DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEVELOPMENT OF ADVANCED DRIVER ASSISTANCE SYSTEM FEATURES FOR VEHICLES

by
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İZMİR

DEVELOPMENT OF ADVANCED DRIVER ASSISTANCE SYSTEM FEATURES FOR VEHICLES

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **“DEVELOPMENT OF ADVANCED DRIVER ASSISTANCE SYSTEM FEATURES FOR VEHICLES”** completed by **EMRE ERCİYAS** under supervision of **ASSOC.PROF.DR. ÖZGE CİHANBEĞENDİ** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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DEVELOPMENT OF ADVANCED DRIVER ASSISTANCE SYSTEM FEATURES FOR VEHICLES

ABSTRACT

An advanced driver-assistant system (ADAS) refers to technology to help the driver with driving and parking tasks. ADAS increases safety on both vehicles and roads. These systems use sensors and cameras to scan the environment of the vehicle and assist drivers with making sense of the information they receive. ADAS supports several degrees of autonomous driving by using its sub features. According to the SAE J3016 standard, there are six levels of automation, from level zero (no automation) to level five (full automation). Many car producers use these technologies and provide different levels of automated cars to the market.

Longitudinal control in vehicles is used for detecting other vehicles in the same line. Generally, it uses lidar, radar sensors, or cameras and provides distance between the vehicle and target. In some new technologies, with the use of a camera, other types of targets can also be detected, such as cars, trucks, or pedestrians. Some of the ADAS features, such as Cruise Control (CC), Adaptive Cruise Control (ACC), Emergency Brake System (EBS), and Collusion Avoidance Warning System (CAWS), are designed to recognize target vehicles and control their speed according to data.

In this work, a new system has been developed to combine the longitudinal control-related features (CC, ACC, EBS and CAWS) in one body unit. With the distance between the vehicle and the target vehicle as an input, the system controls acceleration and deceleration and provides this information for the throttle or brake system.

Keywords: ADAS, Cruise Control, Adaptive Cruise Control, Emergency Brake System, Collusion Avoidance System

ARAÇLAR İÇİN GELİŞMİŞ SÜRÜCÜ DESTEK SİSTEMİ ÖZELLİKLERİNİN GELİŞTİRİLMESİ

ÖZ

Gelişmiş bir sürücü yardım sistemi (ADAS), sürücüye sürüş ve park etme görevlerinde yardımcı olmak için kullanılan teknolojiyi ifade eder. ADAS, hem araçlarda hem de yollarda güvenliği artırır. Bu sistemler, aracın çevresini taramak ve sürücülerin aldıkları bilgileri anlamalarına yardımcı olmak için sensörler ve kameralar kullanır. ADAS, alt özelliklerini kullanarak çeşitli derecelerde otonom sürüş desteği sağlar. SAE J3016 standardına göre, sıfır seviyesinden (otomasyon yok) beşinci seviyeye (tam otomasyon) kadar altı otomasyon seviyesi vardır. Birçok otomobil üreticisi bu teknolojileri kullanarak pazara farklı seviyelerde otomatik araçlar sunmaktadır.

Araçlarda boyuna kontrol, aynı şerit içerisindeki diğer araçları tespit etmek için kullanılır. Genellikle lidar, radar sensörleri veya kameralar kullanır ve araç ile hedef arasındaki mesafeyi sağlar. Bazı yeni teknolojilerde, kamera kullanımı ile arabalar, kamyon veya yaya gibi hedef türlerini de tespit edilebilir. ADAS özelliklerinden bazıları, Hız Sabitleyici (CC), Adaptif Hız Sabitleyici (ACC), Acil Fren Sistemi (EBS) ve Çarpışma Önleme Uyarı Sistemi (CAWS), hedef araçları tanımak ve hızlarını veriye göre kontrol etmek için tasarlanmıştır.

Bu çalışmada, boyuna kontrolle ilgili özellikleri (CC, ACC, EBS, ve CAWS) tek bir ünite altında birleştiren yeni bir sistem geliştirilmiştir. Araç ile hedef araç arasındaki mesafe bir girdi olarak alınır, sistem aracın hızlanmasını ve yavaşlamasını kontrol eder ve bu bilgiyi gaz veya fren sistemine iletir.

Anahtar kelimeler: ADAS, Hız Sabitleyici, Uyarlanabilir Hız Sabitleyici, Acil Fren Sistemleri, Çarpışma Önleme Sistemleri

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CHAPTER ONE
INTRODUCTION

Over the past several decades, many research and development efforts have been made in both academia and industry to advance the automation of driving. Many of the studies have been published, especially on the longitudinal and lateral control of vehicles. Also, many of the projects have been developed on the same topics.

With the latest technologies of sensors and cameras used in vehicles, the Advanced Driver Assistant System (ADAS) has been introduced to the market. Longitudinal control of ADAS includes many sub features, such as Cruise Control (CC), Adaptive Cruise Control (ACC), Collision Avoidance Warning Systems (CAWS), and Emergency Brake Systems (EBS). These systems are designed to control the speed of the vehicle according to the data that comes from sensors. With the analysis of the time gap or distance between the vehicles, these sub-systems are requested to increase vehicle speed from the throttle system or decrease vehicle speed from the brake system. Throughout these processes, the systems prioritize both the safety and comfort of the vehicle's occupants.

1.1 Aim of the study

In the market, the longitudinal control features od ADAS systems have been developed separately, such as Cruise Control (CC), Adaptive Cruise Control (ACC), Collision Avoidance Warning Systems (CAWS), and Emergency Brake Systems (EBS). These features control the speed of the vehicle with requesting increase or decrease. While making this progress, they are also trying to keep the distance between the vehicles safe.

Kural, Hacıbekir, & Güvenç (2020) research adaptive cruise control and stop-and-go systems. The method of calculating safety distance is vitally important for the longitudinal system. There are different ways of calculating the safety distance between the cars, such as constant time headway and variable time headway. There are several types of sensors: radar, which generally uses short ranges (up to 40 meters), and lidar, which generally uses long ranges (up to 300 meters).

Guo, Ge, & Sun (2020) implemented an emergency brake system using both the constant-time headway and variable-time headway methods. Also, time to collusion (TTC) is used for the driver's collision avoidance performance. Both safety distance calculation methods are tested on the road with real cars, and their performances are compared based on reaction time, velocity, and acceleration request.

Hilmi, Abu Bakar, Hashim & Harun (2019) design an emergency brake system with consideration for the maximum deceleration rate of the vehicle. There are several TTCs calculated for forward collision warning, partial braking, and full braking. The system is requesting brake deceleration rate according to these time gap between the vehicles with comparing these TTCs.

There are several methods to calculate safety distance, including Constant Space Headway (CSH) control, Constant Time Headway (CTH) control, and Variable Time Headway (VTH) control. This study will apply all these methods to calculate Safety Distance and will evaluate the characteristics of the unified control unit under each method. And all the sub-features are designed with their acceleration and deceleration rates according to the level of their TTC range. Additionally, in this thesis, the unified control unit has been configured within a real-time operating system, and a microcontroller has been employed to run the system, test various scenarios, and observe the results.

