	3089	3090	3091	3092	3093	3094	3095	3096	3097	3098	3099	3100
0.5	3001	3002	3003	3004	3005	3006	3007	3008	3009	3010	3011	3012	3013	3014	3015	3016	3017	3018	3019	3020	3021	3022	3023	3024	3025	3026	3027	3028	3029	3030	3031	3032	3033	3034	3035	3036	3037	3038	3039	3040	3041	3042	3043	3044	3045	3046	3047	3048	3049	3050
0.4	2951	2952	2953	2954	2955	2956	2957	2958	2959	2960	2961	2962	2963	2964	2965	2966	2967	2968	2969	2970	2971	2972	2973	2974	2975	2976	2977	2978	2979	2980	2981	2982	2983	2984	2985	2986	2987	2988	2989	2990	2991	2992	2993	2994	2995	2996	2997	2998	2999	3000
0.3	2901	2902	2903	2904	2905	2906	2907	2908	2909	2910	2911	2912	2913	2914	2915	2916	2917	2918	2919	2920	2921	2922	2923	2924	2925	2926	2927	2928	2929	2930	2931	2932	2933	2934	2935	2936	2937	2938	2939	2940	2941	2942	2943	2944	2945	2946	2947	2948	2949	2950
0.2	2851	2852	2853	2854	2855	2856	2857	2858	2859	2860	2861	2862	2863	2864	2865	2866	2867	2868	2869	2870	2871	2872	2873	2874	2875	2876	2877	2878	2879	2880	2881	2882	2883	2884	2885	2886	2887	2888	2889	2890	2891	2892	2893	2894	2895	2896	2897	2898	2899	2900
0.1	2801	2802	2803	2804	2805	2806	2807	2808	2809	2810	2811	2812	2813	2814	2815	2816	2817	2818	2819	2820	2821	2822	2823	2824	2825	2826	2827	2828	2829	2830	2831	2832	2833	2834	2835	2836	2837	2838	2839	2840	2841	2842	2843	2844	2845	2846	2847	2848	2849	2850

Ego Velocity [Ve0]
kph 60
m/s 17

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	4151	4152	4153	4154	4155	4156	4157	4158	4159	4160	4161	4162	4163	4164	4165	4166	4167	4168	4169	4170	4171	4172	4173	4174	4175	4176	4177	4178	4179	4180	4181	4182	4183	4184	4185	4186	4187	4188	4189	4190	4191	4192	4193	4194	4195	4196	4197	4198	4199	4200
1.3	4101	4102	4103	4104	4105	4106	4107	4108	4109	4110	4111	4112	4113	4114	4115	4116	4117	4118	4119	4120	4121	4122	4123	4124	4125	4126	4127	4128	4129	4130	4131	4132	4133	4134	4135	4136	4137	4138	4139	4140	4141	4142	4143	4144	4145	4146	4147	4148	4149	4150
1.2	4051	4052	4053	4054	4055	4056	4057	4058	4059	4060	4061	4062	4063	4064	4065	4066	4067	4068	4069	4070	4071	4072	4073	4074	4075	4076	4077	4078	4079	4080	4081	4082	4083	4084	4085	4086	4087	4088	4089	4090	4091	4092	4093	4094	4095	4096	4097	4098	4099	4100
1.1	4001	4002	4003	4004	4005	4006	4007	4008	4009	4010	4011	4012	4013	4014	4015	4016	4017	4018	4019	4020	4021	4022	4023	4024	4025	4026	4027	4028	4029	4030	4031	4032	4033	4034	4035	4036	4037	4038	4039	4040	4041	4042	4043	4044	4045	4046	4047	4048	4049	4050
1.0	3951	3952	3953	3954	3955	3956	3957	3958	3959	3960	3961	3962	3963	3964	3965	3966	3967	3968	3969	3970	3971	3972	3973	3974	3975	3976	3977	3978	3979	3980	3981	3982	3983	3984	3985	3986	3987	3988	3989	3990	3991	3992	3993	3994	3995	3996	3997	3998	3999	4000
0.9	3901	3902	3903	3904	3905	3906	3907	3908	3909	3910	3911	3912	3913	3914	3915	3916	3917	3918	3919	3920	3921	3922	3923	3924	3925	3926	3927	3928	3929	3930	3931	3932	3933	3934	3935	3936	3937	3938	3939	3940	3941	3942	3943	3944	3945	3946	3947	3948	3949	3950
0.8	3851	3852	3853	3854	3855	3856	3857	3858	3859	3860	3861	3862	3863	3864	3865	3866	3867	3868	3869	3870	3871	3872	3873	3874	3875	3876	3877	3878	3879	3880	3881	3882	3883	3884	3885	3886	3887	3888	3889	3890	3891	3892	3893	3894	3895	3896	3897	3898	3899	3900
0.7	3801	3802	3803	3804	3805	3806	3807	3808	3809	3810	3811	3812	3813	3814	3815	3816	3817	3818	3819	3820	3821	3822	3823	3824	3825	3826	3827	3828	3829	3830	3831	3832	3833	3834	3835	3836	3837	3838	3839	3840	3841	3842	3843	3844	3845	3846	3847	3848	3849	3850
0.6	3751	3752	3753	3754	3755	3756	3757	3758	3759	3760	3761	3762	3763	3764	3765	3766	3767	3768	3769	3770	3771	3772	3773	3774	3775	3776	3777	3778	3779	3780	3781	3782	3783	3784	3785	3786	3787	3788	3789	3790	3791	3792	3793	3794	3795	3796	3797	3798	3799	3800
0.5	3701	3702	3703	3704	3705	3706	3707	3708	3709	3710	3711	3712	3713	3714	3715	3716	3717	3718	3719	3720	3721	3722	3723	3724	3725	3726	3727	3728	3729	3730	3731	3732	3733	3734	3735	3736	3737	3738	3739	3740	3741	3742	3743	3744	3745	3746	3747	3748	3749	3750
0.4	3651	3652	3653	3654	3655	3656	3657	3658	3659	3660	3661	3662	3663	3664	3665	3666	3667	3668	3669	3670	3671	3672	3673	3674	3675	3676	3677	3678	3679	3680	3681	3682	3683	3684	3685	3686	3687	3688	3689	3690	3691	3692	3693	3694	3695	3696	3697	3698	3699	3700
0.3	3601	3602	3603	3604	3605	3606	3607	3608	3609	3610	3611	3612	3613	3614	3615	3616	3617	3618	3619	3620	3621	3622	3623	3624	3625	3626	3627	3628	3629	3630	3631	3632	3633	3634	3635	3636	3637	3638	3639	3640	3641	3642	3643	3644	3645	3646	3647	3648	3649	3650
0.2	3551	3552	3553	3554	3555	3556	3557	3558	3559	3560	3561	3562	3563	3564	3565	3566	3567	3568	3569	3570	3571	3572	3573	3574	3575	3576	3577	3578	3579	3580	3581	3582	3583	3584	3585	3586	3587	3588	3589	3590	3591	3592	3593	3594	3595	3596	3597	3598	3599	3600
0.1	3501	3502	3503	3504	3505	3506	3507	3508	3509	3510	3511	3512	3513	3514	3515	3516	3517	3518	3519	3520	3521	3522	3523	3524	3525	3526	3527	3528	3529	3530	3531	3532	3533	3534	3535	3536	3537	3538	3539	3540	3541	3542	3543	3544	3545	3546	3547	3548	3549	3550

In the first set of results of ALKS (Table 6-19), it can be seen that after 30 kph, the roadway condition increases its effect. The failure cases group at the upper left corners. This means with short relative distance and high pedestrian velocity; the collision risk increases substantially. There are also ungrouped failure cases in the mid-section that appear to be random. After inspection, it appeared that these cases failed due to the decision mechanism or vehicle mode selector. In either case, it seemed that implementing hard boundaries for decision mechanisms resulted in a collision in unexpected situations.

After the first inspection, it is decided that “the Weight on change of longitudinal acceleration” was changed to a lower value to observe a different controller configuration.

The 2nd configuration has a lower “Weight on change of longitudinal acceleration” compared to the 1st configuration (Table 6-20). In comparison, the 1st configuration has followed the set longitudinal velocity value with relaxed throttle input. However, 2nd configuration has a lower weight on change, therefore the throttle input was higher.

In order to evaluate the algorithm accurately, now all results were plotted on top of each other, where the blue-colored cells are from the 1st configuration (Table 6-21). After the 1st configuration’s results were inspected, the critical conditions were grouped and the configuration updated. Then, blue failure cases seem to disappear in the 2nd configuration which is an improvement.

6.6. Discussion

The test results for all systems such as AEB, LCA, ACC, LKA were presented in the previous chapter. These results suggested some noteworthy findings of the proposed algorithms. The research's findings will be discussed in this section.

AEB Testing results revealed that:

The roadway condition was affected the results. The minimum safe TTC value increased in the low friction cases. TTC is directly related to initial conditions. However, after the inspection of the results, it has appeared that TTC is not the only parameter that governs the results. Therefore, the initial velocity of the subject vehicle is also considered in evaluations.

The roadway condition should be evaluated in test cases for lateral assistance systems. Both velocities for the subject and the lead vehicle should be varied in test cases. Thus, the simulation cases were designed to reflect the findings.

Then, the following simulation cases varied the roadway condition and the initial velocities.

LCA Testing results revealed that:

In the AEB test case where a collision occurs, an assist from LCA performed a successful maneuver to avoid a collision. However, in the low-friction conditions, the maneuvers can result in a collision.

Therefore, it is evident that there must be a mechanism to evaluate roadway conditions. In low-friction conditions, the vehicle must decide whether it is safe and stable to perform a maneuver or not.

In normal operating conditions, the ACC performed well in velocity and distance control. While ACC control longitudinal motion, LKA controlled the lateral motion. As previously mentioned, the effect of roadway conditions is important in lateral dynamics.

LKA Testing results revealed that:

- In the cases with 0.2 roadway conditions, the Lane Keeping Assist fails to control the vehicle when the velocity is 50 kph and 60 kph.

In the previous section where LCA were inspected, in the cases with 0.2 roadway conditions, the vehicle failed to perform the maneuver. Nevertheless, the vehicle can operate normally in 0.4 and 0.8 roadway conditions with ACC and LKA.

As an important notice, in low friction values the lateral assistance systems tend to fail in the lateral control. In low-friction conditions, the vehicle must decide whether it is safe and stable to drive at all. Therefore, it is important to repeat that there must be a mechanism to evaluate roadway conditions. Note that in these conditions, even a skilled human driver may not be able to control the vehicle.

In the Case study, Lane Crossing Pedestrian scenario results revealed that:

- Lane crossing pedestrian scenario with constant pedestrian velocity is much more complex than a static pedestrian scenario.
- In degraded roadway conditions where the road adhesion coefficient is low, performing maneuver is dangerous, especially for the driver, and may result in a collision with road borders.
- The decision mechanisms such as Decision Block and Vehicle Mode Selector had hard boundaries for triggers. In complex scenarios such as lane crossing pedestrian with constant velocity, this may lead to unexpected situations, therefore, the decision mechanisms must be thought out and tested thoroughly.

After evaluating the test results and discussing the outcomes, it is also useful to mention the study’s limitations. The recommendations for future works were also mentioned in the Conclusion section.

- In the perception block, the V2V and V2X communications were assumed to be available and the sensor noise was not included for the sake of simplicity.
- In the vehicle dynamics block, the single-track bicycle model was assumed to represent realistic lateral dynamics. However, the research revealed that the lateral dynamics have much higher significance, especially in the trajectory studies.
- In the vehicle dynamics block, only road friction and wind drag were considered for disturbance.
- In the motion planning block and control unit block, the decision mechanisms had hard boundaries for triggers. Only relative distances and velocities were considered for decisions.

7. CONCLUSION

In this study, the research objective was to develop a motion planning and control algorithm for lane change and overtake maneuvers assistance. Finally, to test and evaluation of the developed algorithm on the established simulation framework.

According to the findings of the study, the most important feature of an automated system is the ability to design a suitable path to its intended destination and follow that path within acceptable error at the road's speed requirements while safely avoiding obstacles along the way.

In the literature, some studies included unrealistic tire-road and vehicle dynamics models, some studies did not include re-planning while some studies focused only on straight roads. Therefore, in this study, these deficiencies have been addressed.

The main contributions of this work consist of:

- a Motion Planning Algorithm; with a dynamic re-planning of trajectory which is represented by a quintic polynomial and based on the Frenet frame.
- a Simulation Environment in MATLAB®; with a flexible architecture including vehicle dynamics, perception, motion planning and control algorithms.
- an Automated Scenario generation and execution; for exploration of operational design domain and identification of critical scenarios and design imperfections.

The developed algorithm was successfully tested and evaluated. Critical scenarios were identified and design imperfections were addressed. These results yielded the following findings for the proposed algorithms.

- When the road adhesion coefficient is low, performing maneuver is dangerous, and may result in a collision with road borders and other vehicles. It is evident that there must be a mechanism to evaluate roadway conditions. In low-friction conditions, the vehicle must decide whether it is safe and stable to perform a maneuver or not.
- The decision mechanisms such as Decision Block and Vehicle Mode Selector had hard boundaries for triggers. In complex scenarios such as lane crossing pedestrian with constant velocity, this may lead to unexpected situations, therefore, the decision mechanisms must be thought out and tested thoroughly.

Based on the study, some recommendations for future works were given below.

- In the perception block, the V2V and V2X communications were assumed to be available and the sensor noise was not included for the sake of simplicity.
- In the vehicle dynamics block, the single-track bicycle model was assumed to represent lateral dynamics. However, the research revealed that the lateral dynamics have much higher significance, especially in the trajectory studies.
- In the vehicle dynamics block, only road friction and wind drag were considered for disturbance.
- In the motion planning block and control unit block, the decision mechanisms had hard boundaries for triggers. Only relative distances and velocities were considered for decisions.

Furthermore, the following points are strongly suggested in this study.

- A realistic sensor fusion block should be implemented to represent the actual information flow from V2V and V2X communications and the real-world perception. Then sensor noise should be implemented in simulation for further testing and evaluation of the developed algorithm.
- A more realistic vehicle dynamics block should be implemented to represent vehicle dynamics more realistic. 6 DOF Nonlinear Vehicle Dynamics can be considered. Throttle and steering disturbances also should be considered in addition to already included wind drag and road friction disturbances.
- In the motion planning algorithm, the lateral motion values should be also used to create a trajectory that considers the lateral movement. This could significantly improve the trajectory generation performance, especially on curved roads since the vehicle has already a lateral motion such as lateral velocity, acceleration and jerk.
- The decision mechanisms such as decision block in motion planning and vehicle mode selector in control unit should evaluate whether it is safe and stable to perform a maneuver or not. Road adhesion coefficient measurement can be implemented and the information can be sent to decision mechanisms.

- The weight parameters for the path following MPC should be adaptive. There can be several MPC configurations and decision mechanisms can also select the suitable controller for the suitable operation. Thus, the MPC can focus on lateral stability by compromising the longitudinal velocity goal in critical driving conditions.

The following suggestions are also considered to be beneficial to implement however not mandatory.

- A realistic actor mechanics with intelligent vehicles, trucks, bicycles and pedestrians for realistic traffic environments.
- ASAM OpenSCENARIO support for scenario reader block for increased scenario reading capabilities.
- Unreal Engine support for this MATLAB® simulation environment to visualize the simulation in a prettier interface.

As a final note, in the proposed algorithms there are many different parameters and variables that can be changed. More experiments can be performed to obtain an even better understanding of the motion planning and control algorithms. These parameters include simulation configuration, decision mechanics' boundaries and controllers' weights. Parameters used in this research can be deviated to do sensitivity analysis for individual effects and contributions.

REFERENCES

[1] Kardell, S., and Kuosku, M. “Autonomous vehicle control via deep reinforcement learning”. In: Computer Science (2017).

[2] Dai, Y., & Lee, S.-G. (2020). Perception, Planning and Control for Self-Driving System Based on On-board Sensors. In Advances in Mechanical Engineering (Vol. 12, Issue 9, p. 168781402095649). SAGE Publications. https://doi.org/10.1177/1687814020956494

[3] Zhang M., T. Zhang, and, Q. Zhang. “An Autonomous Overtaking Maneuver Based on Relative Position Information”. In: 2018 IEEE 88th Vehicular Technology Conference (VTC-Fall) (2018). doi: 10.1109/VTCFall.2018.8690798.

[4] J. Ziegler and C. Stiller, “Spatiotemporal state lattices for fast trajectory planning in dynamic on-road driving scenarios” 2009.

[5] G. Rousseau, C. Stoica, S. Tebbani, M. Babel, “Minimum-time B-spline trajectories with corridor constraints. Application to quadrotor flight plans” 2019.

[6] W. Yin, L. Sun, M. Wang, S. Dong, J. Liu, “Residual vibration suppression for series elastic actuator based on phase plane analysis and trajectory tracking” 2016.

[7] W.-C. Chen, C.-S. Chen, F.-C. Lee, L.-Y. Chen, “High speed blending motion trajectory planning using a predefined absolute accuracy” 2019.

[8] W. Nelson, “Continuous-curvature paths for autonomous vehicles,” in Proceedings of the 1989 International Conference on Robotics and Automation, pp. 1260–1264, IEEE, Scottsdale, AZ, USA, Scottsdale, AZ, USA, May 1989.

[9] P. J. McNally, “Driver Control and trajectory optimization applied to lane change maneuver,” in Optimization and Optimal Control in Automotive Systems, vol. 6, pp. 93–107, Springer, Berlin, Germany, 2014.

[10] J. Nilsson, M. Brannstrom, E. Coelingh, and J. Fredriksson, “Lane change maneuvers for automated vehicles,” IEEE Transactions on Intelligent Transportation Systems, vol. 18, no. 5, pp. 1087–1096, 2017.

[11] C. Wei, Y. Wang, Y. Asakura, and L. Ma, “A nonlinear programing model for collision-free lane-change trajectory planning based on vehicle-to-vehicle communication,” Journal of Transportation Safety & Security, vol. 11, pp. 1–21, 2019.