1.2 Thesis Outline

There are six chapters in this thesis. As an introduction, Chapter one provides a summary of the research along with an explanation of Advanced Driver Assistance Systems (ADAS) and the rationale for the creation of its sub-features. Chapter two explores related research, analyzing current methods and providing instances of their application to the automation of vehicles. The methods used for the study and the unified control system design are described in depth in Chapter three. The system's application and the parameters management its configuration and functioning are covered in Chapter four. In Chapter Five, a range of test scenarios are presented, along with their analysis and findings, to show how well the unified control unit performs.

Chapter six, which summarizes the results and highlights the study's contributions, concludes the study and offers suggestions for more research.

CHAPTER TWO
PREVIOUS STUDIES

In this section, a comprehensive review of the literature has been collected, and relevant studies are examined. Although there are many publications in that field, they are closely related and similar to the current research. All longitudinal control methods are examined, and related sub-features in ADAS are collected in this section. Additionally, the limitations and basic behaviors of the sub-features are analyzed. Furthermore, similar studies are systematically categorized and grouped to provide a coherent overview.

ADAS features utilize sensor data as input for its sub features. In the case of longitudinal control, cameras and sensors are employed to detect objects in the surrounding environment. Image processing enables cameras to identify many sorts of targets, such as cars and pedestrians. Additionally, radar or lidar sensors are employed to measure the distance of the target.

R. V., Mani, & Kartrict (2023) present a speed controller for an electrical vehicle, and the types of sensors and their usage areas in the vehicle were described as follows: Lidar is used for an emergent brake system and an adaptive cruise control system. The front camera is used for speed limit assistance and lane change support. Driver monitoring cameras are used for driver drowsiness detection systems and driver availability monitoring. Short-range radar is used for blind spot detection and lane detection assistance.

Khader & Cherian (2023) describe how lidar works, the range of the sensors, and the boundaries of the sensors in different weather conditions, as well as the cost and size of the sensors. The hardware part of the sensor is described, and the integration of the sensor into any car system is also explained.

Li at All. (2020) research how to use lidar for autonomous vehicles with deep learning. It is provided to handle some kind of task, such as segmentation, detection, and classification of the target, using a cloud system for autonomous cars. A list of opportunities and research problems was provided to further the possible growth of deep learning in the realm of autonomous driving.

Longitudinal control relies on the measurement of the safety distance between vehicles, which can be determined by many methods. Regulations set by governments and the relative velocity and acceleration of the vehicles impact the outcome in different instances.

Choi & Hedrick (1995) used a method that assumes the distance between the vehicles is constant, which is called constant space headway control. With this method, the system always tries to keep the same distance level between the cars. The safety distance is calculated as a function of the vehicle speed, and it is determined by the regulations of the countries.

Ioannou, Xu, Eckert, Clemons, & Sieja (1993) used a method that tries to keep the distance between the vehicles as a function of the time gap. The time gap is calculated with the expected safety distance and current relative velocity between the vehicle and the target vehicle. This method is called constant-time headway control. With this method, smooth acceleration and deceleration are ensured.

Yanakiev, Eyre, & Kanellakopoulos (1998) used a method that tries to show that the time gap between the cars is a function of the current relative velocity between the vehicles and the acceleration of the target vehicle. This method is called variable-time headway control. The time gap value in this instance is constantly fluctuating.

Hatipoğlu, Özgüner & Sommervill (1996) used a method for switching between the safety distance controllers, which is called intelligent cruise control. The system switches between the methods for smooth acceleration and deceleration. It is tested with simulation, and transitions between the methods are examined in a variety of test cases.

ADAS incorporates multiple functionalities for controlling the vehicle's speed and acceleration. Some individuals require both acceleration features, such as cruise control, and adaptive cruise control. The cruise control keeps the vehicle's speed at a constant value that is chosen by the driver. Adaptive cruise control serves the same goal as regular cruise control, but it additionally aims to uphold a safe distance between vehicles. In order to sustain this condition, it may decrease the velocity and maintain it below the speed specified by the driver.

Kabasakal & Üçüncü (2022) designed an adaptive cruise control simulation with real-life environments such as vehicles, acceleration and deceleration models, and PID and MPC controllers and compared their efficiency, accessibility, and design effort cost. The article shows that the PID controller has better results than the MPC controller.

Haspalamutgil & Adalı (2017) have designed a switching algorithm between speed and distance control for adaptive cruise control. It aims to reduce frequent mode changes between switches and provide a smoother transition. The suggested solution has two controllers: one controls speed and distance and provides an acceleration signal, and the other takes this signal and calculates the required acceleration to throttle. Simulation results show that the switching is effective and increases comfort and safety.

Ynag, Mao, Liu, Du, & Liu (2020) have tried to maintain frequent switching between speed and distance control in adaptive cruise control with logical comparisons and an improved adaptive cruise control model using the variable time headway method on distance control. Its use aims to optimize deceleration adaptivity, safety, and fuel economy. This method ensures the performance and reliability of the adaptive cruise control in various driving conditions.

Sivaji & Sailaja (2013) design an adaptive cruise control with stop-and-go maneuvers that maintains an adaptive cruise control even at lower speeds in urban traffic. The system manages the time gap between the vehicles. system reads host vehicle speed, desired speed set by the driver, headway time set by the driver, and the actual gap, which is measured by the radar sensors. The system controls the speed of the vehicle with those inputs in urban traffic conditions and prevents cars from colliding. The proposed method provides speed acceleration and deceleration for urban traffic while controlling the speed of the host vehicle and the distance between the vehicles.

Zhank at all. (2023) has proposed a new method to avoid accidents because of the cut-in vehicles that enter from different lanes. A new time-to-collision (TTC) parameter has been defined for the vehicles in different directions and lanes. There are two control mechanisms: one is to detect all these collision parameters and maintain tracking ability, and the other is to maintain acceleration and deceleration and apply the maximum longitudinal tire force. These control mechanisms are simulated and tested within a real-time system in various cases. The result shows that the method is working to avoid collisions with the use of new collision parameters for vehicles in another lane.

Ioannou & Chien (1993) have worked on the autonomous cruise control method and aim to control traffic flow more effectively and eliminate human mistakes while driving, such as reaction delay. The method controls throttle and brake automatically while keeping safety distance between the vehicles. With that, it provides more fluent traffic on the road and more safety for the passengers. It may also offer a good solution for urban traffic problems because of sudden stops, vehicle cut ins. The simulation findings suggest the method improves traffic management, especially on crowded urban roadways.

Audi Technology Portal [ATP] (2021) explains adaptive cruise control and stop-and-go functions in Audi. The system makes automatic distance control and controls the speed of the vehicle automatically with accelerating and braking. The system uses two radar sensors on the front side of the vehicle, and it uses the network to get data from other driver's vehicles. Furthermore, it cooperates with the navigation system. Due to all this information, it makes much more accurate decisions and supports the driver in many complex cases on the road.

Bleek (2007) has modeled adaptive cruise control and stop-and-go function control strategies. It proposes Model Predictive Control (MPC) to design hybrid adaptive cruise control systems for real time applications. The virtual target model (VTH) has been used for this hybrid system. It maintains switching between cruise control and adaptive cruise control while assuming a virtual target in the safety distance. If the real target is far away from the virtual target, only cruise control is running, on the other hand, if the real target is closer than the virtual target, adaptive cruise control is running. The main aim is to successfully design the hybrid model, and the system with this design was validated with simulations and road experiments.

ADAS includes multiple functions to manage braking commands, including the emergency brake control capability. This sub-system has been designed to prevent collusion. If there is an urgent scenario, such as a car suddenly entering the lane or a pedestrian on the road, the system will compute the necessary brake request. It has the potential to reduce the velocity or completely halt the vehicle.

Stellet, Vogt, Schumacher, Branz, & Zöllner (2016) have worked on the emergency brake system, analyzing the effects of sensor measurement and measurement uncertainties on the decision-making process. It compares to a brake system based on activation time and collision energy reduction. The analysis considers different scenarios of rear-end accidents between the vehicle and the target vehicle in longitudinal traffic. The collision energy reduction is one of the metrics for effectiveness of the emergency brake system.

Kopetz & Poledna (2013) have worked on the automatic emergency braking system, which proposes to coordinate all emergency brake sub features in cars to avoid collisions and improve safety. The automatic emergency brake system takes sensor values, sensor fusion, and human input from the driver, such as the driver's gaze and pedestrian control, as input and controls the brake request using them. The system also includes fault mitigation measures such as self-checking hardware, fault containment units, and redundant sensor components.

Lucan, Duchon, Bata, Mikle, & Andoes (2022) proposed a design for emergency brake systems for racing cars. The system had been tested to determine the relationship between the braking distance and the vehicle velocity. Also, the effect of the pressure system on the braking distance is tested. The design covered requirements defined by the formula student rules, such as reaction time, average deceleration rate, and stability of deceleration.

Ariyanto, Haryadi, Muunadi, Ismail & Hendra (2018) developed a low-cost autonomous emergency braking system for electric cars. The system uses a DC motor as the actuator, which pulls the brake pedal. It takes distance to use an ultrasonic sensor. The system is designed for low-level speed, and it is activated when the distance between vehicle and obstacle is under 3.6 meters. According to the requested acceleration rate, the DC motor pulls the cable that connects the brake pedal, and it may slow down the vehicle. The system has been tested at low-level speed on the road, and it seems that the vehicle can stop before hitting an obstacle.

Dixit, Devangbhai, & Kumar C (2021) modeled an emergency braking system using radar and vision sensors. The model has been simulated with Matlab Simulink, and it calculates parameters such as time to collusion and stopping time and tests the model with predefined scenarios. The purpose of using sensor fusion technology in automatic emergency brake systems is to improve the perception capability of the system, have a more reliable system, and obtain more intelligent decision-making for collision avoidance.

Abunei, Comsa, Mnesciuc Ferent, & Drenciu (2018) implemented an open-source inter-vehicular communication system for emergency braking systems in autonomous cars. By using inter-vehicular communication between cars, it purposefully improves the safety of the cars by avoiding accidents and improves traffic congestion reduction. Moreover, autonomous emergency brake systems also benefit from this communication. The system has a warning signal for the drivers if any of the front cars have brakes or stop suddenly. It will also improve safety in case of bad weather, foggy weather, or any circumstances that cause poor visibility.

Zhu, Xu, An, Zhang, & Lu (2022) created emergency braking systems that improve system perception by combining millimeter-wave radars and smart cameras. The system calculates time to collision, braking time, and expected deceleration, and according to the level of time to collision, comparing the braking time levels, the system requests the actual deceleration rate. The developed system was tested with simulations and with real cars on the road. Lidar is used in an actual vehicle test to determine the distance between the vehicle and the target vehicle. Both the simulation and real-life car test were successfully completed, and their results were so close to each other. It proposes to establish a physical model for future works.

The collision avoidance warning system is a sub-feature of ADAS that helps to sustain brake demands. The technology use sensors to identify possible collisions. The system utilizes the distance, speed, and relative position of cars and objects in the vehicle's path to compute the time to collision and assess the likelihood of a collision occurring. Typically, it is equipped with an alert system, such as dashboard lights, auditory signals (such as beeps or whistles), or vibration in the steering wheel or seat.

Funke, Brown, Erlien, & Gerdes (2017) have discussed the integration of collusion avoidance systems based on their stabilization and path tracking. The model has trajectory algorithms and environmental constraints to provide a complete guidance system for autonomous cars. The main purpose is that in the event of collusion, the vehicle can maneuver inside its lane to avoid collusion and, meanwhile, maintain its stability. The system has been tested with the following: no obstacle, known obstacle, and pop-up obstacle. In tests with no obstacles and known obstacles, the system protects the vehicle's stability and takes needed action in time, but for pop-up obstacles, it does not protect stability for each case; in that case, the system prefers collision avoidance over stabilization in accepted ranges.

Gehrig & Stein (2007) have designed a system which uses elastic-band framework for collision avoidance for vehicle-following. It is kind of an intelligent car system where one car imitates the other for obstacles on the road. The systems take into account the position and velocity of the obstacles. The results show that the elastic-band framework provides dynamic collision avoidance for intelligent cars in a mixed-traffic environment. The system was tested on various cases with simulation and also on the road. The leader vehicle was able to avoid obstacles while keeping a safe distance from the other vehicles. Also on the road test, the vehicles were able to avoid pedestrians, bicycles, and other obstacles.

Coelingh, Eidehall, & Bengtsson (2010) developed a system to detect potential collusions using long-range radar and cameras with an intelligent algorithm. It called a collusion warning with full auto brake and pedestrian detection (CWAB-PD). CWAB-PD has two main functions: first, giving a warning to drivers in case of an emergency to take action for risk. Second, if the driver doesn't take any action, the system has an emergency brake to slow down the car. This brake can reduce the crash speed, and it may also prevent the crash in low-speed cases. The system is tested on the road, and CWAB-PD has been tested with various tests. The system has shown good results in both speed reduction and collision avoidance.

Hafner, Cunningham, Caminiti, & Domitilla (2013) have developed a method for cooperative collision avoidance at intersections. The system includes communication between the cars, estimation of any collision risk, and control of the environment. The method shared the locations of the cars between them, determined the control inputs for collision avoidance, and provided safety certificates to guarantee collision-free operation. The system tries to keep the state outside of the capture set, which makes collusion unavoidable. It was tested with prototype cars and the results show the method provides a good capture set and cars don't get into the collision set under any test conditions.

Katare & Sharkawy (2019) propose a model using the real-time multi-sensor application (RTMaps) framework and the forward-facing automotive radar in the vehicle. There are two approaches: one is the regression approach, which trains a model with input data such as velocity, acceleration, and distance between the cars and calculates the expected warning range to prevent collision. And the second is the classification approach, which is a kind of machine learning algorithm such as a decision tree, support vector machine, or neutral network to classify the scenario as warning or no-warning based on inputs. The model has been trained with data collected from a hundred naturalistic driving studies. Using the trained models, the RTMaps embedded framework successfully integrates the collision warning system.

Eidehall, Pohl, Gustavsson, & Ekmark (2007) propose a system that combines a lane guidance system and a threat assessment module, called Emergency Lane Assist (ELA), to prevent dangerous lane departure maneuvers. The system monitors the adjacent lanes, and if there is a risk of collision, it activates the steering intervention system and gets the car back in the original lane in a safe position. The system calculates a threat level for any object in the next lane. If the object threat level is higher than an acceptable threshold, the steering intervention system is activated. ELA was tested on 2000 km of roads in traffic without any failure, demonstrating how well it works to avoid collisions when changing lanes.