[12] M. Oosterhaven, “Overtaking control systems for autonomous vehicles” Master Thesis, University of Groningen

[13] De Iaco, R., Smith, S. L., & Czarnecki, K. (2021). Universally Safe Swerve Maneuvers for Autonomous Driving. In IEEE Open Journal of Intelligent Transportation Systems (Vol. 2, pp. 482–494). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/ojits.2021.3138953

[14] Wei, C., Wang, Y., Asakura, Y., & Ma, L. (2019). A nonlinear programing model for collision-free lane-change trajectory planning based on vehicle-to-vehicle communication. In Journal of Transportation Safety & Security (Vol. 13, Issue 9, pp. 936–956). Informa UK Limited. https://doi.org/10.1080/19439962.2019.1701165

[15] Wu, C.-S., Chiu, Z.-Y., & Liu, J.-S. (2018). Time-Optimal Trajectory Planning along Parametric Polynomial Lane-Change Curves with Bounded Velocity and Acceleration: Simulations for a Unicycle Based on Numerical Integration. In Modelling and Simulation in Engineering (Vol. 2018, pp. 1–19). Hindawi Limited. https://doi.org/10.1155/2018/9348907

[16] Wang, Y., & Wei, C. (2020). A Universal Trajectory Planning Method for Automated Lane-Changing and Overtaking Maneuvers. In Mathematical Problems in Engineering (Vol. 2020, pp. 1–13). Hindawi Limited. https://doi.org/10.1155/2020/1023975

[17] S. Zhang, W. Deng, Q. Zhao, H. Sun, and B. Litkouhi, "Dynamic trajectory planning for vehicle autonomous driving," in Proceedings of the 2013 IEEE International Conference on Systems, pp. 4161–4166, IEEE, Manchester, UK, Manchester, UK, October 2013.

[18] Lex, C., Nalic, D., Samiee, S., & Eichberger, A. (2022). Automated Lane Change Featuring Re-Planning in Dynamic Environments and Sensitivity Analysis of Main Operational Parameters. In IEEE Access (Vol. 10, pp. 8604–8616). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/access.2022.3143807

[19] Tota, A., Velardocchia, M., & Güvenç, L. (2017). Path Tracking Control for Autonomous Driving Applications. In Advances in Service and Industrial Robotics (pp. 456–467). Springer International Publishing. https://doi.org/10.1007/978-3-319-61276-8_49

[20] Baslamisli SÇ, Köse IE and Anlaç G. Handling stability improvement through robust active front steering and active differential control. Vehicle Syst Dyn 2011; 49: 657–683.

[21] Zhou, H., Guvenc, L., & Liu, Z. (2017). Design and evaluation of path following controller based on MPC for autonomous vehicle. In 2017 36th Chinese Control Conference (CCC). 2017 36th Chinese Control Conference (CCC). IEEE. https://doi.org/10.23919/chicc.2017.8028942

[22] Lin, Y.-C., Lin, C.-L., Huang, S.-T., & Kuo, C.-H. (2021). Implementation of an Autonomous Overtaking System Based on Time to Lane Crossing Estimation and Model Predictive Control. In Electronics (Vol. 10, Issue 18, p. 2293). MDPI AG. https://doi.org/10.3390/electronics10182293

[23] He, X., Liu, Y., Lv, C., Ji, X., & Liu, Y. (2018). Emergency steering control of autonomous vehicle for collision avoidance and stabilisation. In Vehicle System Dynamics (Vol. 57, Issue 8, pp. 1163–1187). Informa UK Limited. https://doi.org/10.1080/00423114.2018.1537494

[24] Takahama, T., & Akasaka, D. (2018). Model Predictive Control Approach to Design Practical Adaptive Cruise Control for Traffic Jam. In International Journal of Automotive Engineering (Vol. 9, Issue 3, pp. 99–104). Society of Automotive Engineers of Japan, Inc. https://doi.org/10.20485/jsaeijae.9.3_99

[25] A. Dosovitskiy, G. Ros, F. Codevilla, A. López, and V. Koltun, "CARLA: An Open Urban Driving Simulator." Accessed: Oct. 15, 2018. [Online]. Available: http://proceedings.mlr.press/v78/dosovitskiy17a/dosovitskiy17a.pdf.

[26] G. Rong et al., "LGSVL Simulator: A High Fidelity Simulator for Autonomous Driving," 2020, [Online]. Available: http://arxiv.org/abs/2005.03778.

[27] S. Shah, D. Dey, C. Lovett, and A. Kapoor, "AirSim: High- Fidelity Visual and Physical Simulation for Autonomous Vehicles," pp. 621–635, 2018, doi: 10.1007/978-3-319-67361- 5_40.

[28] SAE International, "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems J3016," 2018.

[29] United Nations Economic and Social Council, "ECE/TRANS/WP.29/2020/81: Proposal for a new UN Regulation on uniform provisions concerning the approval of vehicles with regards to Automated Lane Keeping System," 06 2020. [Online]. Available: https://undocs.org/ECE/TRANS/WP.29/2020/81

[30] ISO/WD 34501 (20XX) "Road vehicles -Terms and definitions of test scenarios for automated driving systems", ISO Working Document

[31] ISO 2631/1 1997, Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements, International Standards Organization, Geneva, Switzerland.

[32] Vehicle Body 3DOF Longitudinal. https://www.mathworks.com /help/vdynblks/ref/vehiclebody3dof.html. 3DOF rigid vehicle body to calculate longitudinal, lateral, and yaw motion – Simulink. Date accessed: May 17, 2022

[33] Adaptive Cruise Control System. URL: https://www.mathworks.com /help/mpc/ref/pathfollowingcontrolsystem.html. Simulate path-following control using adaptive model predictive controller – Simulink. Date accessed: May 17, 2022

[34] Time Resolution. https://www.mathworks.com /help/nav/ref/trajectorygenerator frenet.html. Find optimal trajectory along reference path – MATLAB. Date accessed: May 18, 2022.

[35] Andrew Alleyne (1997) A Comparison of Alternative Intervention Strategies for Unintended Roadway Departure (URD) Control, Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, 27:3, 157-186, DOI: 10.1080/00423119708969327

[36] "Uniform provisions concerning the approval of motor vehicles with regard to the Advanced Emergency Braking System (AEBS) for M1 and N1 vehicles" (PDF). United Nations Economic Commission for Europe. 4 February 2020. P. 8. Retrieved 31 July 2020.

APPENDIX

A1. Lane crossing pedestrian – 1st configuration's results

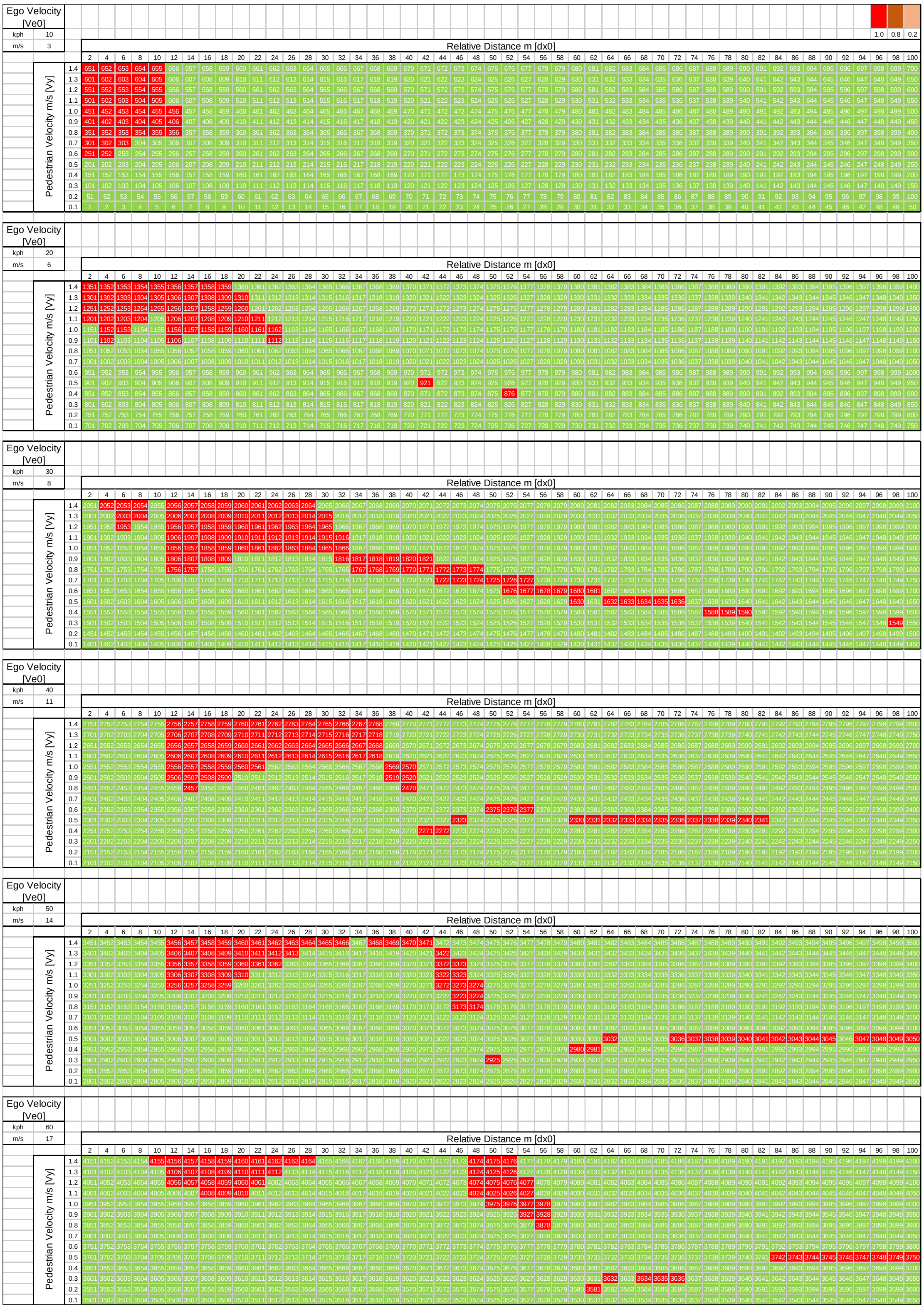
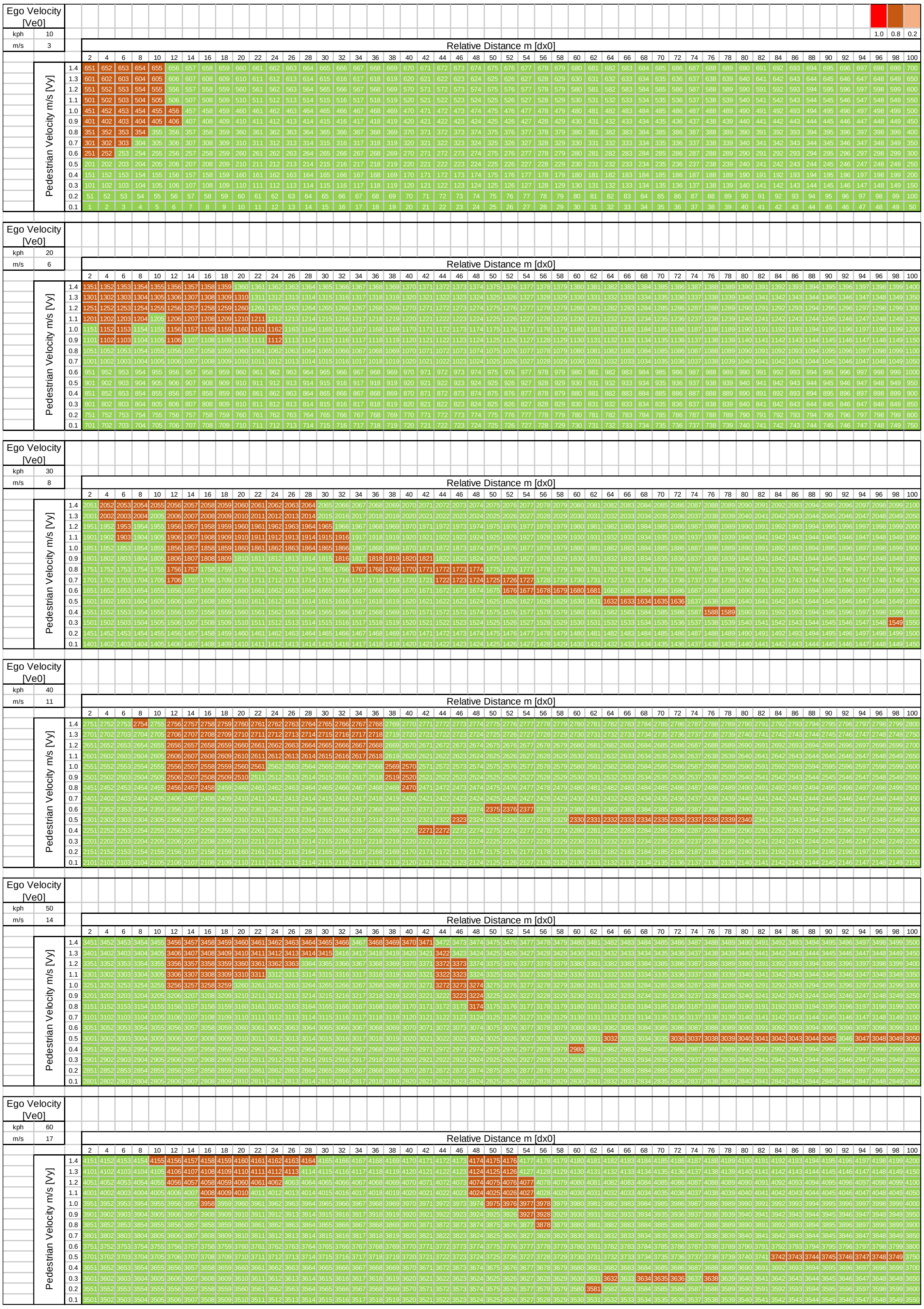


Figure A1-1 Lane Crossing Pedestrian Scenario Results for 1.0 Roadway Condition with 1st Configuration



🟥 1.0 | 🟧 0.8 | ▨ 0.2

Ego Velocity [Ve0]
kph 10
m/s 3

	Relative Distance m [dx0]																																																
Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700
1.3	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650
1.2	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600
1.1	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550
1.0	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500
0.9	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450
0.8	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
0.7	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350
0.6	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300
0.5	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250
0.4	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
0.3	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
0.2	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
0.1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

Ego Velocity [Ve0]
kph 20
m/s 6

	Relative Distance m [dx0]																																																
Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	1351	1352	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362	1363	1364	1365	1366	1367	1368	1369	1370	1371	1372	1373	1374	1375	1376	1377	1378	1379	1380	1381	1382	1383	1384	1385	1386	1387	1388	1389	1390	1391	1392	1393	1394	1395	1396	1397	1398	1399	1400
1.3	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343	1344	1345	1346	1347	1348	1349	1350
1.2	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296	1297	1298	1299	1300
1.1	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250
1.0	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200
0.9	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150
0.8	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100
0.7	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050
0.6	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000
0.5	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950
0.4	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900
0.3	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850
0.2	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800
0.1	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750

Ego Velocity [Ve0]
kph 30
m/s 8

	Relative Distance m [dx0]																																																
Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
1.3	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1.2	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1.1	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
1.0	1851	1852	1853	1854	1855	1856	1857	1858	1859	1860	1861	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900
0.9	1801	1802	1803	1804	1805	1806	1807	1808	1809	1810	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826	1827	1828	1829	1830	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840	1841	1842	1843	1844	1845	1846	1847	1848	1849	1850
0.8	1751	1752	1753	1754	1755	1756	1757	1758	1759	1760	1761	1762	1763	1764	1765	1766	1767	1768	1769	1770	1771	1772	1773	1774	1775	1776	1777	1778	1779	1780	1781	1782	1783	1784	1785	1786	1787	1788	1789	1790	1791	1792	1793	1794	1795	1796	1797	1798	1799	1800
0.7	1701	1702	1703	1704	1705	1706	1707	1708	1709	1710	1711	1712	1713	1714	1715	1716	1717	1718	1719	1720	1721	1722	1723	1724	1725	1726	1727	1728	1729	1730	1731	1732	1733	1734	1735	1736	1737	1738	1739	1740	1741	1742	1743	1744	1745	1746	1747	1748	1749	1750
0.6	1651	1652	1653	1654	1655	1656	1657	1658	1659	1660	1661	1662	1663	1664	1665	1666	1667	1668	1669	1670	1671	1672	1673	1674	1675	1676	1677	1678	1679	1680	1681	1682	1683	1684	1685	1686	1687	1688	1689	1690	1691	1692	1693	1694	1695	1696	1697	1698	1699	1700
0.5	1601	1602	1603	1604	1605	1606	1607	1608	1609	1610	1611	1612	1613	1614	1615	1616	1617	1618	1619	1620	1621	1622	1623	1624	1625	1626	1627	1628	1629	1630	1631	1632	1633	1634	1635	1636	1637	1638	1639	1640	1641	1642	1643	1644	1645	1646	1647	1648	1649	1650
0.4	1551	1552	1553	1554	1555	1556	1557	1558	1559	1560	1561	1562	1563	1564	1565	1566	1567	1568	1569	1570	1571	1572	1573	1574	1575	1576	1577	1578	1579	1580	1581	1582	1583	1584	1585	1586	1587	1588	1589	1590	1591	1592	1593	1594	1595	1596	1597	1598	1599	1600
0.3	1501	1502	1503	1504	1505	1506	1507	1508	1509	1510	1511	1512	1513	1514	1515	1516	1517	1518	1519	1520	1521	1522	1523	1524	1525	1526	1527	1528	1529	1530	1531	1532	1533	1534	1535	1536	1537	1538	1539	1540	1541	1542	1543	1544	1545	1546	1547	1548	1549	1550
0.2	1451	1452	1453	1454	1455	1456	1457	1458	1459	1460	1461	1462	1463	1464	1465	1466	1467	1468	1469	1470	1471	1472	1473	1474	1475	1476	1477	1478	1479	1480	1481	1482	1483	1484	1485	1486	1487	1488	1489	1490	1491	1492	1493	1494	1495	1496	1497	1498	1499	1500
0.1	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423	1424	1425	1426	1427	1428	1429	1430	1431	1432	1433	1434	1435	1436	1437	1438	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448	1449	1450