Longitudinal control features generally use several pieces of data as an input, such as distance sensors (radar for short or middle range, lidar for long range), cameras, and cameras also used to detect type of vehicle or obstacles, vehicle speed, its acceleration, etc. In some articles, some intelligent systems have been developed to share data between the cars for their position or detect obstacles on the road. By evaluating these data, the designed models, systems calculate the acceleration to speed up the car or the deceleration to slow down the car. In most of the work, each sub-feature for longitudinal control, such as Cruise Control (CC), Adaptive Cruise Control (ACC), Collision Avoidance Warning System (CAWS), and Emergency Brake System (EBS), has been developed separately. However, in some cases, CC and ACC have been collected in one feature, the system has only run the CC part if the distance of the target vehicle is greater than the expected threshold; if it is lower than the threshold, ACC has been run. Also, in some other articles, CAWS and EBS can be developed together. There are also some thresholds to activate CAWS and EBS. By comparing the target vehicle's distance, the system decides whether to activate CAWS or EBS. These systems use safety distance as a threshold to activate CAWS or EBS. In some cases, safety distance can be used as tracking distance in ACC modules. Also, there is some Time to Collision (TTC) calculations with relative speed and relative distance between the cars. CAWS or EBS can also be activated by comparing TTC with the threshold for calculated activation of the features.

In this work, all the sub-features mentioned above CC, ACC, CAWS, and EBS are collected into one feature, which is called the Acceleration Deceleration Determination System (ADDS). ADDS has taken the speed of the vehicle, the relative distance between the vehicles, the desired speed set by the driver for the CC or ACC module, and the enable-disable parameters for the sub features as input. It calculates the relative speed between the cars and target vehicle acceleration to calculate the safety distance needed between the cars. ADDS also calculates threshold values for the relative distance between the cars and the TTC. By comparing the actual distance and TTC with the threshold, it decides which sub feature is active and calculates the required acceleration or deceleration rate.

CHAPTER THREE
METHODOLOGY

3.1 Methodology

In automotive, there are many Electronic Control Units (ECUs) in a car. They are responsible for controlling or monitoring many functions, such as engines, transmissions, ADAS systems, entertainment, steering, and many other systems. The Engine Control Unit is the central controller of the engine management system, controlling functions such as fuel supply, air management, oil management, or, in electric vehicles, voltage supply and current management. They receive information from the sensor, process the information, and send outputs to the actuators. Also, ECUs transfer information between them using communication protocols such as Controller Area Network (CAN), Flex Ray, and Local Interconnect Network (LIN).

In this study, longitudinal control-related ADAS features have been designed and implemented. The system takes relative distance, the current speed of the vehicle, the desired speed set by the driver, and enables values for sub features (CC, ACC, CAWS, and EBS) as an input. After its progress, it provides the acceleration-deceleration rate and which feature is active at the current time. Figure 3.1 displays the system block diagram.

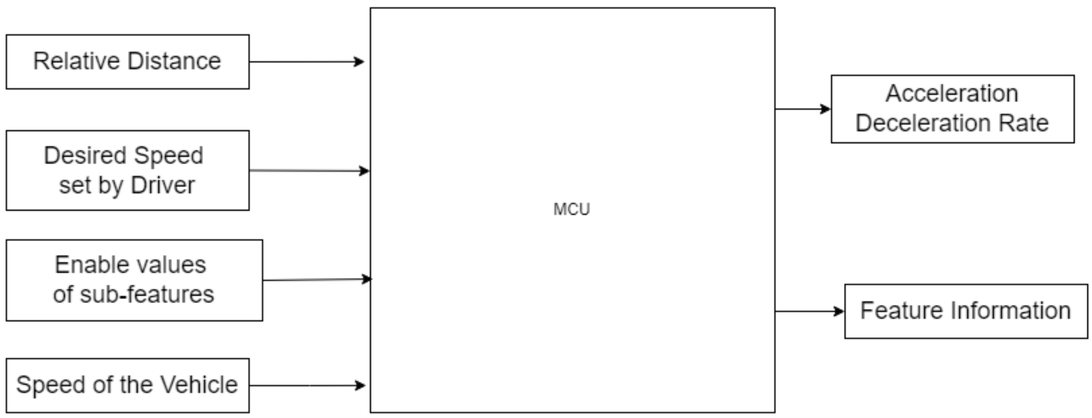

Figure 3.1 Block Diagram of the System

The system has been mainly implemented in two parts: the calculation of relative speed and target vehicle acceleration, and the Acceleration Deceleration Determination System (ADDS). For the calculation of estimated relative speed and estimated target vehicle acceleration, the system uses the speed of the host vehicle and the relative distance value. Figure 3.2 displays the high-level design of the system.

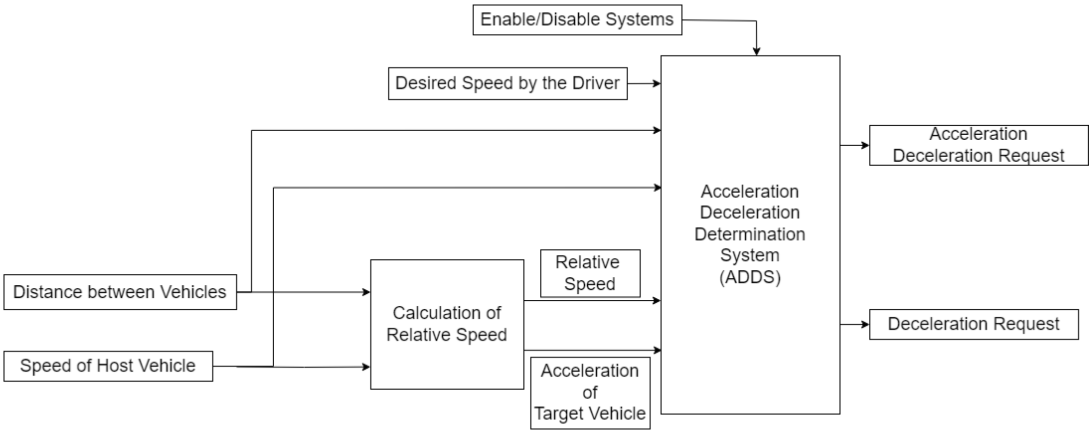

Figure 3.2 High Level Design

To collect all these sub features into one method, the ADDS has two parts, one of which is CC and ACC, which are implemented, and the other is CAWS and EMS. In part of the CC and ACC, the virtual target model has been implemented (Bleek 2007). This method assumes a virtual target at a defined distance from the vehicle at the same speed as the vehicle. If the real target's distance is higher than the defined distance, then the system runs CC; if the real target's distance is closer than the defined distance, then the system runs ACC. Depending on the current data, the system may switch between CC and ACC. Figure 3.3 displays the virtual target model.