Ego Velocity [Ve0]
kph 40
m/s 11

	Relative Distance m [dx0]																																																
Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	2751	2752	2753	2754	2755	2756	2757	2758	2759	2760	2761	2762	2763	2764	2765	2766	2767	2768	2769	2770	2771	2772	2773	2774	2775	2776	2777	2778	2779	2780	2781	2782	2783	2784	2785	2786	2787	2788	2789	2790	2791	2792	2793	2794	2795	2796	2797	2798	2799	2800
1.3	2701	2702	2703	2704	2705	2706	2707	2708	2709	2710	2711	2712	2713	2714	2715	2716	2717	2718	2719	2720	2721	2722	2723	2724	2725	2726	2727	2728	2729	2730	2731	2732	2733	2734	2735	2736	2737	2738	2739	2740	2741	2742	2743	2744	2745	2746	2747	2748	2749	2750
1.2	2651	2652	2653	2654	2655	2656	2657	2658	2659	2660	2661	2662	2663	2664	2665	2666	2667	2668	2669	2670	2671	2672	2673	2674	2675	2676	2677	2678	2679	2680	2681	2682	2683	2684	2685	2686	2687	2688	2689	2690	2691	2692	2693	2694	2695	2696	2697	2698	2699	2700
1.1	2601	2602	2603	2604	2605	2606	2607	2608	2609	2610	2611	2612	2613	2614	2615	2616	2617	2618	2619	2620	2621	2622	2623	2624	2625	2626	2627	2628	2629	2630	2631	2632	2633	2634	2635	2636	2637	2638	2639	2640	2641	2642	2643	2644	2645	2646	2647	2648	2649	2650
1.0	2551	2552	2553	2554	2555	2556	2557	2558	2559	2560	2561	2562	2563	2564	2565	2566	2567	2568	2569	2570	2571	2572	2573	2574	2575	2576	2577	2578	2579	2580	2581	2582	2583	2584	2585	2586	2587	2588	2589	2590	2591	2592	2593	2594	2595	2596	2597	2598	2599	2600
0.9	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534	2535	2536	2537	2538	2539	2540	2541	2542	2543	2544	2545	2546	2547	2548	2549	2550
0.8	2451	2452	2453	2454	2455	2456	2457	2458	2459	2460	2461	2462	2463	2464	2465	2466	2467	2468	2469	2470	2471	2472	2473	2474	2475	2476	2477	2478	2479	2480	2481	2482	2483	2484	2485	2486	2487	2488	2489	2490	2491	2492	2493	2494	2495	2496	2497	2498	2499	2500
0.7	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450
0.6	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400
0.5	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350
0.4	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300
0.3	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250
0.2	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200
0.1	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150

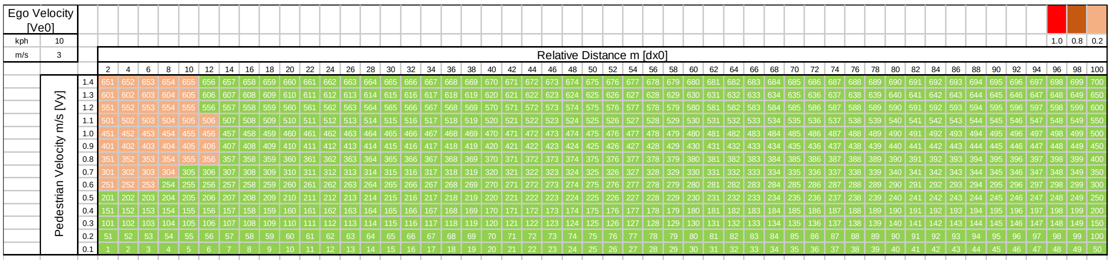
Ego Velocity [Ve0]
kph 50
m/s 14

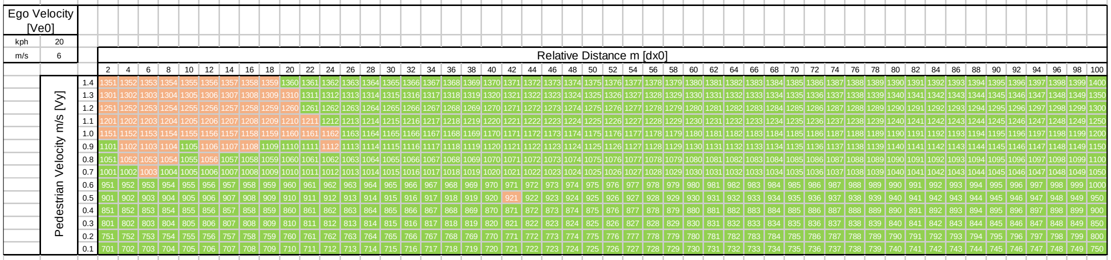
	Relative Distance m [dx0]																																																
Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	3451	3452	3453	3454	3455	3456	3457	3458	3459	3460	3461	3462	3463	3464	3465	3466	3467	3468	3469	3470	3471	3472	3473	3474	3475	3476	3477	3478	3479	3480	3481	3482	3483	3484	3485	3486	3487	3488	3489	3490	3491	3492	3493	3494	3495	3496	3497	3498	3499	3500
1.3	3401	3402	3403	3404	3405	3406	3407	3408	3409	3410	3411	3412	3413	3414	3415	3416	3417	3418	3419	3420	3421	3422	3423	3424	3425	3426	3427	3428	3429	3430	3431	3432	3433	3434	3435	3436	3437	3438	3439	3440	3441	3442	3443	3444	3445	3446	3447	3448	3449	3450
1.2	3351	3352	3353	3354	3355	3356	3357	3358	3359	3360	3361	3362	3363	3364	3365	3366	3367	3368	3369	3370	3371	3372	3373	3374	3375	3376	3377	3378	3379	3380	3381	3382	3383	3384	3385	3386	3387	3388	3389	3390	3391	3392	3393	3394	3395	3396	3397	3398	3399	3400
1.1	3301	3302	3303	3304	3305	3306	3307	3308	3309	3310	3311	3312	3313	3314	3315	3316	3317	3318	3319	3320	3321	3322	3323	3324	3325	3326	3327	3328	3329	3330	3331	3332	3333	3334	3335	3336	3337	3338	3339	3340	3341	3342	3343	3344	3345	3346	3347	3348	3349	3350
1.0	3251	3252	3253	3254	3255	3256	3257	3258	3259	3260	3261	3262	3263	3264	3265	3266	3267	3268	3269	3270	3271	3272	3273	3274	3275	3276	3277	3278	3279	3280	3281	3282	3283	3284	3285	3286	3287	3288	3289	3290	3291	3292	3293	3294	3295	3296	3297	3298	3299	3300
0.9	3201	3202	3203	3204	3205	3206	3207	3208	3209	3210	3211	3212	3213	3214	3215	3216	3217	3218	3219	3220	3221	3222	3223	3224	3225	3226	3227	3228	3229	3230	3231	3232	3233	3234	3235	3236	3237	3238	3239	3240	3241	3242	3243	3244	3245	3246	3247	3248	3249	3250
0.8	3151	3152	3153	3154	3155	3156	3157	3158	3159	3160	3161	3162	3163	3164	3165	3166	3167	3168	3169	3170	3171	3172	3173	3174	3175	3176	3177	3178	3179	3180	3181	3182	3183	3184	3185	3186	3187	3188	3189	3190	3191	3192	3193	3194	3195	3196	3197	3198	3199	3200
0.7	3101	3102	3103	3104	3105	3106	3107	3108	3109	3110	3111	3112	3113	3114	3115	3116	3117	3118	3119	3120	3121	3122	3123	3124	3125	3126	3127	3128	3129	3130	3131	3132	3133	3134	3135	3136	3137	3138	3139	3140	3141	3142	3143	3144	3145	3146	3147	3148	3149	3150
0.6	3051	3052	3053	3054	3055	3056	3057	3058	3059	3060	3061	3062	3063	3064	3065	3066	3067	3068	3069	3070	3071	3072	3073	3074	3075	3076	3077	3078	3079	3080	3081	3082	3083	3084	3085	3086	3087	3088	3089	3090	3091	3092	3093	3094	3095	3096	3097	3098	3099	3100
0.5	3001	3002	3003	3004	3005	3006	3007	3008	3009	3010	3011	3012	3013	3014	3015	3016	3017	3018	3019	3020	3021	3022	3023	3024	3025	3026	3027	3028	3029	3030	3031	3032	3033	3034	3035	3036	3037	3038	3039	3040	3041	3042	3043	3044	3045	3046	3047	3048	3049	3050
0.4	2951	2952	2953	2954	2955	2956	2957	2958	2959	2960	2961	2962	2963	2964	2965	2966	2967	2968	2969	2970	2971	2972	2973	2974	2975	2976	2977	2978	2979	2980	2981	2982	2983	2984	2985	2986	2987	2988	2989	2990	2991	2992	2993	2994	2995	2996	2997	2998	2999	3000
0.3	2901	2902	2903	2904	2905	2906	2907	2908	2909	2910	2911	2912	2913	2914	2915	2916	2917	2918	2919	2920	2921	2922	2923	2924	2925	2926	2927	2928	2929	2930	2931	2932	2933	2934	2935	2936	2937	2938	2939	2940	2941	2942	2943	2944	2945	2946	2947	2948	2949	2950
0.2	2851	2852	2853	2854	2855	2856	2857	2858	2859	2860	2861	2862	2863	2864	2865	2866	2867	2868	2869	2870	2871	2872	2873	2874	2875	2876	2877	2878	2879	2880	2881	2882	2883	2884	2885	2886	2887	2888	2889	2890	2891	2892	2893	2894	2895	2896	2897	2898	2899	2900
0.1	2801	2802	2803	2804	2805	2806	2807	2808	2809	2810	2811	2812	2813	2814	2815	2816	2817	2818	2819	2820	2821	2822	2823	2824	2825	2826	2827	2828	2829	2830	2831	2832	2833	2834	2835	2836	2837	2838	2839	2840	2841	2842	2843	2844	2845	2846	2847	2848	2849	2850

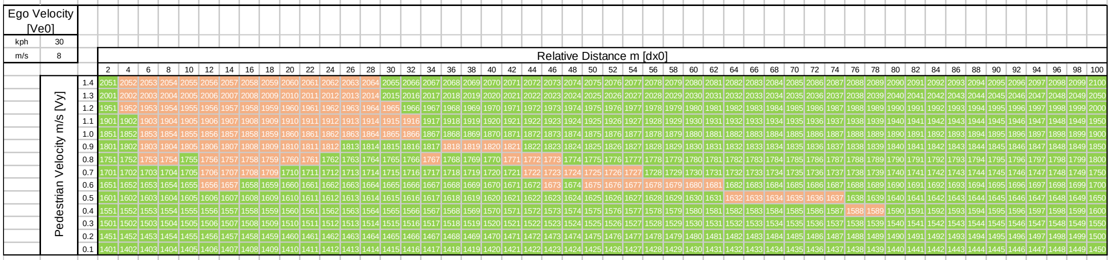
Ego Velocity [Ve0]
kph 60
m/s 17

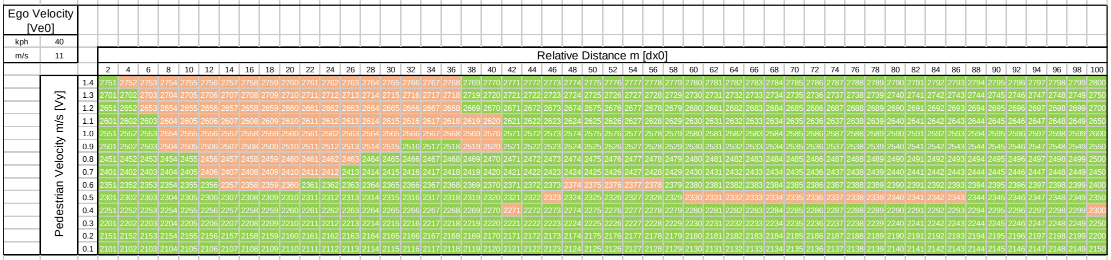
	Relative Distance m [dx0]																																																
Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	4151	4152	4153	4154	4155	4156	4157	4158	4159	4160	4161	4162	4163	4164	4165	4166	4167	4168	4169	4170	4171	4172	4173	4174	4175	4176	4177	4178	4179	4180	4181	4182	4183	4184	4185	4186	4187	4188	4189	4190	4191	4192	4193	4194	4195	4196	4197	4198	4199	4200
1.3	4101	4102	4103	4104	4105	4106	4107	4108	4109	4110	4111	4112	4113	4114	4115	4116	4117	4118	4119	4120	4121	4122	4123	4124	4125	4126	4127	4128	4129	4130	4131	4132	4133	4134	4135	4136	4137	4138	4139	4140	4141	4142	4143	4144	4145	4146	4147	4148	4149	4150
1.2	4051	4052	4053	4054	4055	4056	4057	4058	4059	4060	4061	4062	4063	4064	4065	4066	4067	4068	4069	4070	4071	4072	4073	4074	4075	4076	4077	4078	4079	4080	4081	4082	4083	4084	4085	4086	4087	4088	4089	4090	4091	4092	4093	4094	4095	4096	4097	4098	4099	4100
1.1	4001	4002	4003	4004	4005	4006	4007	4008	4009	4010	4011	4012	4013	4014	4015	4016	4017	4018	4019	4020	4021	4022	4023	4024	4025	4026	4027	4028	4029	4030	4031	4032	4033	4034	4035	4036	4037	4038	4039	4040	4041	4042	4043	4044	4045	4046	4047	4048	4049	4050
1.0	3951	3952	3953	3954	3955	3956	3957	3958	3959	3960	3961	3962	3963	3964	3965	3966	3967	3968	3969	3970	3971	3972	3973	3974	3975	3976	3977	3978	3979	3980	3981	3982	3983	3984	3985	3986	3987	3988	3989	3990	3991	3992	3993	3994	3995	3996	3997	3998	3999	4000
0.9	3901	3902	3903	3904	3905	3906	3907	3908	3909	3910	3911	3912	3913	3914	3915	3916	3917	3918	3919	3920	3921	3922	3923	3924	3925	3926	3927	3928	3929	3930	3931	3932	3933	3934	3935	3936	3937	3938	3939	3940	3941	3942	3943	3944	3945	3946	3947	3948	3949	3950
0.8	3851	3852	3853	3854	3855	3856	3857	3858	3859	3860	3861	3862	3863	3864	3865	3866	3867	3868	3869	3870	3871	3872	3873	3874	3875	3876	3877	3878	3879	3880	3881	3882	3883	3884	3885	3886	3887	3888	3889	3890	3891	3892	3893	3894	3895	3896	3897	3898	3899	3900
0.7	3801	3802	3803	3804	3805	3806	3807	3808	3809	3810	3811	3812	3813	3814	3815	3816	3817	3818	3819	3820	3821	3822	3823	3824	3825	3826	3827	3828	3829	3830	3831	3832	3833	3834	3835	3836	3837	3838	3839	3840	3841	3842	3843	3844	3845	3846	3847	3848	3849	3850
0.6	3751	3752	3753	3754	3755	3756	3757	3758	3759	3760	3761	3762	3763	3764	3765	3766	3767	3768	3769	3770	3771	3772	3773	3774	3775	3776	3777	3778	3779	3780	3781	3782	3783	3784	3785	3786	3787	3788	3789	3790	3791	3792	3793	3794	3795	3796	3797	3798	3799	3800
0.5	3701	3702	3703	3704	3705	3706	3707	3708	3709	3710	3711	3712	3713	3714	3715	3716	3717	3718	3719	3720	3721	3722	3723	3724	3725	3726	3727	3728	3729	3730	3731	3732	3733	3734	3735	3736	3737	3738	3739	3740	3741	3742	3743	3744	3745	3746	3747	3748	3749	3750
0.4	3651	3652	3653	3654	3655	3656	3657	3658	3659	3660	3661	3662	3663	3664	3665	3666	3667	3668	3669	3670	3671	3672	3673	3674	3675	3676	3677	3678	3679	3680	3681	3682	3683	3684	3685	3686	3687	3688	3689	3690	3691	3692	3693	3694	3695	3696	3697	3698	3699	3700
0.3	3601	3602	3603	3604	3605	3606	3607	3608	3609	3610	3611	3612	3613	3614	3615	3616	3617	3618	3619	3620	3621	3622	3623	3624	3625	3626	3627	3628	3629	3630	3631	3632	3633	3634	3635	3636	3637	3638	3639	3640	3641	3642	3643	3644	3645	3646	3647	3648	3649	3650
0.2	3551	3552	3553	3554	3555	3556	3557	3558	3559	3560	3561	3562	3563	3564	3565	3566	3567	3568	3569	3570	3571	3572	3573	3574	3575	3576	3577	3578	3579	3580	3581	3582	3583	3584	3585	3586	3587	3588	3589	3590	3591	3592	3593	3594	3595	3596	3597	3598	3599	3600
0.1	3501	3502	3503	3504	3505	3506	3507	3508	3509	3510	3511	3512	3513	3514	3515	3516	3517	3518	3519	3520	3521	3522	3523	3524	3525	3526	3527	3528	3529	3530	3531	3532	3533	3534	3535	3536	3537	3538	3539	3540	3541	3542	3543	3544	3545	3546	3547	3548	3549	3550

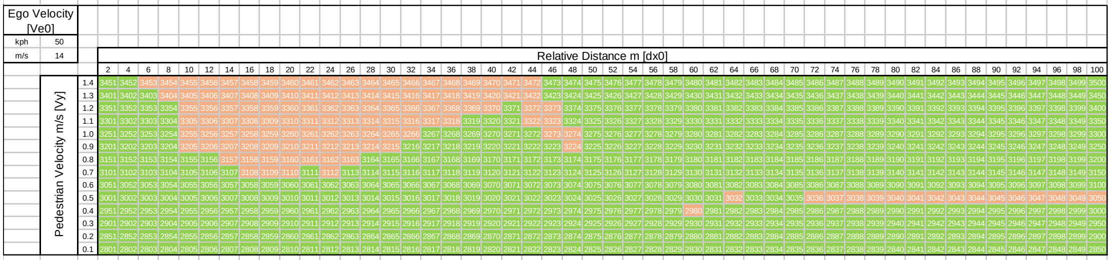
Figure A1-2 Lane Crossing Pedestrian Scenario Results for 0.8 Roadway Condition with 1st Configuration











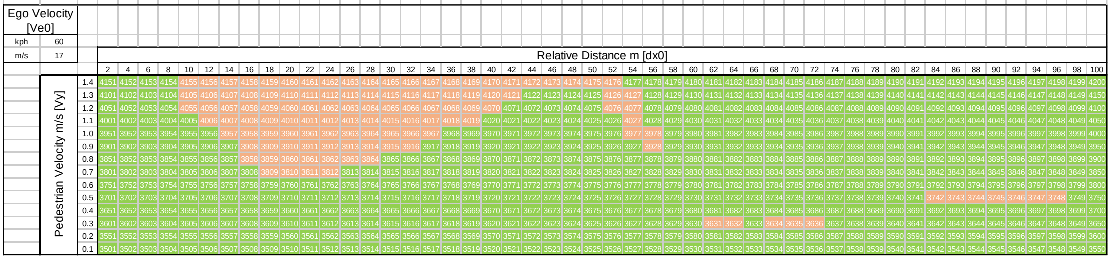
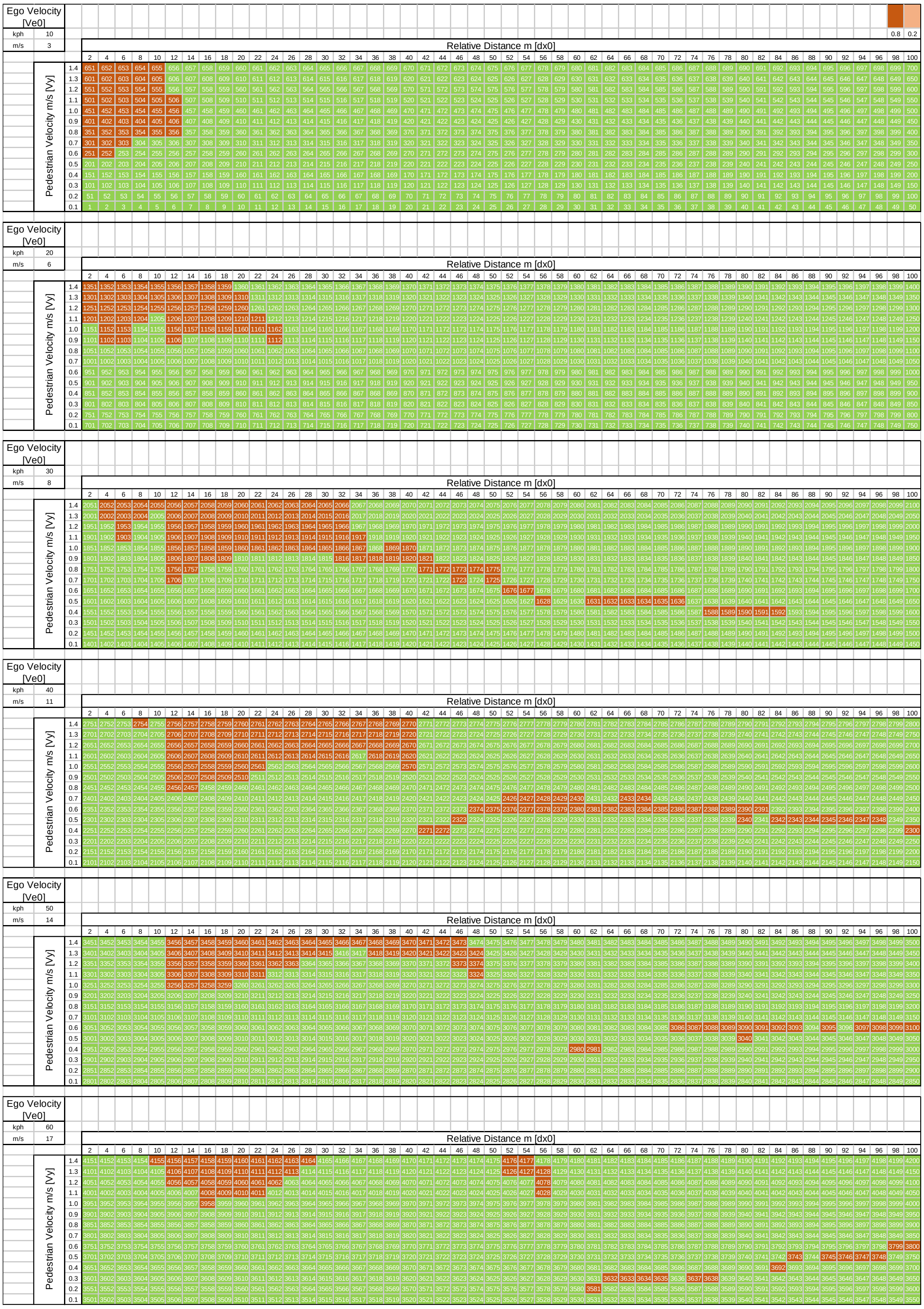


Figure A1-3 Lane Crossing Pedestrian Scenario Results for 0.2 Roadway Condition with 1st Configuration

A2. Lane crossing pedestrian – 2nd configuration's results



Ego Velocity [Ve0]		🟥	🟧
kph	10	0.8	0.2
m/s	3		

		Relative Distance m [dx0]																																																	
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
Pedestrian Velocity m/s [Vy]	1.4	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700
	1.3	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650
	1.2	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600
	1.1	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550
	1.0	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500
	0.9	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450
	0.8	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
	0.7	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350
	0.6	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300
	0.5	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250
	0.4	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
	0.3	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
	0.2	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
	0.1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

Ego Velocity [Ve0]	
kph	20
m/s	6

		Relative Distance m [dx0]																																																	
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
Pedestrian Velocity m/s [Vy]	1.4	1351	1352	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362	1363	1364	1365	1366	1367	1368	1369	1370	1371	1372	1373	1374	1375	1376	1377	1378	1379	1380	1381	1382	1383	1384	1385	1386	1387	1388	1389	1390	1391	1392	1393	1394	1395	1396	1397	1398	1399	1400
	1.3	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343	1344	1345	1346	1347	1348	1349	1350
	1.2	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296	1297	1298	1299	1300
	1.1	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250
	1.0	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200
	0.9	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150
	0.8	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100
	0.7	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050
	0.6	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000
	0.5	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950
	0.4	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900
	0.3	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850
	0.2	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800
	0.1	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750

Ego Velocity [Ve0]	
kph	30
m/s	8

		Relative Distance m [dx0]																																																	
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
Pedestrian Velocity m/s [Vy]	1.4	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
	1.3	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
	1.2	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	1.1	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
	1.0	1851	1852	1853	1854	1855	1856	1857	1858	1859	1860	1861	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900
	0.9	1801	1802	1803	1804	1805	1806	1807	1808	1809	1810	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826	1827	1828	1829	1830	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840	1841	1842	1843	1844	1845	1846	1847	1848	1849	1850
	0.8	1751	1752	1753	1754	1755	1756	1757	1758	1759	1760	1761	1762	1763	1764	1765	1766	1767	1768	1769	1770	1771	1772	1773	1774	1775	1776	1777	1778	1779	1780	1781	1782	1783	1784	1785	1786	1787	1788	1789	1790	1791	1792	1793	1794	1795	1796	1797	1798	1799	1800
	0.7	1701	1702	1703	1704	1705	1706	1707	1708	1709	1710	1711	1712	1713	1714	1715	1716	1717	1718	1719	1720	1721	1722	1723	1724	1725	1726	1727	1728	1729	1730	1731	1732	1733	1734	1735	1736	1737	1738	1739	1740	1741	1742	1743	1744	1745	1746	1747	1748	1749	1750
	0.6	1651	1652	1653	1654	1655	1656	1657	1658	1659	1660	1661	1662	1663	1664	1665	1666	1667	1668	1669	1670	1671	1672	1673	1674	1675	1676	1677	1678	1679	1680	1681	1682	1683	1684	1685	1686	1687	1688	1689	1690	1691	1692	1693	1694	1695	1696	1697	1698	1699	1700
	0.5	1601	1602	1603	1604	1605	1606	1607	1608	1609	1610	1611	1612	1613	1614	1615	1616	1617	1618	1619	1620	1621	1622	1623	1624	1625	1626	1627	1628	1629	1630	1631	1632	1633	1634	1635	1636	1637	1638	1639	1640	1641	1642	1643	1644	1645	1646	1647	1648	1649	1650
	0.4	1551	1552	1553	1554	1555	1556	1557	1558	1559	1560	1561	1562	1563	1564	1565	1566	1567	1568	1569	1570	1571	1572	1573	1574	1575	1576	1577	1578	1579	1580	1581	1582	1583	1584	1585	1586	1587	1588	1589	1590	1591	1592	1593	1594	1595	1596	1597	1598	1599	1600
	0.3	1501	1502	1503	1504	1505	1506	1507	1508	1509	1510	1511	1512	1513	1514	1515	1516	1517	1518	1519	1520	1521	1522	1523	1524	1525	1526	1527	1528	1529	1530	1531	1532	1533	1534	1535	1536	1537	1538	1539	1540	1541	1542	1543	1544	1545	1546	1547	1548	1549	1550
	0.2	1451	1452	1453	1454	1455	1456	1457	1458	1459	1460	1461	1462	1463	1464	1465	1466	1467	1468	1469	1470	1471	1472	1473	1474	1475	1476	1477	1478	1479	1480	1481	1482	1483	1484	1485	1486	1487	1488	1489	1490	1491	1492	1493	1494	1495	1496	1497	1498	1499	1500
	0.1	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423	1424	1425	1426	1427	1428	1429	1430	1431	1432	1433	1434	1435	1436	1437	1438	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448	1449	1450

Ego Velocity [Ve0]	
kph	40
m/s	11

		Relative Distance m [dx0]																																																	
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
Pedestrian Velocity m/s [Vy]	1.4	2751	2752	2753	2754	2755	2756	2757	2758	2759	2760	2761	2762	2763	2764	2765	2766	2767	2768	2769	2770	2771	2772	2773	2774	2775	2776	2777	2778	2779	2780	2781	2782	2783	2784	2785	2786	2787	2788	2789	2790	2791	2792	2793	2794	2795	2796	2797	2798	2799	2800
	1.3	2701	2702	2703	2704	2705	2706	2707	2708	2709	2710	2711	2712	2713	2714	2715	2716	2717	2718	2719	2720	2721	2722	2723	2724	2725	2726	2727	2728	2729	2730	2731	2732	2733	2734	2735	2736	2737	2738	2739	2740	2741	2742	2743	2744	2745	2746	2747	2748	2749	2750
	1.2	2651	2652	2653	2654	2655	2656	2657	2658	2659	2660	2661	2662	2663	2664	2665	2666	2667	2668	2669	2670	2671	2672	2673	2674	2675	2676	2677	2678	2679	2680	2681	2682	2683	2684	2685	2686	2687	2688	2689	2690	2691	2692	2693	2694	2695	2696	2697	2698	2699	2700
	1.1	2601	2602	2603	2604	2605	2606	2607	2608	2609	2610	2611	2612	2613	2614	2615	2616	2617	2618	2619	2620	2621	2622	2623	2624	2625	2626	2627	2628	2629	2630	2631	2632	2633	2634	2635	2636	2637	2638	2639	2640	2641	2642	2643	2644	2645	2646	2647	2648	2649	2650
	1.0	2551	2552	2553	2554	2555	2556	2557	2558	2559	2560	2561	2562	2563	2564	2565	2566	2567	2568	2569	2570	2571	2572	2573	2574	2575	2576	2577	2578	2579	2580	2581	2582	2583	2584	2585	2586	2587	2588	2589	2590	2591	2592	2593	2594	2595	2596	2597	2598	2599	2600
	0.9	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534	2535	2536	2537	2538	2539	2540	2541	2542	2543	2544	2545	2546	2547	2548	2549	2550
	0.8	2451	2452	2453	2454	2455	2456	2457	2458	2459	2460	2461	2462	2463	2464	2465	2466	2467	2468	2469	2470	2471	2472	2473	2474	2475	2476	2477	2478	2479	2480	2481	2482	2483	2484	2485	2486	2487	2488	2489	2490	2491	2492	2493	2494	2495	2496	2497	2498	2499	2500
	0.7	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450
	0.6	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400
	0.5	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350
	0.4	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300
	0.3	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250
	0.2	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200
	0.1	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150

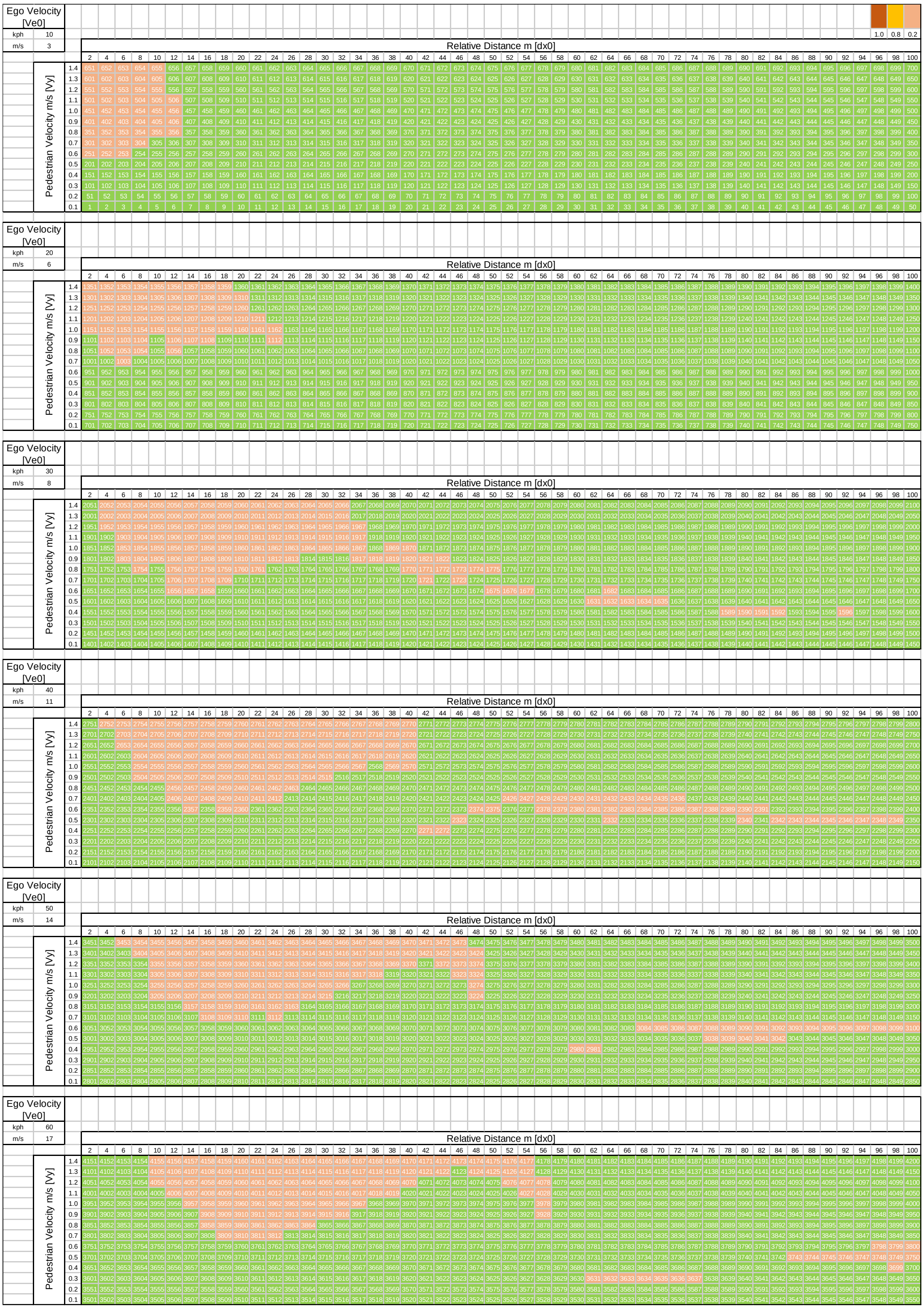
Ego Velocity [Ve0]	
kph	50
m/s	14

		Relative Distance m [dx0]																																																	
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
Pedestrian Velocity m/s [Vy]	1.4	3451	3452	3453	3454	3455	3456	3457	3458	3459	3460	3461	3462	3463	3464	3465	3466	3467	3468	3469	3470	3471	3472	3473	3474	3475	3476	3477	3478	3479	3480	3481	3482	3483	3484	3485	3486	3487	3488	3489	3490	3491	3492	3493	3494	3495	3496	3497	3498	3499	3500
	1.3	3401	3402	3403	3404	3405	3406	3407	3408	3409	3410	3411	3412	3413	3414	3415	3416	3417	3418	3419	3420	3421	3422	3423	3424	3425	3426	3427	3428	3429	3430	3431	3432	3433	3434	3435	3436	3437	3438	3439	3440	3441	3442	3443	3444	3445	3446	3447	3448	3449	3450
	1.2	3351	3352	3353	3354	3355	3356	3357	3358	3359	3360	3361	3362	3363	3364	3365	3366	3367	3368	3369	3370	3371	3372	3373	3374	3375	3376	3377	3378	3379	3380	3381	3382	3383	3384	3385	3386	3387	3388	3389	3390	3391	3392	3393	3394	3395	3396	3397	3398	3399	3400
	1.1	3301	3302	3303	3304	3305	3306	3307	3308	3309	3310	3311	3312	3313	3314	3315	3316	3317	3318	3319	3320	3321	3322	3323	3324	3325	3326	3327	3328	3329	3330	3331	3332	3333	3334	3335	3336	3337	3338	3339	3340	3341	3342	3343	3344	3345	3346	3347	3348	3349	3350
	1.0	3251	3252	3253	3254	3255	3256	3257	3258	3259	3260	3261	3262	3263	3264	3265	3266	3267	3268	3269	3270	3271	3272	3273	3274	3275	3276	3277	3278	3279	3280	3281	3282	3283	3284	3285	3286	3287	3288	3289	3290	3291	3292	3293	3294	3295	3296	3297	3298	3299	3300
	0.9	3201	3202	3203	3204	3205	3206	3207	3208	3209	3210	3211	3212	3213	3214	3215	3216	3217	3218	3219	3220	3221	3222	3223	3224	3225	3226	3227	3228	3229	3230	3231	3232	3233	3234	3235	3236	3237	3238	3239	3240	3241	3242	3243	3244	3245	3246	3247	3248	3249	3250
	0.8	3151	3152	3153	3154	3155	3156	3157	3158	3159	3160	3161	3162	3163	3164	3165	3166	3167	3168	3169	3170	3171	3172	3173	3174	3175	3176	3177	3178	3179	3180	3181	3182	3183	3184	3185	3186	3187	3188	3189	3190	3191	3192	3193	3194	3195	3196	3197	3198	3199	3200
	0.7	3101	3102	3103	3104	3105	3106	3107	3108	3109	3110	3111	3112	3113	3114	3115	3116	3117	3118	3119	3120	3121	3122	3123	3124	3125	3126	3127	3128	3129	3130	3131	3132	3133	3134	3135	3136	3137	3138	3139	3140	3141	3142	3143	3144	3145	3146	3147	3148	3149	3150
	0.6	3051	3052	3053	3054	3055	3056	3057	3058	3059	3060	3061	3062	3063	3064	3065	3066	3067	3068	3069	3070	3071	3072	3073	3074	3075	3076	3077	3078	3079	3080	3081	3082	3083	3084	3085	3086	3087	3088	3089	3090	3091	3092	3093	3094	3095	3096	3097	3098	3099	3100
	0.5	3001	3002	3003	3004	3005	3006	3007	3008	3009	3010	3011	3012	3013	3014	3015	3016	3017	3018	3019	3020	3021	3022	3023	3024	3025	3026	3027	3028	3029	3030	3031	3032	3033	3034	3035	3036	3037	3038	3039	3040	3041	3042	3043	3044	3045	3046	3047	3048	3049	3050
	0.4	2951	2952	2953	2954	2955	2956	2957	2958	2959	2960	2961	2962	2963	2964	2965	2966	2967	2968	2969	2970	2971	2972	2973	2974	2975	2976	2977	2978	2979	2980	2981	2982	2983	2984	2985	2986	2987	2988	2989	2990	2991	2992	2993	2994	2995	2996	2997	2998	2999	3000
	0.3	2901	2902	2903	2904	2905	2906	2907	2908	2909	2910	2911	2912	2913	2914	2915	2916	2917	2918	2919	2920	2921	2922	2923	2924	2925	2926	2927	2928	2929	2930	2931	2932	2933	2934	2935	2936	2937	2938	2939	2940	2941	2942	2943	2944	2945	2946	2947	2948	2949	2950
	0.2	2851	2852	2853	2854	2855	2856	2857	2858	2859	2860	2861	2862	2863	2864	2865	2866	2867	2868	2869	2870	2871	2872	2873	2874	2875	2876	2877	2878	2879	2880	2881	2882	2883	2884	2885	2886	2887	2888	2889	2890	2891	2892	2893	2894	2895	2896	2897	2898	2899	2900
	0.1	2801	2802	2803	2804	2805	2806	2807	2808	2809	2810	2811	2812	2813	2814	2815	2816	2817	2818	2819	2820	2821	2822	2823	2824	2825	2826	2827	2828	2829	2830	2831	2832	2833	2834	2835	2836	2837	2838	2839	2840	2841	2842	2843	2844	2845	2846	2847	2848	2849	2850