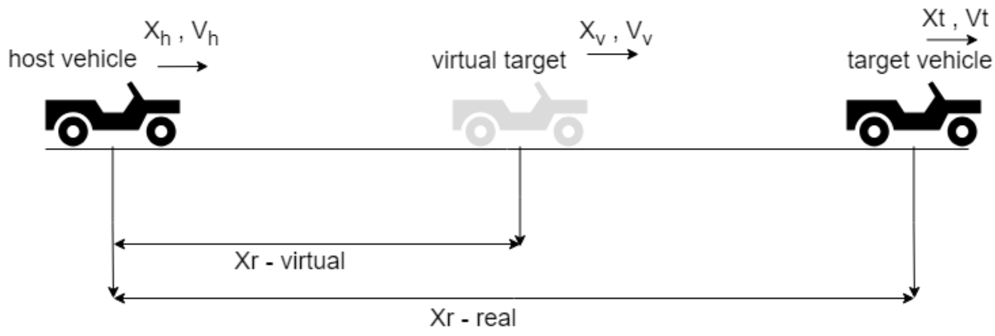

Figure 3.3 Virtual Target Model

The brake application time indicated by the system has been implemented for the second phase. The system has determined the time it takes for a collision to occur at different brake levels, including full brake, partial brake, and forward collision warning. The system determines the required amount of braking force by evaluating the present time in relation to the collision level thresholds. It then transmits this request to the brake control unit (Hilmi, 2019). The calculation for Time to Collusion (TTC) can be determined using the equation provided in section 3.1.

$$TTC = \frac{\mathrm{Xr}}{\mathrm{Vr}} \tag{3.1}$$

where x_r is the relative distance and v_r is the relative speed between vehicles.

3.2 Sensors

In the automobile industry, a wide range of sensors are utilized to accurately monitor various parameters such as temperature, pressure, and quantities of different elements. The ADAS system is equipped with many sensors, including radar, cameras, ultrasonic sensors, and lidar. Radar use electromagnetic waves to determine the distance between objects. It utilizes electromagnetic radiation that can be employed across many frequency ranges. Radars have the ability to ascertain the relative movement of the things they detect, and they are extremely strong in various conditions. Radar sensors are employed in longitudinal control functions to determine the relative distance between vehicles, and their range can be adjusted to meet the requirements of the system. Table 3.1 displays the various radar types available in the market together with their respective ranges, as documented by (Rohling & Moller, 2008).

Table 3.1 Radar Types and Ranges

Radar	**Maximum Range (Approximate)**	**Opening Angle**
SRR (Short Range Radar)	50 m	Wide
MRR (Mid Range Radar)	80 to 100 m	Wide to medium
LRR (Long Range Radar)	250 to 300 m	narrow

Cameras utilize passive light sensors to generate a digital image of the area being monitored. Cameras have the ability to identify and perceive both objects that are in motion and those that are stationary in their immediate surroundings. In addition, lights have the capability to identify and differentiate between road signs, traffic signals, lane markings, and various types of objects such as automobiles, pedestrians, and trucks. Typically, there are two kind of cameras that are commonly employed in ADAS (Advanced Driver Assistance Systems). A monocular camera consists of a vision-capturing array and a processing module. Although it is inexpensive, compact, and can be calibrated with relative ease, it has a restricted ability to estimate depth. The second camera is a stereo camera, equipped with multiple lenses, each with its own image sensor. This camera employs a technique that replicates the visual perception of human binocular vision, enabling it to record a three-dimensional image. Nevertheless, it is costly and challenging to calibrate.

Ultrasonic sensors are commonly employed in automatic parking or parking aid systems. The object's distance is measured using waves. They exhibit considerable durability in various situations and demonstrate consistent performance in the majority of environments. Typically, they are utilized for measuring distances within surroundings that are no more than 2.5 meters. The automated parking system utilizes ultrasonic sensor measurements as an input and issues commands to the steering, accelerating, and braking systems in order to perform parallel parking and garage parking maneuvers.

Lidar (ligth detection and ranging) is one of the other sensors that uses ligths to measure that distance. It is capable of producing point clouds, which are extremely dense networks of elevation points with high resolution. These point clouds are used to identify objects in the immediate area around the vehicle. A good lidar has 8 to 128 laser beams to scan the complete environment at high resolution. It sends these laser beams, which consist of many light photons in the environment, around 360° and collects the bounce-back data. Its numerous thousand points provide a very high-resolution point cloud that aids in both excellent object classification and the recognition of even the smallest objects surrounding the car. In order to assess the material characteristics of the object the laser bounces off of, it additionally gives laser intensity.

3.3 Operating System

In order to build and establish the open electronic system architecture and standardized software framework for intelligent mobility, top software and automotive businesses worldwide have partnered to form AUTOSAR (automotive open system architecture). The goals of the AUTOSAR standard are to facilitate software reuse, standardization, and interoperability. The AUTOSAR standards offer two platforms to support the software implementation of the car's electronic control unit, both now and in the future. The first is a traditional platform that supports systems like the body, interior electronics, and engine. The second is an adaptable platform that supports online software updates and automated driving, among other technologies.

3.3.1 OSEK Operating System

OSEK OS is an operating system that is activated by events. This provides a significant level of autonomy for the development, arrangement, and maintenance of AUTOSAR-based systems. Event triggering allows for flexible runtime scheduling based on several criteria, including rotational rotation, local or global time sources, and error occurrence. The fundamental functionality of the AUTOSAR OS will be derived from the OSEK OS for these reasons. OSEK OS provides resource management capabilities to efficiently utilize resources and coordinate tasks and events. The automotive systems are equipped with error management, fault detection, and error reporting capabilities to guarantee their safe operation.

In OSEK, there are primarily two categories of tasks: the basic task and the extended task. Simple tasks only free up the CPU in the following situations: when they finish, when the OSEK system shifts to a task with higher priority, or when an interrupt happens. The extended task includes a waiting event in addition to the basic task. The extended task has the ability to remain in a state of waiting. The operating system has the ability to allocate lower-priority tasks while the extended task is in a waiting state, until it transitions to a ready state. The user has the ability to determine the priority of the work, choose between basic or extended options, and provide a source for the task. The OSEK Implementation Language (OIL) can be utilized for configuring the OSEK system.

3.4 Longitudinal Control Methods

Longitudinal control plays a crucial role in the automation of the vehicle by managing the vehicle's speed and assisting with brake and acceleration requests. These methods generally manage vehicle speed based on the relative distance between vehicles. Safety distance plays a vital role in these methods, as they are the minimum acceptable distance between the vehicles in giving circumtances. There are three methods for calculating safety distance: Constant Space Headway (CSH), Constant Time Headway (CTH), and Variable Time Headway (VTH).

3.4.1 Constant Space Headway Method

Constant Space Headway (CSH) is a method to maintain a consistent distance between the vehicles. This distance calculation is dependent on the vehicle's current speed as well as certain restrictions outlined in laws or standards. This guarantees that the car stays safely apart from the one in front. Constant Space Headway Control considers variables including speed limitations and safety rules to calculate the minimum safe following distance while adhering to industry standards and established legislation. In Turkey, regulations for safety distance are equivalent to at least half of the current vehicle's speed in kilometers per hour, measured in meters. This can also be calculated as the distance a vehicle can cover in two sec., measured in meters. The CSH safety distance can be calculated using equation 3.2.

$$D_s = \frac{V_c}{2} \tag{3.2}$$

where D_s is the safety distance and V_c is current speed of the vehicle.