Ego Velocity [Ve0]	
kph	60
m/s	17

		Relative Distance m [dx0]																																																	
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
Pedestrian Velocity m/s [Vy]	1.4	4151	4152	4153	4154	4155	4156	4157	4158	4159	4160	4161	4162	4163	4164	4165	4166	4167	4168	4169	4170	4171	4172	4173	4174	4175	4176	4177	4178	4179	4180	4181	4182	4183	4184	4185	4186	4187	4188	4189	4190	4191	4192	4193	4194	4195	4196	4197	4198	4199	4200
	1.3	4101	4102	4103	4104	4105	4106	4107	4108	4109	4110	4111	4112	4113	4114	4115	4116	4117	4118	4119	4120	4121	4122	4123	4124	4125	4126	4127	4128	4129	4130	4131	4132	4133	4134	4135	4136	4137	4138	4139	4140	4141	4142	4143	4144	4145	4146	4147	4148	4149	4150
	1.2	4051	4052	4053	4054	4055	4056	4057	4058	4059	4060	4061	4062	4063	4064	4065	4066	4067	4068	4069	4070	4071	4072	4073	4074	4075	4076	4077	4078	4079	4080	4081	4082	4083	4084	4085	4086	4087	4088	4089	4090	4091	4092	4093	4094	4095	4096	4097	4098	4099	4100
	1.1	4001	4002	4003	4004	4005	4006	4007	4008	4009	4010	4011	4012	4013	4014	4015	4016	4017	4018	4019	4020	4021	4022	4023	4024	4025	4026	4027	4028	4029	4030	4031	4032	4033	4034	4035	4036	4037	4038	4039	4040	4041	4042	4043	4044	4045	4046	4047	4048	4049	4050
	1.0	3951	3952	3953	3954	3955	3956	3957	3958	3959	3960	3961	3962	3963	3964	3965	3966	3967	3968	3969	3970	3971	3972	3973	3974	3975	3976	3977	3978	3979	3980	3981	3982	3983	3984	3985	3986	3987	3988	3989	3990	3991	3992	3993	3994	3995	3996	3997	3998	3999	4000
	0.9	3901	3902	3903	3904	3905	3906	3907	3908	3909	3910	3911	3912	3913	3914	3915	3916	3917	3918	3919	3920	3921	3922	3923	3924	3925	3926	3927	3928	3929	3930	3931	3932	3933	3934	3935	3936	3937	3938	3939	3940	3941	3942	3943	3944	3945	3946	3947	3948	3949	3950
	0.8	3851	3852	3853	3854	3855	3856	3857	3858	3859	3860	3861	3862	3863	3864	3865	3866	3867	3868	3869	3870	3871	3872	3873	3874	3875	3876	3877	3878	3879	3880	3881	3882	3883	3884	3885	3886	3887	3888	3889	3890	3891	3892	3893	3894	3895	3896	3897	3898	3899	3900
	0.7	3801	3802	3803	3804	3805	3806	3807	3808	3809	3810	3811	3812	3813	3814	3815	3816	3817	3818	3819	3820	3821	3822	3823	3824	3825	3826	3827	3828	3829	3830	3831	3832	3833	3834	3835	3836	3837	3838	3839	3840	3841	3842	3843	3844	3845	3846	3847	3848	3849	3850
	0.6	3751	3752	3753	3754	3755	3756	3757	3758	3759	3760	3761	3762	3763	3764	3765	3766	3767	3768	3769	3770	3771	3772	3773	3774	3775	3776	3777	3778	3779	3780	3781	3782	3783	3784	3785	3786	3787	3788	3789	3790	3791	3792	3793	3794	3795	3796	3797	3798	3799	3800
	0.5	3701	3702	3703	3704	3705	3706	3707	3708	3709	3710	3711	3712	3713	3714	3715	3716	3717	3718	3719	3720	3721	3722	3723	3724	3725	3726	3727	3728	3729	3730	3731	3732	3733	3734	3735	3736	3737	3738	3739	3740	3741	3742	3743	3744	3745	3746	3747	3748	3749	3750
	0.4	3651	3652	3653	3654	3655	3656	3657	3658	3659	3660	3661	3662	3663	3664	3665	3666	3667	3668	3669	3670	3671	3672	3673	3674	3675	3676	3677	3678	3679	3680	3681	3682	3683	3684	3685	3686	3687	3688	3689	3690	3691	3692	3693	3694	3695	3696	3697	3698	3699	3700
	0.3	3601	3602	3603	3604	3605	3606	3607	3608	3609	3610	3611	3612	3613	3614	3615	3616	3617	3618	3619	3620	3621	3622	3623	3624	3625	3626	3627	3628	3629	3630	3631	3632	3633	3634	3635	3636	3637	3638	3639	3640	3641	3642	3643	3644	3645	3646	3647	3648	3649	3650
	0.2	3551	3552	3553	3554	3555	3556	3557	3558	3559	3560	3561	3562	3563	3564	3565	3566	3567	3568	3569	3570	3571	3572	3573	3574	3575	3576	3577	3578	3579	3580	3581	3582	3583	3584	3585	3586	3587	3588	3589	3590	3591	3592	3593	3594	3595	3596	3597	3598	3599	3600
	0.1	3501	3502	3503	3504	3505	3506	3507	3508	3509	3510	3511	3512	3513	3514	3515	3516	3517	3518	3519	3520	3521	3522	3523	3524	3525	3526	3527	3528	3529	3530	3531	3532	3533	3534	3535	3536	3537	3538	3539	3540	3541	3542	3543	3544	3545	3546	3547	3548	3549	3550

Figure A2-1 Lane Crossing Pedestrian Scenario Results for 0.8 Roadway Condition with 2nd Configuration



Ego Velocity [Ve0]
kph 10
m/s 3

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700
1.3	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650
1.2	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600
1.1	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550
1.0	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500
0.9	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450
0.8	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
0.7	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350
0.6	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300
0.5	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250
0.4	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
0.3	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
0.2	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
0.1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

Ego Velocity [Ve0]
kph 20
m/s 6

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	1351	1352	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362	1363	1364	1365	1366	1367	1368	1369	1370	1371	1372	1373	1374	1375	1376	1377	1378	1379	1380	1381	1382	1383	1384	1385	1386	1387	1388	1389	1390	1391	1392	1393	1394	1395	1396	1397	1398	1399	1400
1.3	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343	1344	1345	1346	1347	1348	1349	1350
1.2	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296	1297	1298	1299	1300
1.1	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250
1.0	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200
0.9	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150
0.8	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100
0.7	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050
0.6	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000
0.5	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950
0.4	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900
0.3	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850
0.2	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800
0.1	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750

Ego Velocity [Ve0]
kph 30
m/s 8

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
1.3	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1.2	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1.1	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
1.0	1851	1852	1853	1854	1855	1856	1857	1858	1859	1860	1861	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900
0.9	1801	1802	1803	1804	1805	1806	1807	1808	1809	1810	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826	1827	1828	1829	1830	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840	1841	1842	1843	1844	1845	1846	1847	1848	1849	1850
0.8	1751	1752	1753	1754	1755	1756	1757	1758	1759	1760	1761	1762	1763	1764	1765	1766	1767	1768	1769	1770	1771	1772	1773	1774	1775	1776	1777	1778	1779	1780	1781	1782	1783	1784	1785	1786	1787	1788	1789	1790	1791	1792	1793	1794	1795	1796	1797	1798	1799	1800
0.7	1701	1702	1703	1704	1705	1706	1707	1708	1709	1710	1711	1712	1713	1714	1715	1716	1717	1718	1719	1720	1721	1722	1723	1724	1725	1726	1727	1728	1729	1730	1731	1732	1733	1734	1735	1736	1737	1738	1739	1740	1741	1742	1743	1744	1745	1746	1747	1748	1749	1750
0.6	1651	1652	1653	1654	1655	1656	1657	1658	1659	1660	1661	1662	1663	1664	1665	1666	1667	1668	1669	1670	1671	1672	1673	1674	1675	1676	1677	1678	1679	1680	1681	1682	1683	1684	1685	1686	1687	1688	1689	1690	1691	1692	1693	1694	1695	1696	1697	1698	1699	1700
0.5	1601	1602	1603	1604	1605	1606	1607	1608	1609	1610	1611	1612	1613	1614	1615	1616	1617	1618	1619	1620	1621	1622	1623	1624	1625	1626	1627	1628	1629	1630	1631	1632	1633	1634	1635	1636	1637	1638	1639	1640	1641	1642	1643	1644	1645	1646	1647	1648	1649	1650
0.4	1551	1552	1553	1554	1555	1556	1557	1558	1559	1560	1561	1562	1563	1564	1565	1566	1567	1568	1569	1570	1571	1572	1573	1574	1575	1576	1577	1578	1579	1580	1581	1582	1583	1584	1585	1586	1587	1588	1589	1590	1591	1592	1593	1594	1595	1596	1597	1598	1599	1600
0.3	1501	1502	1503	1504	1505	1506	1507	1508	1509	1510	1511	1512	1513	1514	1515	1516	1517	1518	1519	1520	1521	1522	1523	1524	1525	1526	1527	1528	1529	1530	1531	1532	1533	1534	1535	1536	1537	1538	1539	1540	1541	1542	1543	1544	1545	1546	1547	1548	1549	1550
0.2	1451	1452	1453	1454	1455	1456	1457	1458	1459	1460	1461	1462	1463	1464	1465	1466	1467	1468	1469	1470	1471	1472	1473	1474	1475	1476	1477	1478	1479	1480	1481	1482	1483	1484	1485	1486	1487	1488	1489	1490	1491	1492	1493	1494	1495	1496	1497	1498	1499	1500
0.1	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423	1424	1425	1426	1427	1428	1429	1430	1431	1432	1433	1434	1435	1436	1437	1438	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448	1449	1450

Ego Velocity [Ve0]
kph 40
m/s 11

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	2751	2752	2753	2754	2755	2756	2757	2758	2759	2760	2761	2762	2763	2764	2765	2766	2767	2768	2769	2770	2771	2772	2773	2774	2775	2776	2777	2778	2779	2780	2781	2782	2783	2784	2785	2786	2787	2788	2789	2790	2791	2792	2793	2794	2795	2796	2797	2798	2799	2800
1.3	2701	2702	2703	2704	2705	2706	2707	2708	2709	2710	2711	2712	2713	2714	2715	2716	2717	2718	2719	2720	2721	2722	2723	2724	2725	2726	2727	2728	2729	2730	2731	2732	2733	2734	2735	2736	2737	2738	2739	2740	2741	2742	2743	2744	2745	2746	2747	2748	2749	2750
1.2	2651	2652	2653	2654	2655	2656	2657	2658	2659	2660	2661	2662	2663	2664	2665	2666	2667	2668	2669	2670	2671	2672	2673	2674	2675	2676	2677	2678	2679	2680	2681	2682	2683	2684	2685	2686	2687	2688	2689	2690	2691	2692	2693	2694	2695	2696	2697	2698	2699	2700
1.1	2601	2602	2603	2604	2605	2606	2607	2608	2609	2610	2611	2612	2613	2614	2615	2616	2617	2618	2619	2620	2621	2622	2623	2624	2625	2626	2627	2628	2629	2630	2631	2632	2633	2634	2635	2636	2637	2638	2639	2640	2641	2642	2643	2644	2645	2646	2647	2648	2649	2650
1.0	2551	2552	2553	2554	2555	2556	2557	2558	2559	2560	2561	2562	2563	2564	2565	2566	2567	2568	2569	2570	2571	2572	2573	2574	2575	2576	2577	2578	2579	2580	2581	2582	2583	2584	2585	2586	2587	2588	2589	2590	2591	2592	2593	2594	2595	2596	2597	2598	2599	2600
0.9	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534	2535	2536	2537	2538	2539	2540	2541	2542	2543	2544	2545	2546	2547	2548	2549	2550
0.8	2451	2452	2453	2454	2455	2456	2457	2458	2459	2460	2461	2462	2463	2464	2465	2466	2467	2468	2469	2470	2471	2472	2473	2474	2475	2476	2477	2478	2479	2480	2481	2482	2483	2484	2485	2486	2487	2488	2489	2490	2491	2492	2493	2494	2495	2496	2497	2498	2499	2500
0.7	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450
0.6	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400
0.5	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350
0.4	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300
0.3	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250
0.2	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200
0.1	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150

Ego Velocity [Ve0]
kph 50
m/s 14

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	3451	3452	3453	3454	3455	3456	3457	3458	3459	3460	3461	3462	3463	3464	3465	3466	3467	3468	3469	3470	3471	3472	3473	3474	3475	3476	3477	3478	3479	3480	3481	3482	3483	3484	3485	3486	3487	3488	3489	3490	3491	3492	3493	3494	3495	3496	3497	3498	3499	3500
1.3	3401	3402	3403	3404	3405	3406	3407	3408	3409	3410	3411	3412	3413	3414	3415	3416	3417	3418	3419	3420	3421	3422	3423	3424	3425	3426	3427	3428	3429	3430	3431	3432	3433	3434	3435	3436	3437	3438	3439	3440	3441	3442	3443	3444	3445	3446	3447	3448	3449	3450
1.2	3351	3352	3353	3354	3355	3356	3357	3358	3359	3360	3361	3362	3363	3364	3365	3366	3367	3368	3369	3370	3371	3372	3373	3374	3375	3376	3377	3378	3379	3380	3381	3382	3383	3384	3385	3386	3387	3388	3389	3390	3391	3392	3393	3394	3395	3396	3397	3398	3399	3400
1.1	3301	3302	3303	3304	3305	3306	3307	3308	3309	3310	3311	3312	3313	3314	3315	3316	3317	3318	3319	3320	3321	3322	3323	3324	3325	3326	3327	3328	3329	3330	3331	3332	3333	3334	3335	3336	3337	3338	3339	3340	3341	3342	3343	3344	3345	3346	3347	3348	3349	3350
1.0	3251	3252	3253	3254	3255	3256	3257	3258	3259	3260	3261	3262	3263	3264	3265	3266	3267	3268	3269	3270	3271	3272	3273	3274	3275	3276	3277	3278	3279	3280	3281	3282	3283	3284	3285	3286	3287	3288	3289	3290	3291	3292	3293	3294	3295	3296	3297	3298	3299	3300
0.9	3201	3202	3203	3204	3205	3206	3207	3208	3209	3210	3211	3212	3213	3214	3215	3216	3217	3218	3219	3220	3221	3222	3223	3224	3225	3226	3227	3228	3229	3230	3231	3232	3233	3234	3235	3236	3237	3238	3239	3240	3241	3242	3243	3244	3245	3246	3247	3248	3249	3250
0.8	3151	3152	3153	3154	3155	3156	3157	3158	3159	3160	3161	3162	3163	3164	3165	3166	3167	3168	3169	3170	3171	3172	3173	3174	3175	3176	3177	3178	3179	3180	3181	3182	3183	3184	3185	3186	3187	3188	3189	3190	3191	3192	3193	3194	3195	3196	3197	3198	3199	3200
0.7	3101	3102	3103	3104	3105	3106	3107	3108	3109	3110	3111	3112	3113	3114	3115	3116	3117	3118	3119	3120	3121	3122	3123	3124	3125	3126	3127	3128	3129	3130	3131	3132	3133	3134	3135	3136	3137	3138	3139	3140	3141	3142	3143	3144	3145	3146	3147	3148	3149	3150
0.6	3051	3052	3053	3054	3055	3056	3057	3058	3059	3060	3061	3062	3063	3064	3065	3066	3067	3068	3069	3070	3071	3072	3073	3074	3075	3076	3077	3078	3079	3080	3081	3082	3083	3084	3085	3086	3087	3088	3089	3090	3091	3092	3093	3094	3095	3096	3097	3098	3099	3100
0.5	3001	3002	3003	3004	3005	3006	3007	3008	3009	3010	3011	3012	3013	3014	3015	3016	3017	3018	3019	3020	3021	3022	3023	3024	3025	3026	3027	3028	3029	3030	3031	3032	3033	3034	3035	3036	3037	3038	3039	3040	3041	3042	3043	3044	3045	3046	3047	3048	3049	3050
0.4	2951	2952	2953	2954	2955	2956	2957	2958	2959	2960	2961	2962	2963	2964	2965	2966	2967	2968	2969	2970	2971	2972	2973	2974	2975	2976	2977	2978	2979	2980	2981	2982	2983	2984	2985	2986	2987	2988	2989	2990	2991	2992	2993	2994	2995	2996	2997	2998	2999	3000
0.3	2901	2902	2903	2904	2905	2906	2907	2908	2909	2910	2911	2912	2913	2914	2915	2916	2917	2918	2919	2920	2921	2922	2923	2924	2925	2926	2927	2928	2929	2930	2931	2932	2933	2934	2935	2936	2937	2938	2939	2940	2941	2942	2943	2944	2945	2946	2947	2948	2949	2950
0.2	2851	2852	2853	2854	2855	2856	2857	2858	2859	2860	2861	2862	2863	2864	2865	2866	2867	2868	2869	2870	2871	2872	2873	2874	2875	2876	2877	2878	2879	2880	2881	2882	2883	2884	2885	2886	2887	2888	2889	2890	2891	2892	2893	2894	2895	2896	2897	2898	2899	2900
0.1	2801	2802	2803	2804	2805	2806	2807	2808	2809	2810	2811	2812	2813	2814	2815	2816	2817	2818	2819	2820	2821	2822	2823	2824	2825	2826	2827	2828	2829	2830	2831	2832	2833	2834	2835	2836	2837	2838	2839	2840	2841	2842	2843	2844	2845	2846	2847	2848	2849	2850

Ego Velocity [Ve0]
kph 60
m/s 17

Relative Distance m [dx0]

Pedestrian Velocity m/s [Vy]	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
1.4	4151	4152	4153	4154	4155	4156	4157	4158	4159	4160	4161	4162	4163	4164	4165	4166	4167	4168	4169	4170	4171	4172	4173	4174	4175	4176	4177	4178	4179	4180	4181	4182	4183	4184	4185	4186	4187	4188	4189	4190	4191	4192	4193	4194	4195	4196	4197	4198	4199	4200
1.3	4101	4102	4103	4104	4105	4106	4107	4108	4109	4110	4111	4112	4113	4114	4115	4116	4117	4118	4119	4120	4121	4122	4123	4124	4125	4126	4127	4128	4129	4130	4131	4132	4133	4134	4135	4136	4137	4138	4139	4140	4141	4142	4143	4144	4145	4146	4147	4148	4149	4150
1.2	4051	4052	4053	4054	4055	4056	4057	4058	4059	4060	4061	4062	4063	4064	4065	4066	4067	4068	4069	4070	4071	4072	4073	4074	4075	4076	4077	4078	4079	4080	4081	4082	4083	4084	4085	4086	4087	4088	4089	4090	4091	4092	4093	4094	4095	4096	4097	4098	4099	4100
1.1	4001	4002	4003	4004	4005	4006	4007	4008	4009	4010	4011	4012	4013	4014	4015	4016	4017	4018	4019	4020	4021	4022	4023	4024	4025	4026	4027	4028	4029	4030	4031	4032	4033	4034	4035	4036	4037	4038	4039	4040	4041	4042	4043	4044	4045	4046	4047	4048	4049	4050
1.0	3951	3952	3953	3954	3955	3956	3957	3958	3959	3960	3961	3962	3963	3964	3965	3966	3967	3968	3969	3970	3971	3972	3973	3974	3975	3976	3977	3978	3979	3980	3981	3982	3983	3984	3985	3986	3987	3988	3989	3990	3991	3992	3993	3994	3995	3996	3997	3998	3999	4000
0.9	3901	3902	3903	3904	3905	3906	3907	3908	3909	3910	3911	3912	3913	3914	3915	3916	3917	3918	3919	3920	3921	3922	3923	3924	3925	3926	3927	3928	3929	3930	3931	3932	3933	3934	3935	3936	3937	3938	3939	3940	3941	3942	3943	3944	3945	3946	3947	3948	3949	3950
0.8	3851	3852	3853	3854	3855	3856	3857	3858	3859	3860	3861	3862	3863	3864	3865	3866	3867	3868	3869	3870	3871	3872	3873	3874	3875	3876	3877	3878	3879	3880	3881	3882	3883	3884	3885	3886	3887	3888	3889	3890	3891	3892	3893	3894	3895	3896	3897	3898	3899	3900
0.7	3801	3802	3803	3804	3805	3806	3807	3808	3809	3810	3811	3812	3813	3814	3815	3816	3817	3818	3819	3820	3821	3822	3823	3824	3825	3826	3827	3828	3829	3830	3831	3832	3833	3834	3835	3836	3837	3838	3839	3840	3841	3842	3843	3844	3845	3846	3847	3848	3849	3850
0.6	3751	3752	3753	3754	3755	3756	3757	3758	3759	3760	3761	3762	3763	3764	3765	3766	3767	3768	3769	3770	3771	3772	3773	3774	3775	3776	3777	3778	3779	3780	3781	3782	3783	3784	3785	3786	3787	3788	3789	3790	3791	3792	3793	3794	3795	3796	3797	3798	3799	3800
0.5	3701	3702	3703	3704	3705	3706	3707	3708	3709	3710	3711	3712	3713	3714	3715	3716	3717	3718	3719	3720	3721	3722	3723	3724	3725	3726	3727	3728	3729	3730	3731	3732	3733	3734	3735	3736	3737	3738	3739	3740	3741	3742	3743	3744	3745	3746	3747	3748	3749	3750
0.4	3651	3652	3653	3654	3655	3656	3657	3658	3659	3660	3661	3662	3663	3664	3665	3666	3667	3668	3669	3670	3671	3672	3673	3674	3675	3676	3677	3678	3679	3680	3681	3682	3683	3684	3685	3686	3687	3688	3689	3690	3691	3692	3693	3694	3695	3696	3697	3698	3699	3700
0.3	3601	3602	3603	3604	3605	3606	3607	3608	3609	3610	3611	3612	3613	3614	3615	3616	3617	3618	3619	3620	3621	3622	3623	3624	3625	3626	3627	3628	3629	3630	3631	3632	3633	3634	3635	3636	3637	3638	3639	3640	3641	3642	3643	3644	3645	3646	3647	3648	3649	3650
0.2	3551	3552	3553	3554	3555	3556	3557	3558	3559	3560	3561	3562	3563	3564	3565	3566	3567	3568	3569	3570	3571	3572	3573	3574	3575	3576	3577	3578	3579	3580	3581	3582	3583	3584	3585	3586	3587	3588	3589	3590	3591	3592	3593	3594	3595	3596	3597	3598	3599	3600
0.1	3501	3502	3503	3504	3505	3506	3507	3508	3509	3510	3511	3512	3513	3514	3515	3516	3517	3518	3519	3520	3521	3522	3523	3524	3525	3526	3527	3528	3529	3530	3531	3532	3533	3534	3535	3536	3537	3538	3539	3540	3541	3542	3543	3544	3545	3546	3547	3548	3549	3550

Figure A2-2 Lane Crossing Pedestrian Scenario Results for 0.2 Roadway Condition with 2nd Configuration

A3. Scenario Template

Table A3-1 Scenario Parameters Template

Scenario Parameters Template				
Operating conditions	Roadway	Number of lanes	✓	*the number of adjacent lanes in the same direction*
		Lane Width	✓	*the width of each lane*
		Roadway grade	x	*grade of the roadway*
		Roadway condition	✓	*tire-road coefficient of friction*
		Lane markings	x	*the type, color, width, visibility*
	Environmental conditions	Lighting conditions	x	*the amount of light and direction (day, night, etc.)*
		Weather conditions	x	*the amount, type and intensity of wind, rain, snow, etc.*
Initial condition	Initial velocity	V_{e0}	✓	*Subject vehicle (ego)*
		V_{o0}	✓	*Leading vehicle*
		V_{f0}	✓	*Vehicle in front of the leading vehicle*
	Initial distance	d_{x0}	✓	*distance in the longitudinal direction between leading vehicle*
		d_{y0}	✓	*distance in the lateral direction between leading vehicle*
		d_{y0_f}	✓	*distance in the longitudinal direction between the vehicle in front of the leading vehicle*
		d_{x0_f}	✓	*distance in the lateral direction between the vehicle in front of the leading vehicle*
		d_{fy}	✓	*width of the vehicle in front of the leading vehicle*
		d_{oy}	✓	*width of the leading vehicle*
		d_{ox}	✓	*length of the leading vehicle*
Vehicle motion	Lateral motion	V_y	✓	*leading vehicle lateral velocity*
	Deceleration	G_{x_max}	x	*maximum deceleration of the leading vehicle in G*
		dG/dt	x	*deceleration rate (jerk) of the leading vehicle*