3.4.2 Constant Time Headway Method

The Constant Time Headway (CTH) method is a method to maintain a consistent time gap between the vehicles. The selected time gap is multiplied with the vehicle's speed by the control system to determine the desired safety distance. By keeping regular time intervals between cars, Constant Time Headway Control is intended to preserve the stability of a vehicle or a group of vehicles moving in the same direction. Through smooth acceleration and deceleration, this control strategy makes driving more comfortable and safer by regulating the vehicle's speed to maintain the appropriate time gap. The CTH safety distance can be calculated using equation 3.3.

$$D_s = V_c * t_h + d_0 \tag{3.3}$$

where Ds is the critical safety distance, t_h is the constant time headway, and d_0 is the minimum safety distance. The constant tine headway can be calculated using the equation 3.4.

$$t_h = t_0 - c_1 * V_{rel} \tag{3.4}$$

where t_0 is a constant time headway, c_1 is an adjustment factor greater than 0, and V_{rel} is the relative velocity between the vehicles.

3.4.3 Variable Time Headway Method

The Variable Time Headway (VTH) method is a method to maintain a dynamic time gap between the vehicles based on current speeds and accelerations. Real-time response to traffic conditions is provided via variable-time headway control. It makes it possible to maintain safety distances with more flexibility, particularly when traffic circumstances change quickly. This control strategy can aid in more efficient use of road space and better traffic flow by dynamically adjusting the following distance.

When there is heavy traffic and frequent lane changes, variable-time headway control is especially helpful for improving safety and traffic control. The VTH safety distance can be calculated using equation 3.5.

$$D_s = V_c * t_h + d_0 \tag{3.5}$$

where D_s is the critical safety distance, t_h is the variable time headway, and d_0 is the minimum safety distance. The variable tine headway can be calculated using the equation 3.6.

$$t_h = t_0 - c_1 * V_{rel} - c_2 * a_t \tag{3.6}$$

where t_0 is a constant time headway, c_1 is an adjustment factor greater than 0, V_{rel} is the relative velocity between the vehicles, c_2 is an adjustment factor greater than 0, and a_t is the acceleration of the target vehicle.

3.5 Time-Based brake system

Time-based brake systems are a technique employed in emergency brake systems that avoid frontal collisions in automobiles. The data is acquired from radar, lidar, and cameras; the system identifies probable collisions for the vehicle. As the car nears the collision, the system activates the collision warning component and simultaneously engages the brake. If the driver does not take any response, the system will initiate partial braking. If the driver still does not respond, the system will then engage complete braking (Hilmi, 2019). The system activates each state, namely collusion warning, partial braking, and complete braking, by employing a time to collusion computation. Each state has its own specific time required to achieve the threshold of collusion. If the current time to collision of the vehicle is less than the threshold of any state, that state will be triggered and activated. ADAS features involve the system observing and controlling the driver's actions. However, with autonomous automobiles, the system directly executes the actions since there is no driver present. Figure 3.4 displays the Time Based Brake System.

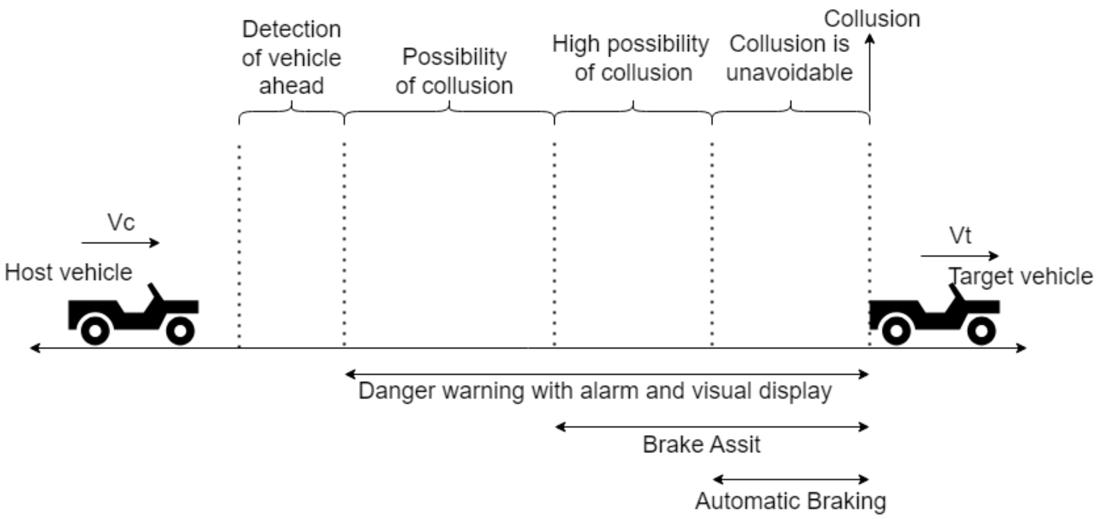

Figure 3.4 Time Based Brake System

CHAPTER FOUR

APPLICATION AND DESIGN

This study presents the development and use of a single control system that combines the features of Cruise Control (CC), Adaptive Cruise Control (ACC), Collision Avoidance Warning System (CAWS), and Emergency Brake System (EBS). The overall configuration of the implemented model with Microcontroller Unit (MCU) is depicted in Figure 3.1, while the conceptual design is illustrated in Figure 3.2. Erica OSEK has been configured on the Arduino Uno board. The system has implemented a distance sensor input that is sent at a frequency of 100 milliseconds to provide complete coverage of the input. Typically, sensors in the market are manufactured with a duration of either 50 or 100 milliseconds to provide distance information. To encompass all the sub characteristics, a single integrated system was established, and a periodic task was developed with a 100 milliseconds interval. Figure 4.1 displays the diagram of the operating system (OS) and the unified system.

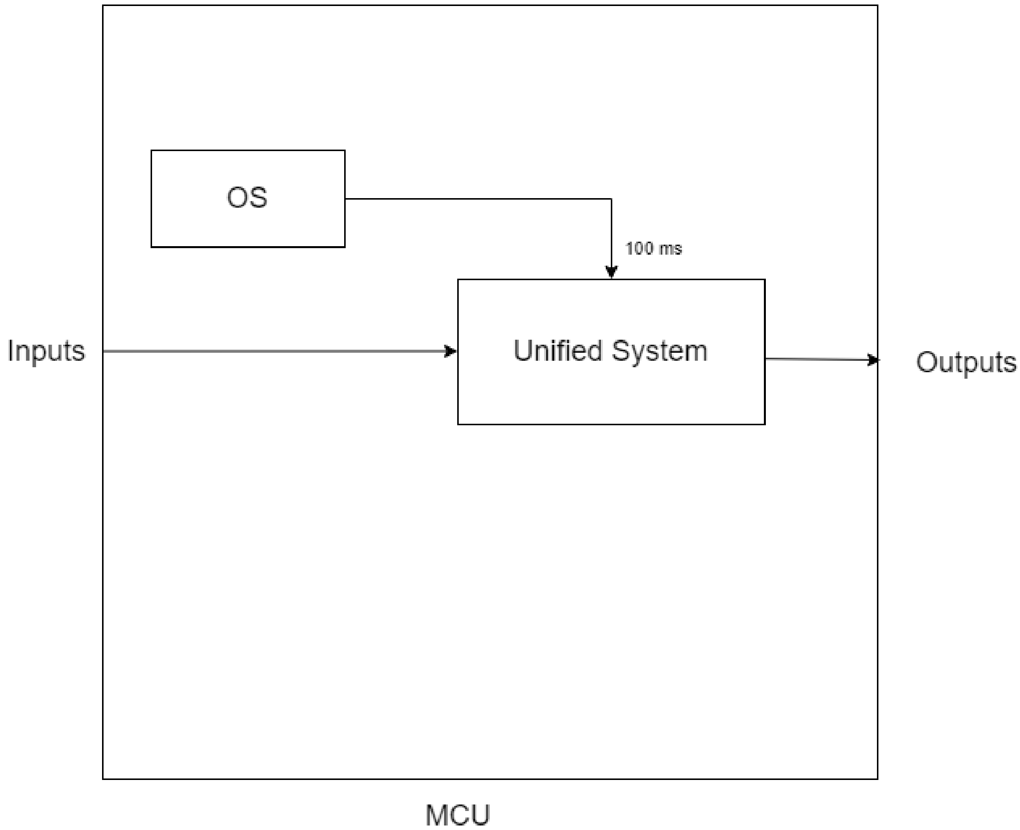

Figure 4.1 Diagram of OS and Unified System

4.1 Calculation Relative Speed and Target Vehicle Acceleration

The unified system consists of two components, as represented in Figure 3.2: high-level design. The first segment computes the approximate relative velocity and acceleration of the target vehicle based on the relative distance and the velocity of the host vehicle. The relative speed can be determined by dividing the relative distance by the time elapsed. The calculation of relative speed is represented by equation 4.1.

$$V_{rel} = \frac{d_D}{d_t} \tag{4.1}$$

where d_D is the difference between the relative distances between two reads of the distance sensor input, and d_t is the period of the read of the distance sensor input.

Target vehicle acceleration can be calculated using the relative speed and current speed of the vehicle. The target vehicle acceleration calculation can be seen in equation 4.2.

$$a_t = \frac{\left(V_{rel_{prev}} - V_{rel_{current}}\right) + \left(V_{c_{current}} - V_{c_{prev}}\right)}{d_t} \tag{4.2}$$

where $V_{rel_{prev}}$ is previous relative speed, $V_{rel_{current}}$ is current relative speed , $V_{c_{current}}$ is current host vehicle speed, $V_{c_{prev}}$ previous host vehicle speed and d_t is the period of the read of the distance sensor input.

According to equation 4.1, the system first calculates the relative speed. The diagram of these subsystems can be seen in Figure 4.2.

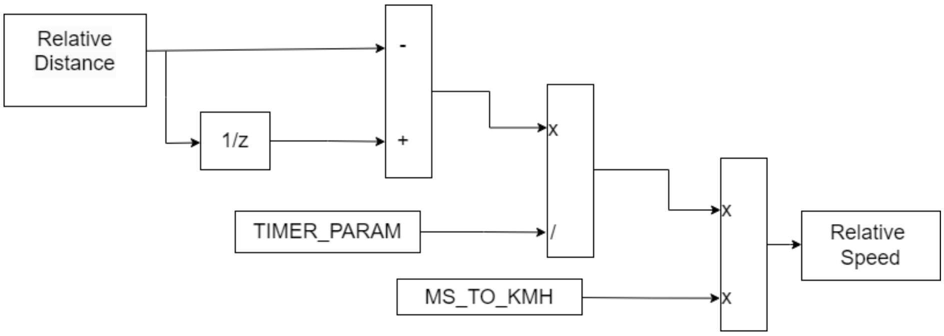

Figure 4.2 Calculation of Relative Speed

According to equation 4.2, the system calculates acceleration of the target vehicle. The diagram of these subsystems can be seen in Figure 4.3. In the model, 1/z blocks are used to store the previous value of the input.

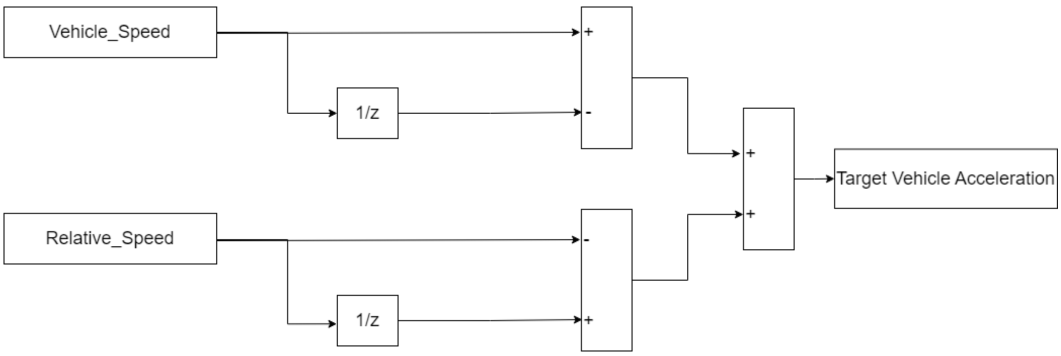

Figure 4.3 Calculation of Target Vehicle Acceleration

4.2 Acceleration Deceleration Determination System

The second component of the integrated system is the Acceleration Deceleration Determination System (ADDS). The ADDS module receives the outputs from the relative speed calculator subsystem, as well as additional inputs. This subsystem is activated when any of the enable flags of the subfeature are set. Alternatively, if no other action is taken, it will remain under the default control, which will result in the output acceleration being set to 0. If any of the subfeatures are activated, ADDS initially estimates the safety distance. The system is specifically intended to determine three distinct methods of safety distance, as outlined in Section 3.3. ADDS utilizes one of the methods based on the configuration option. Following the determination of the safety distance, ADDS evaluates all parameters related to Time-to-Collision (TTC) and determines the critical distance for the time-based brake system based on the present circumstances. By utilizing these computations, ADDS estimates the required acceleration-deceleration rate and identifies the active feature based on the present circumstances. Finally, the system verifies the activation of the sub features and assigns the required output values. Figure 4.4 displays the overall diagram of the ADDS.