A4. Simulation Framework

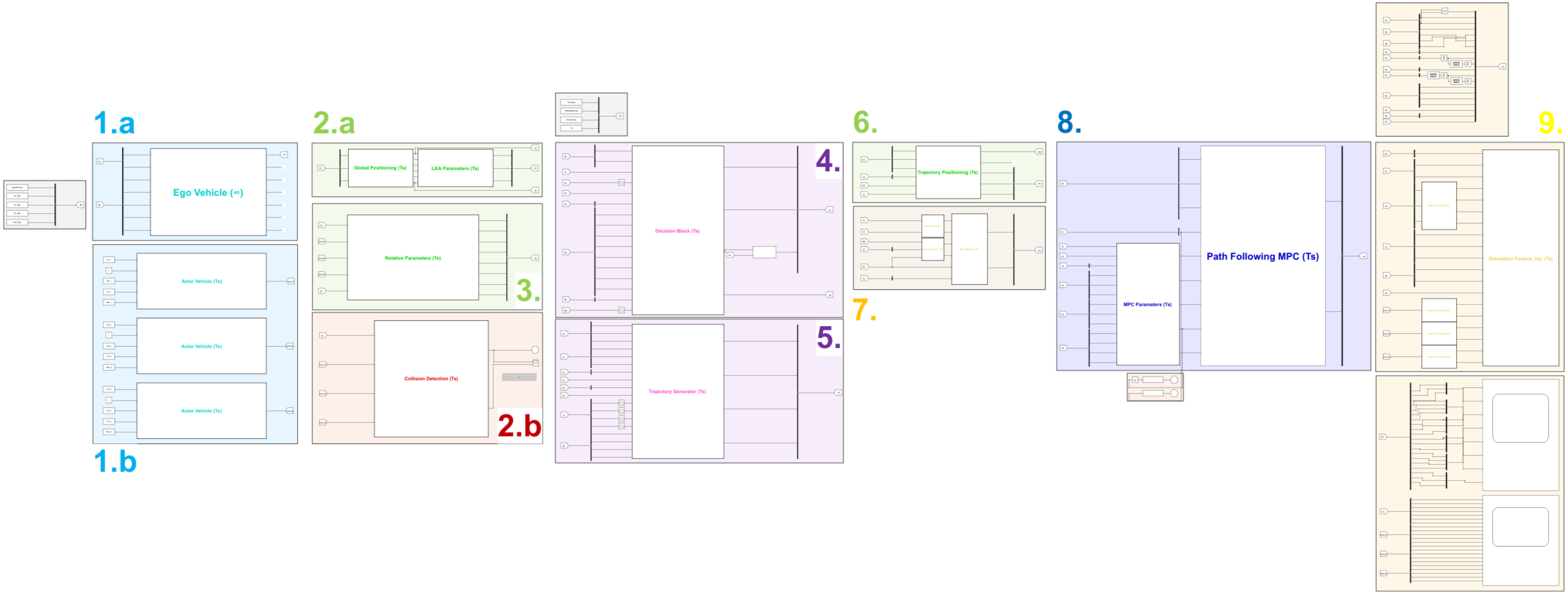


Figure A4-1 Simulation Environment from MATLAB® Simulink

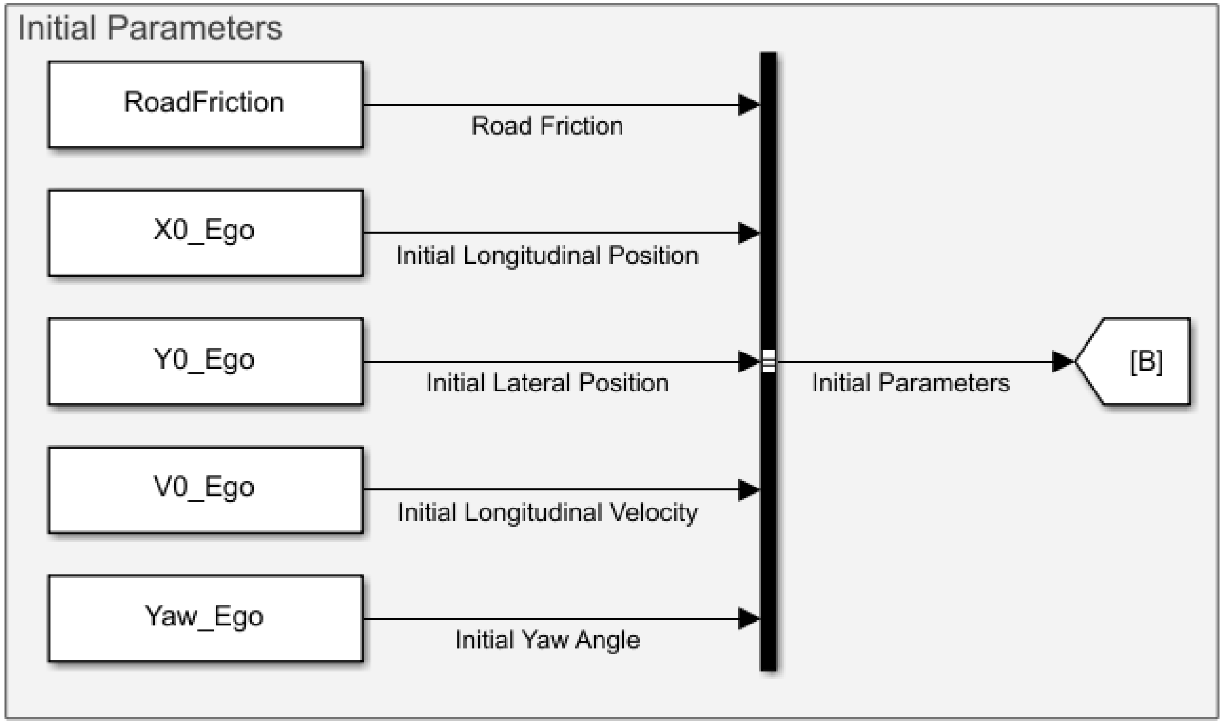


Figure A4-2 Initial Parameters Block

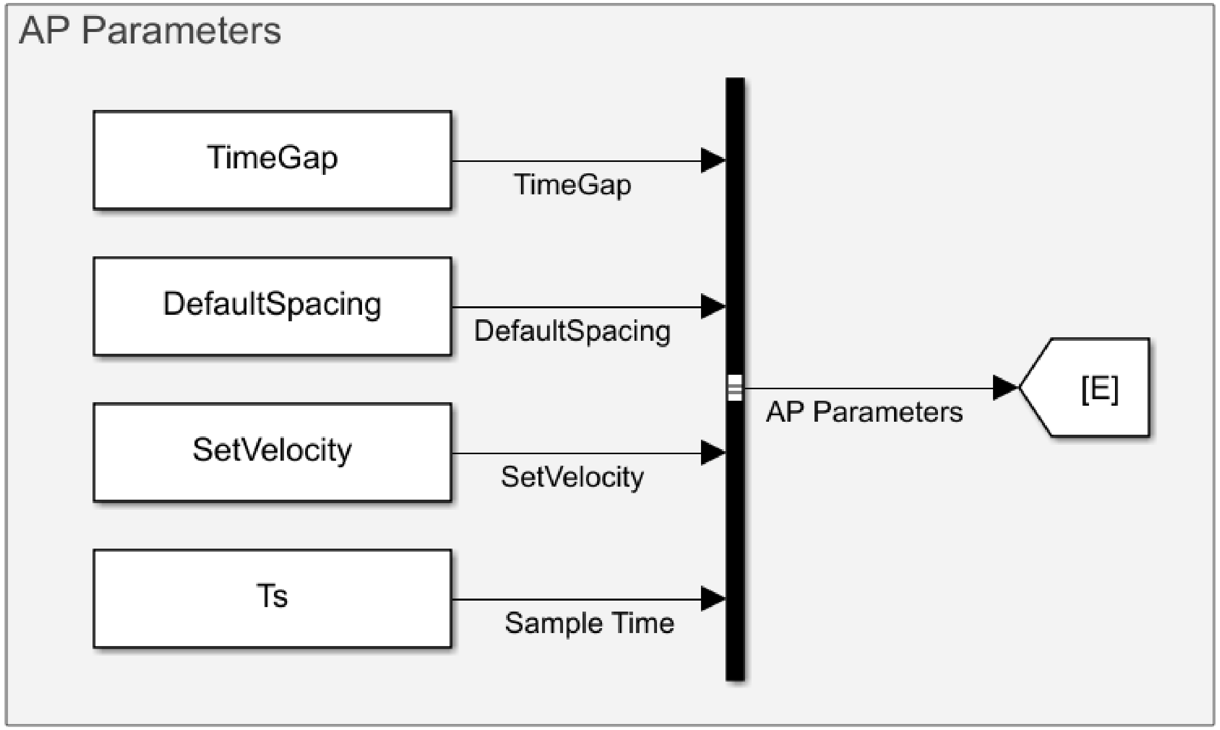


Figure A4-3 ADS Parameters Block

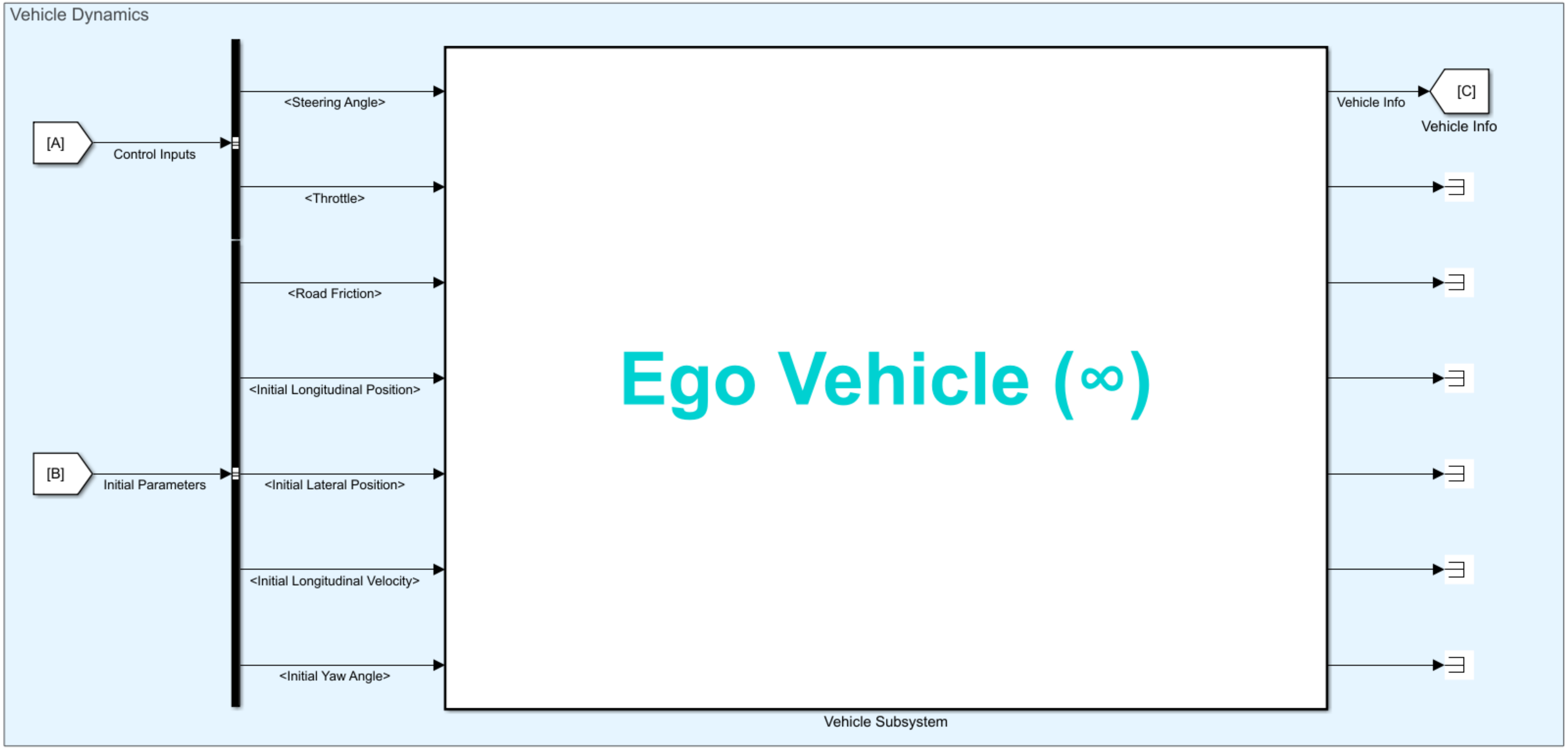


Figure A4-4 Vehicle Dynamics Block

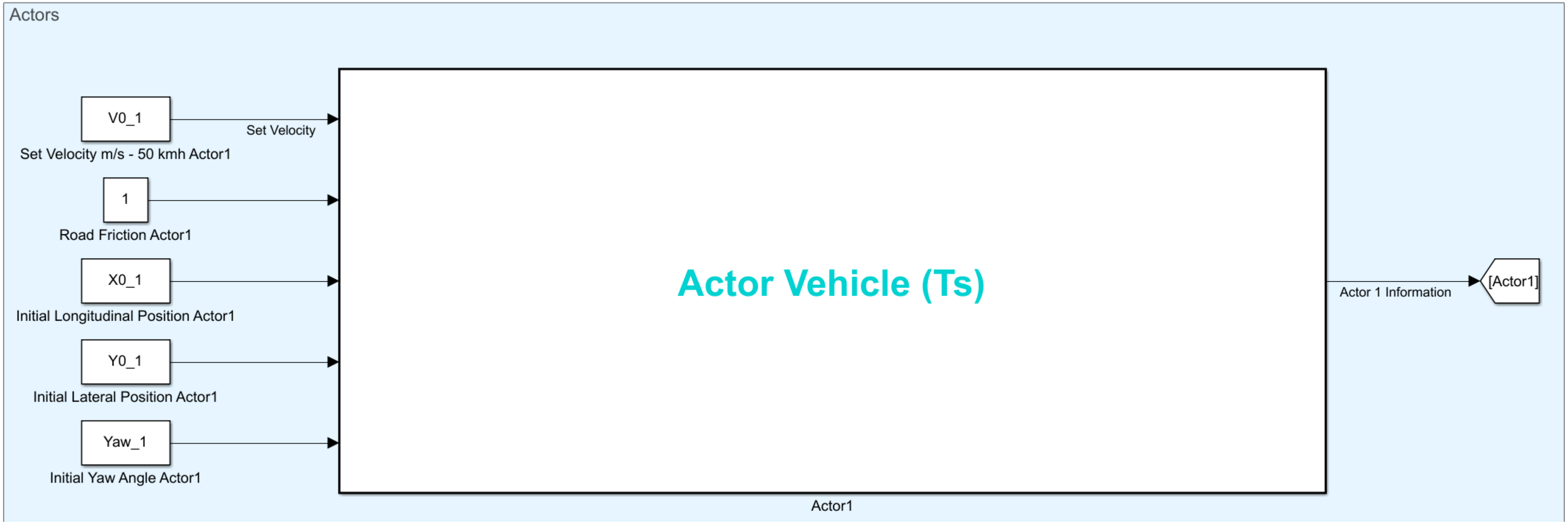


Figure A4-5 Actors Block

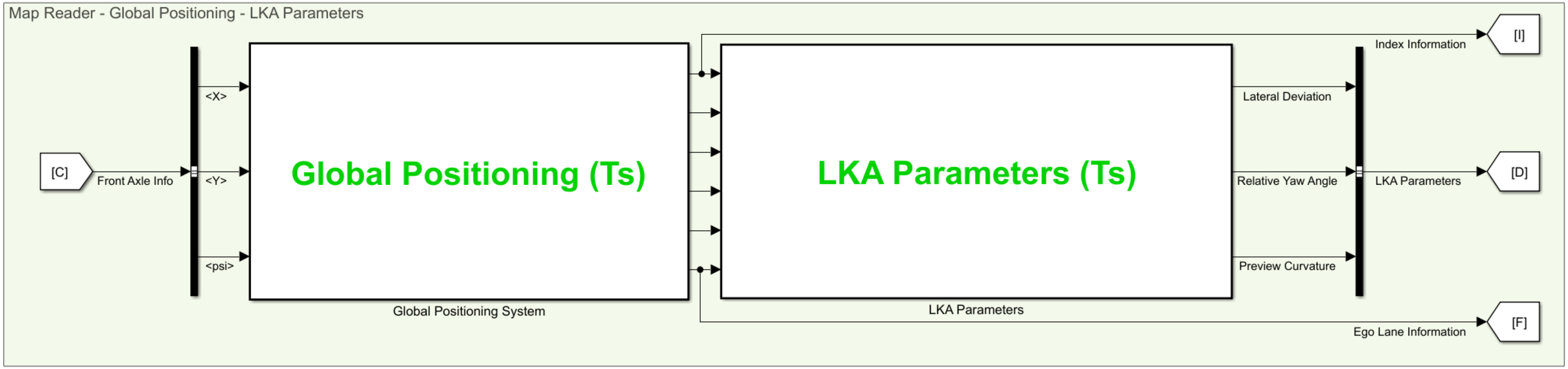


Figure A4-6 Global Positioning and LKA Parameters Sensors Block

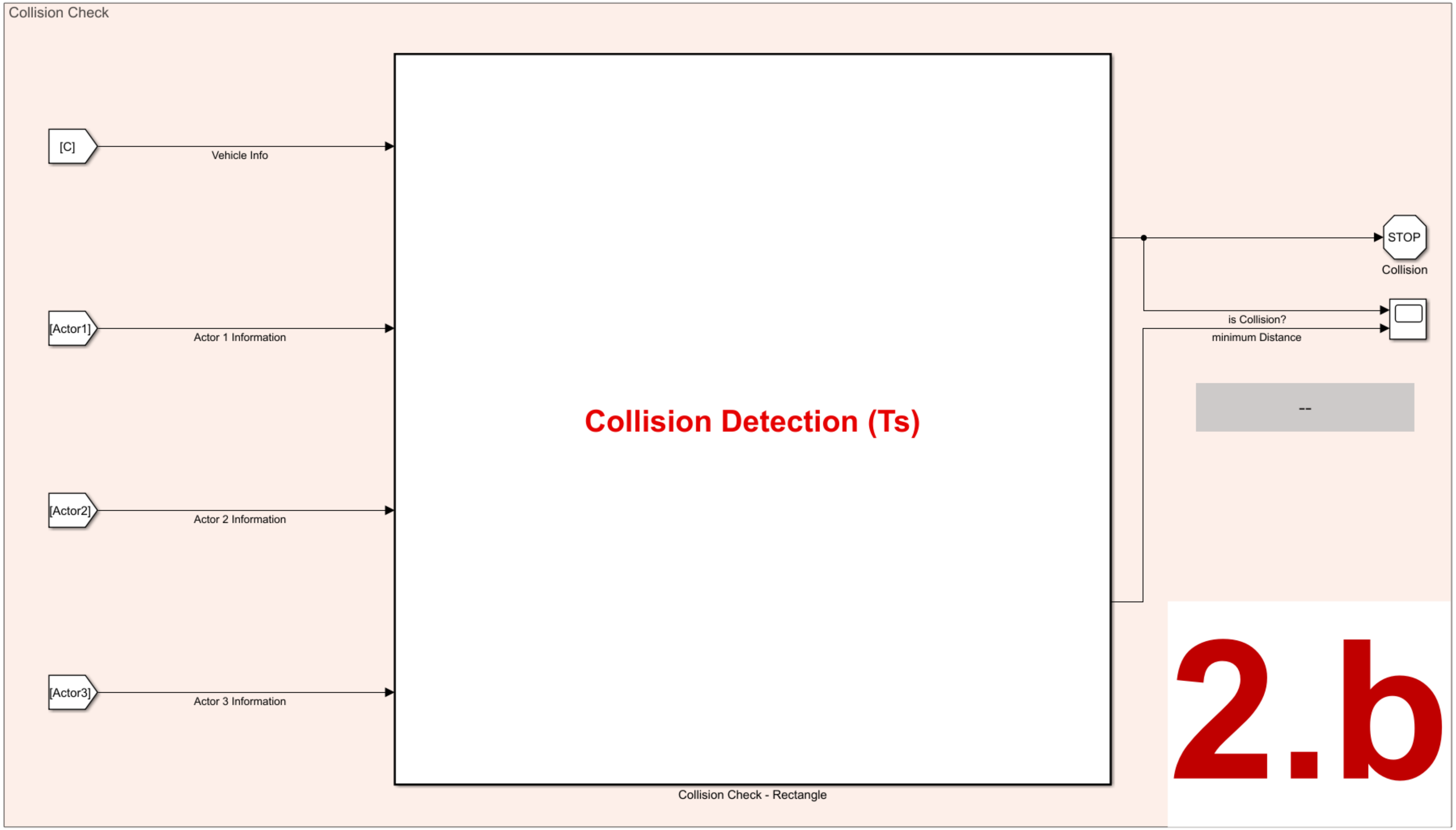


Figure A4-7 Collision Detection Block

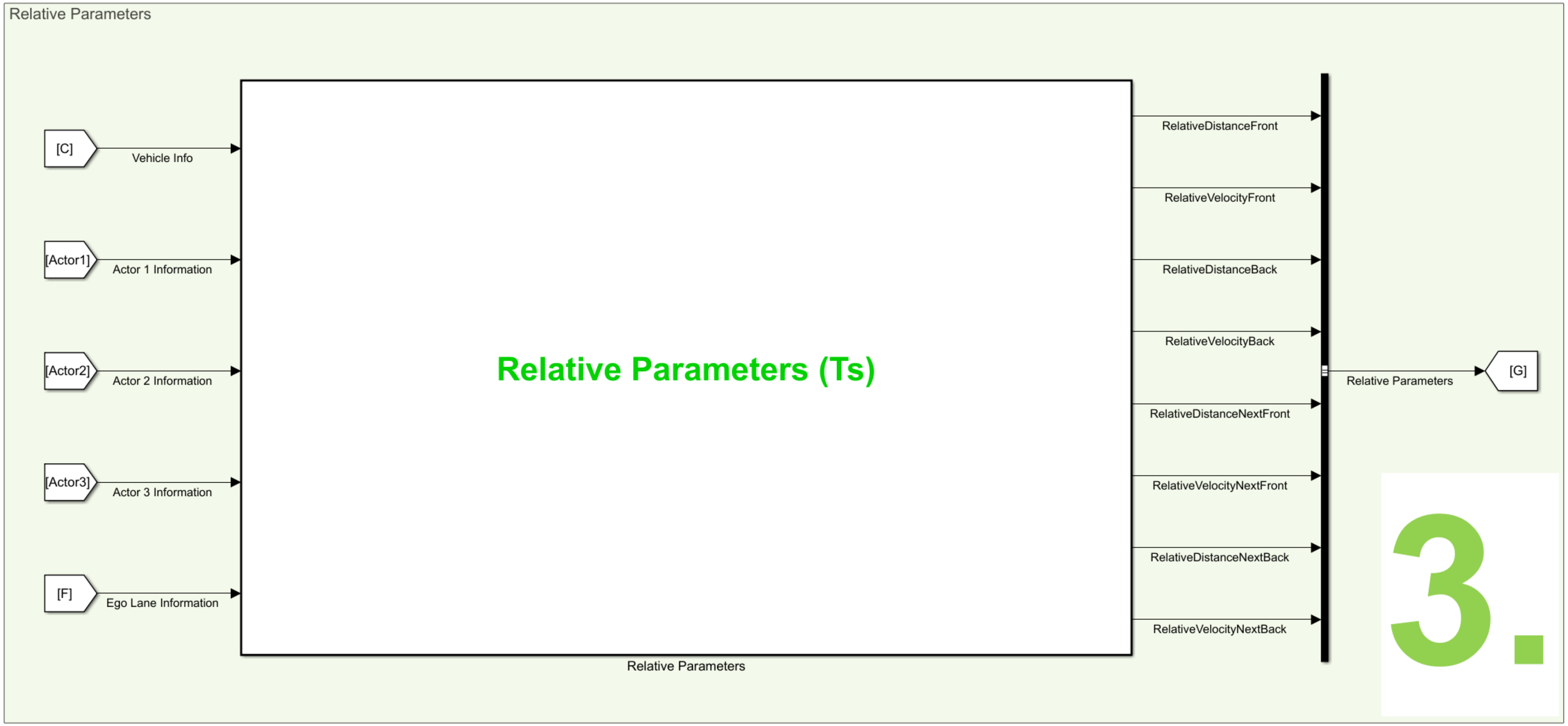


Figure A4-8 Relative Parameters Block

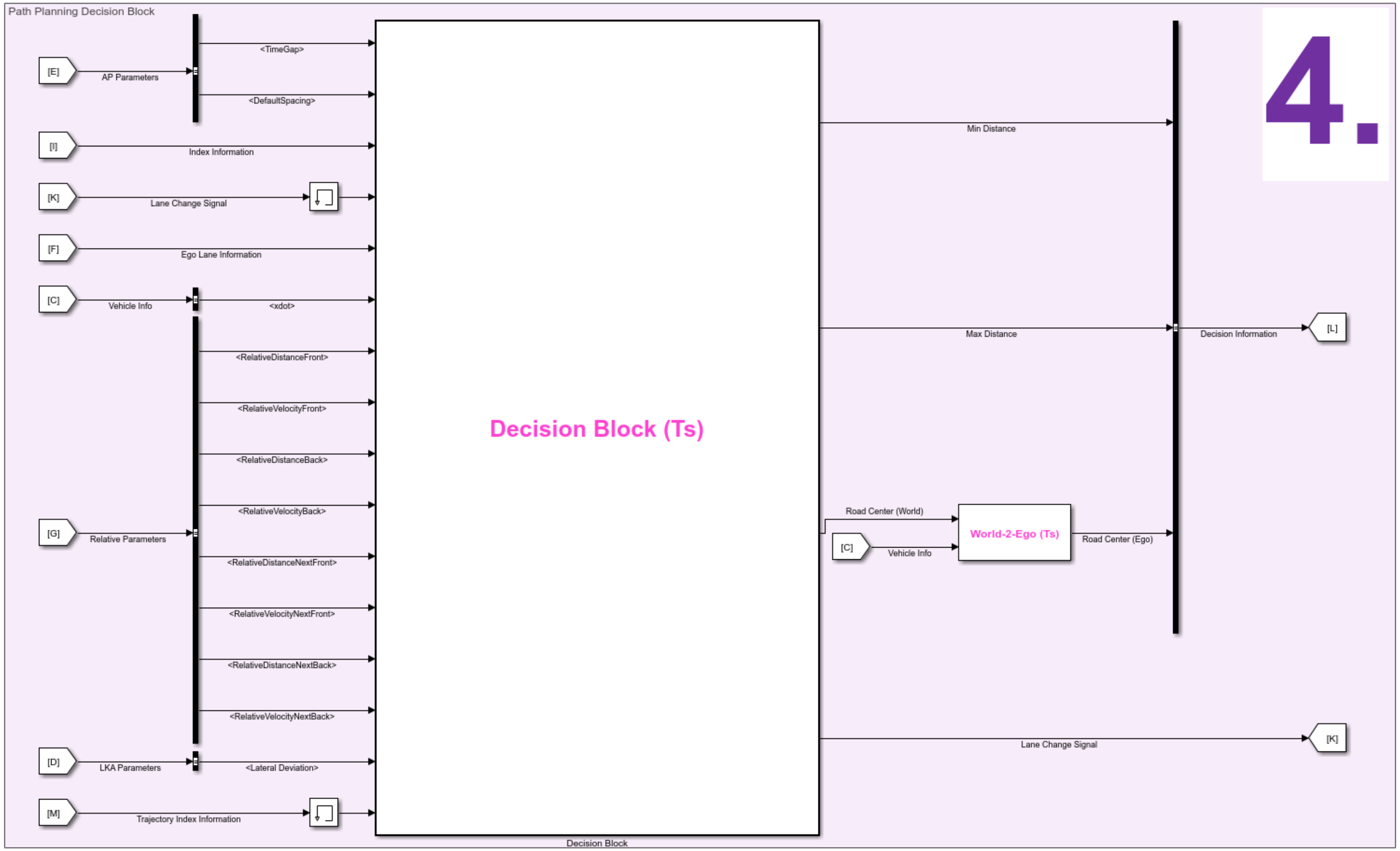


Figure A4-9 Decision Block

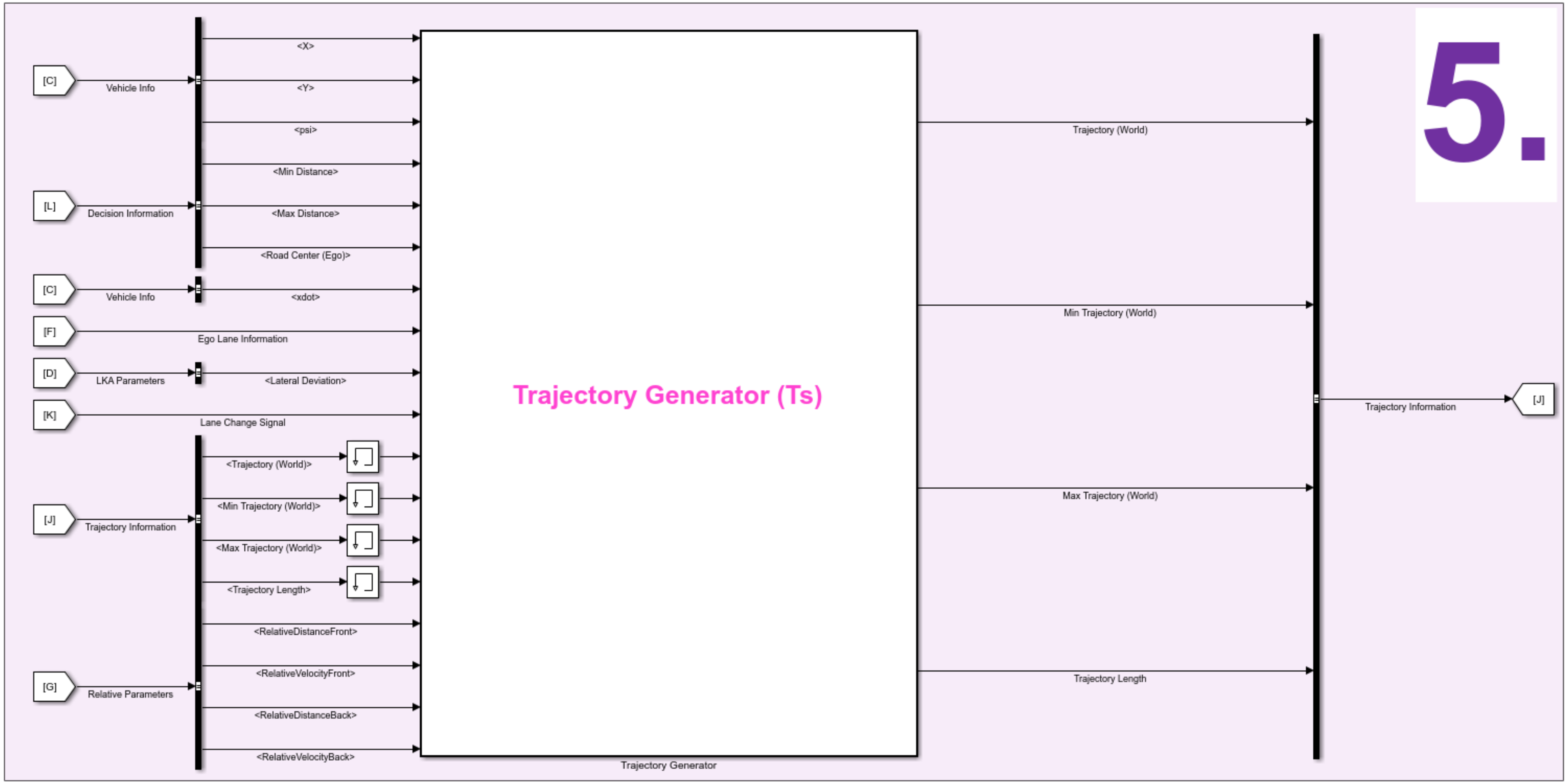


Figure A4-10 Trajectory Generator Block

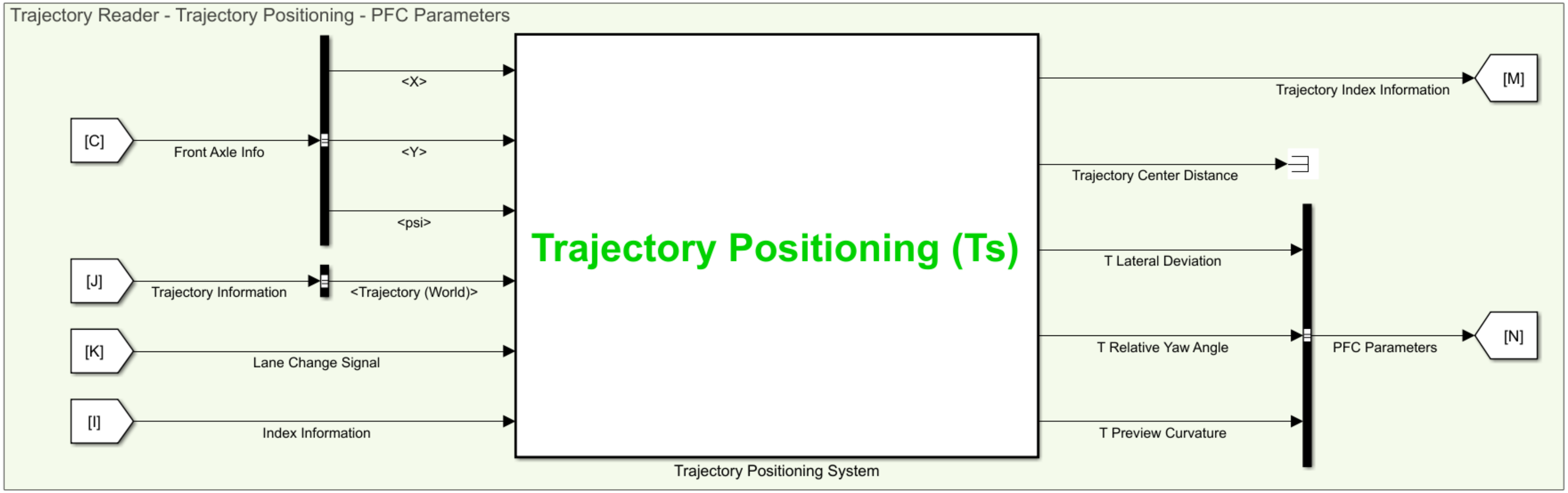


Figure A4-11 Trajectory Positioning Block

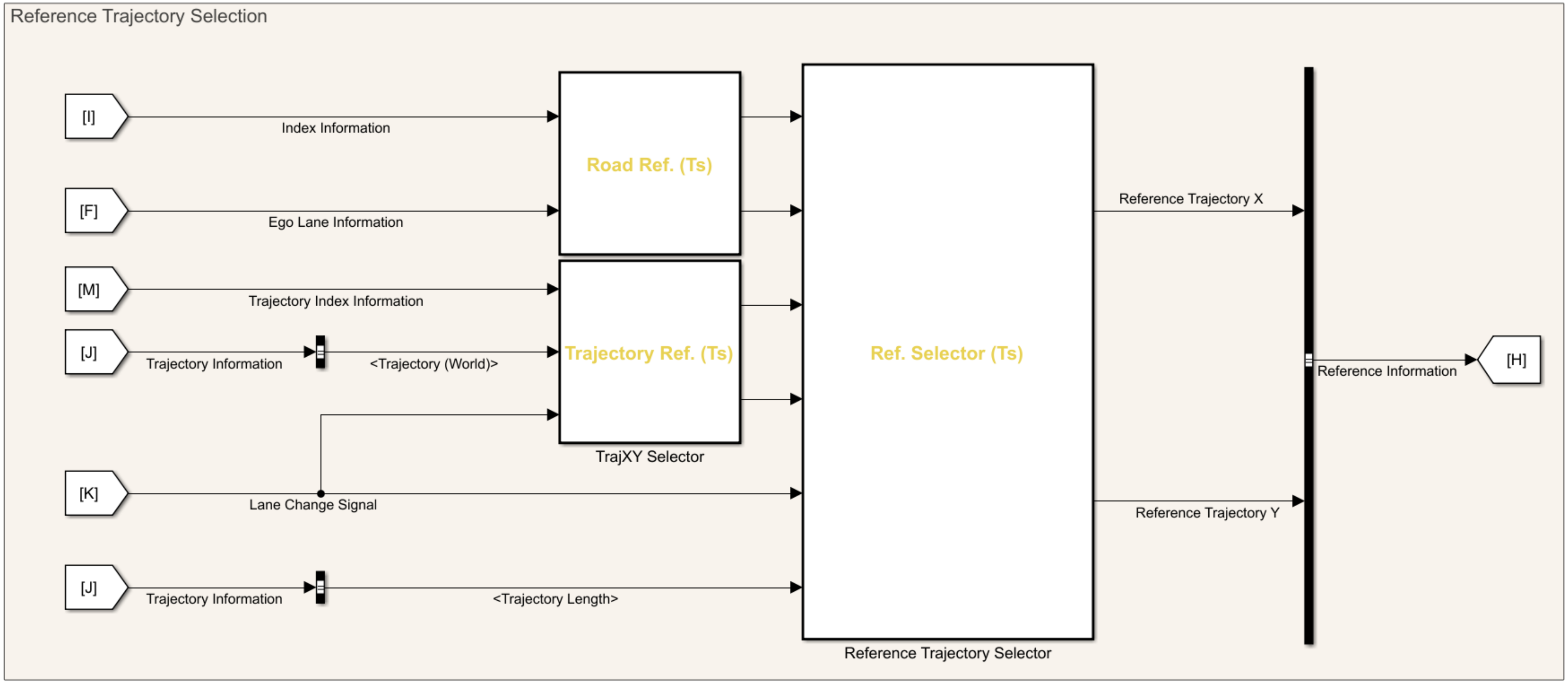


Figure A4-12 Reference Trajectory Selection Block

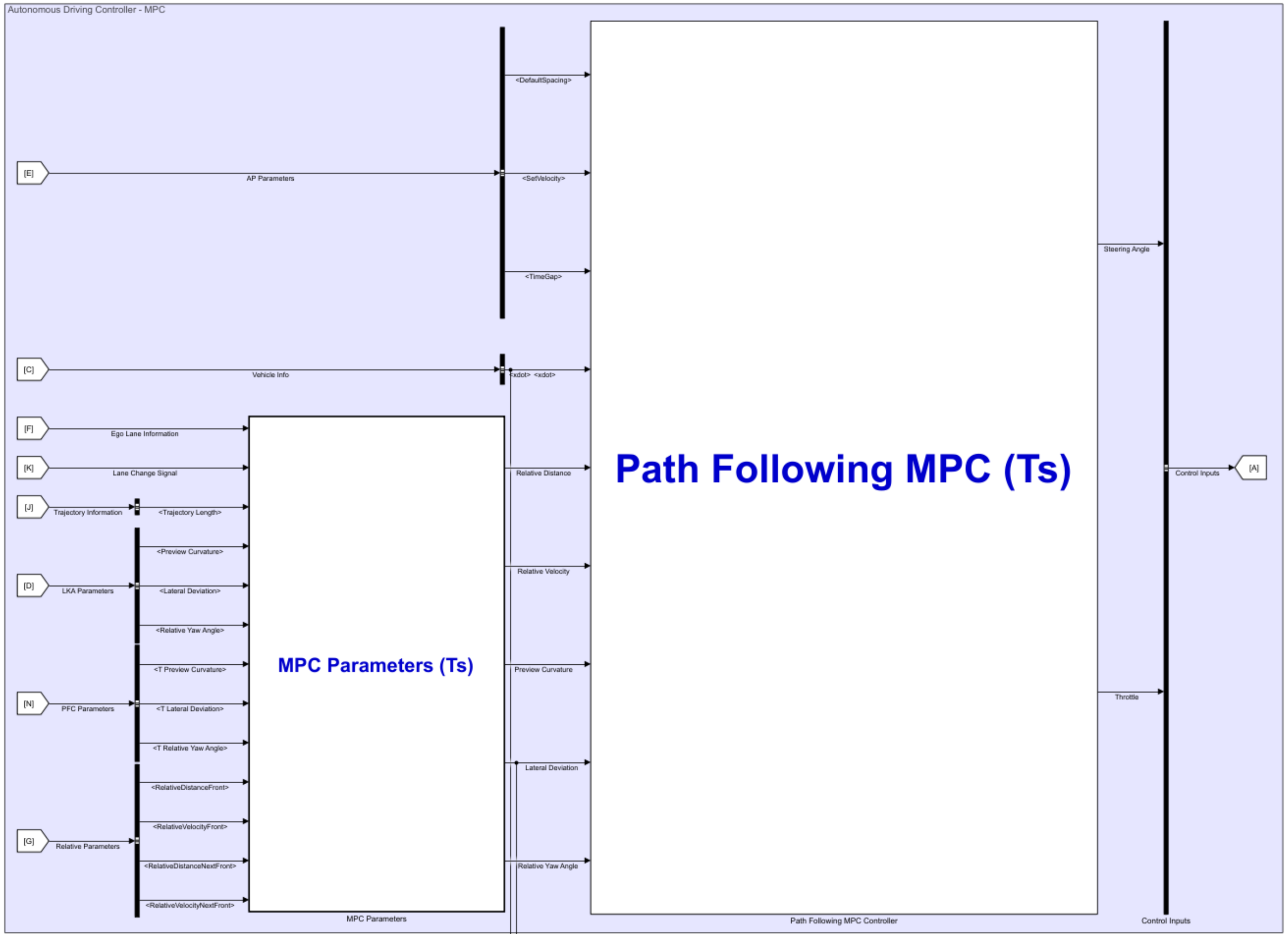


Figure A4-13 ADS Controller Block

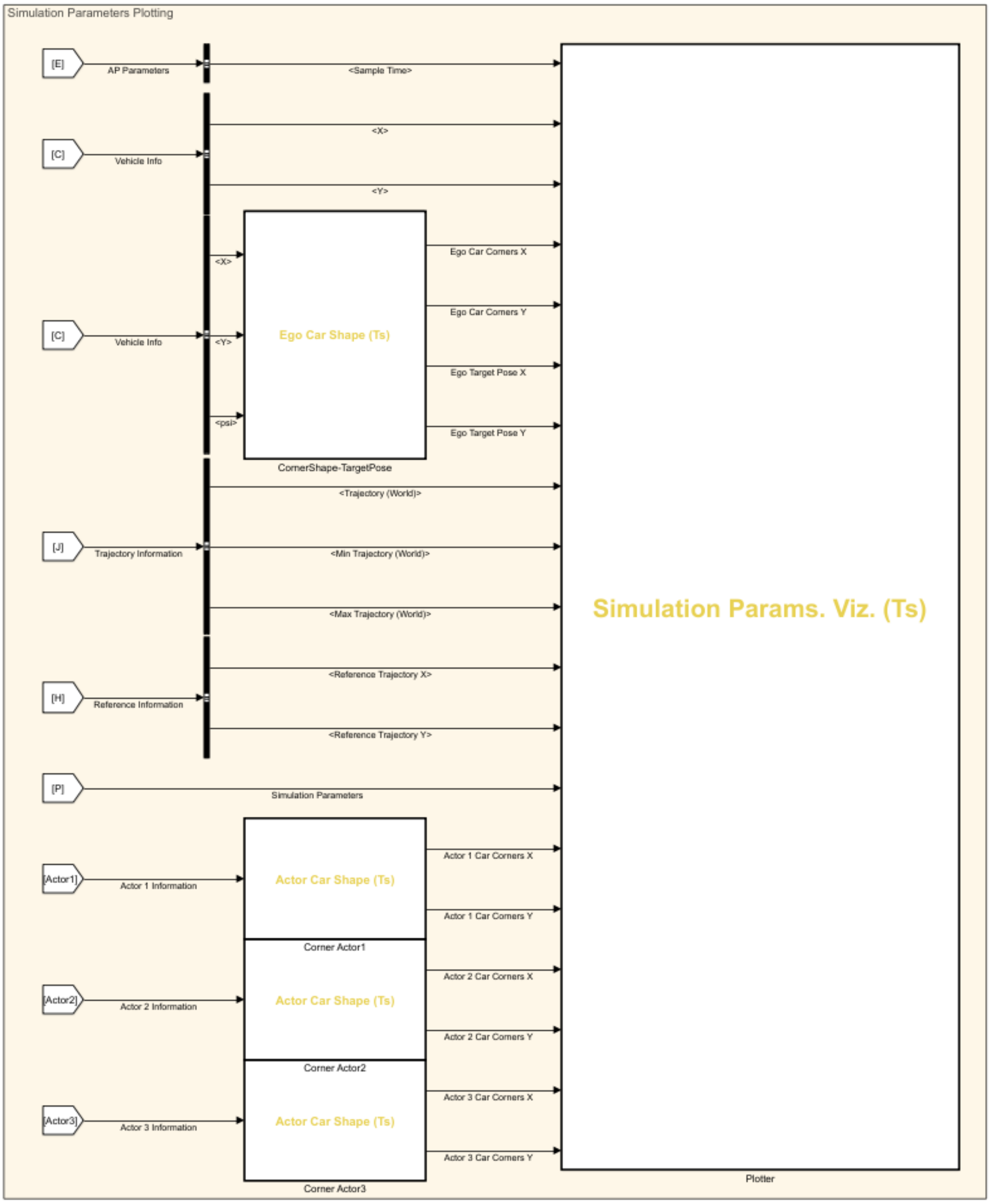


Figure A4-14 Simulation Visualization Block