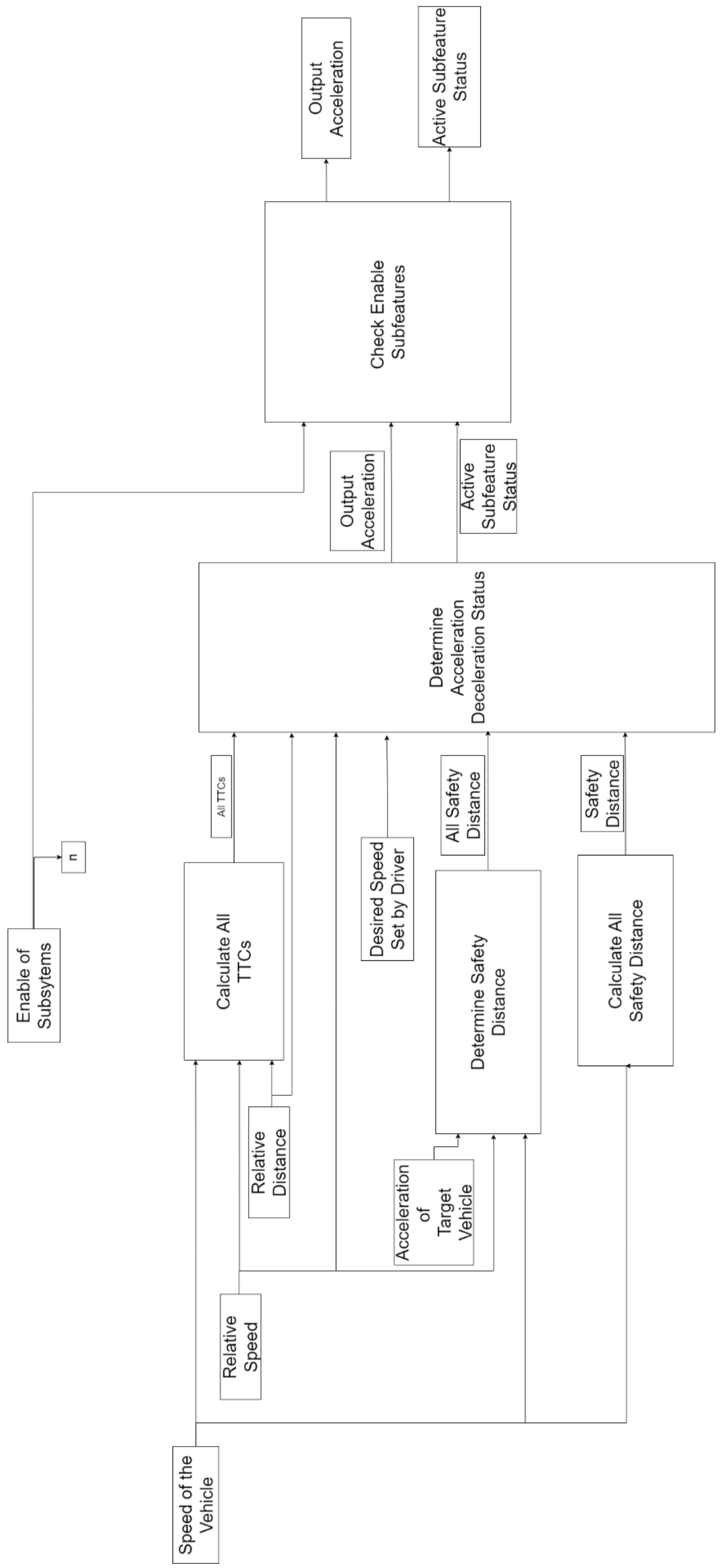

Figure 4.4 General Diagram of the ADDS

4.2.1 Determination of Safety Distance

The subsystem to determine safety distance has been designed to be able to calculate three methods: constant space headway, constant time headway, and variable time headway, according to equations 3.2, 3.3, and 3.5. Constant time headway and variable time headway parameters have been designed with upper and lower threshold values for protecting the system from any spark at the relative distance or acceleration of the target vehicle (Yang, 2020). The diagram of the safety distance for constant space headway, constant time headway, and variable time headway can be seen in Figures 4.5, 4.6, and 4.7.

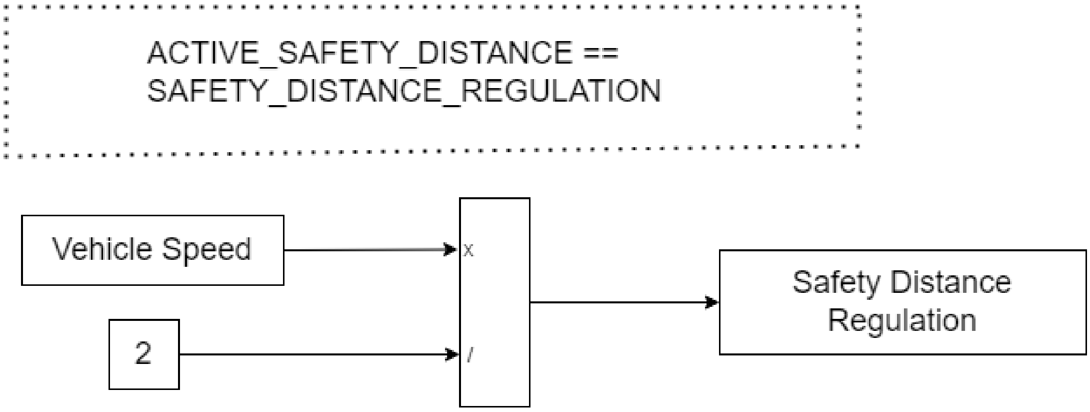

Figure 4.5 Safety Distance Calculation with CSH

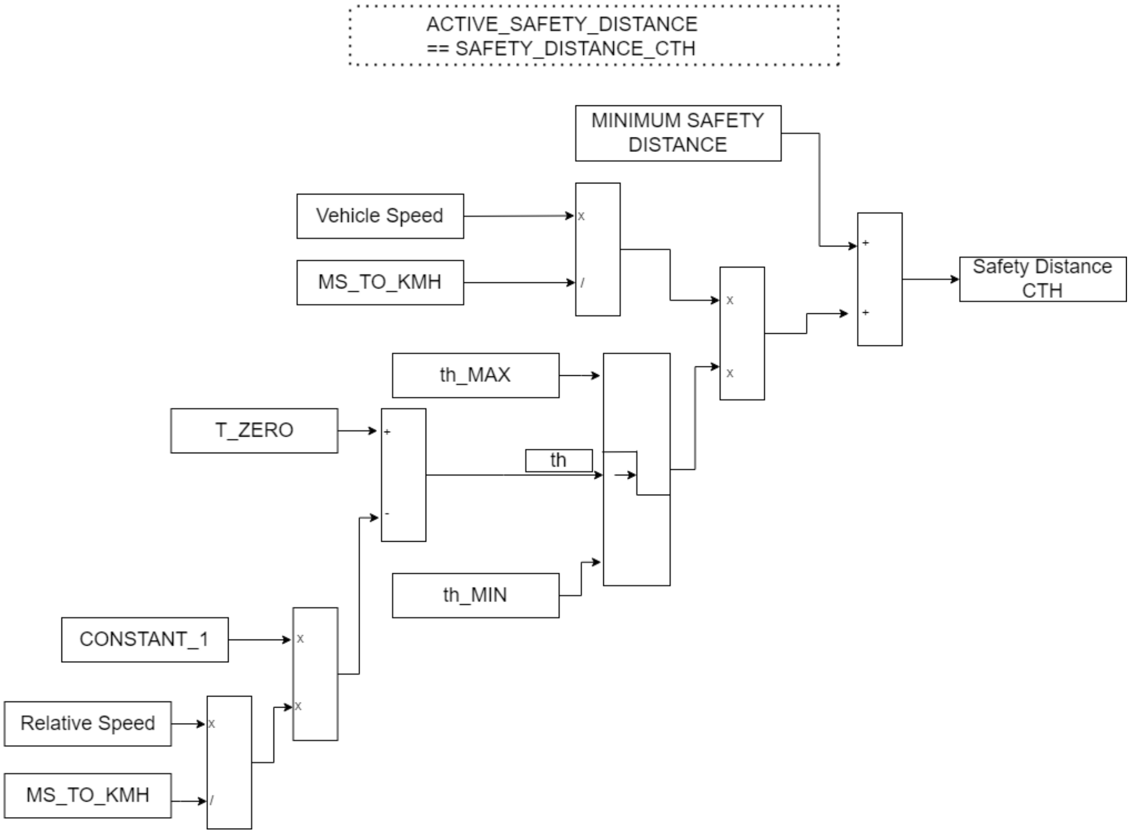

Figure 4.6 Safety Distance Calculation with CTH

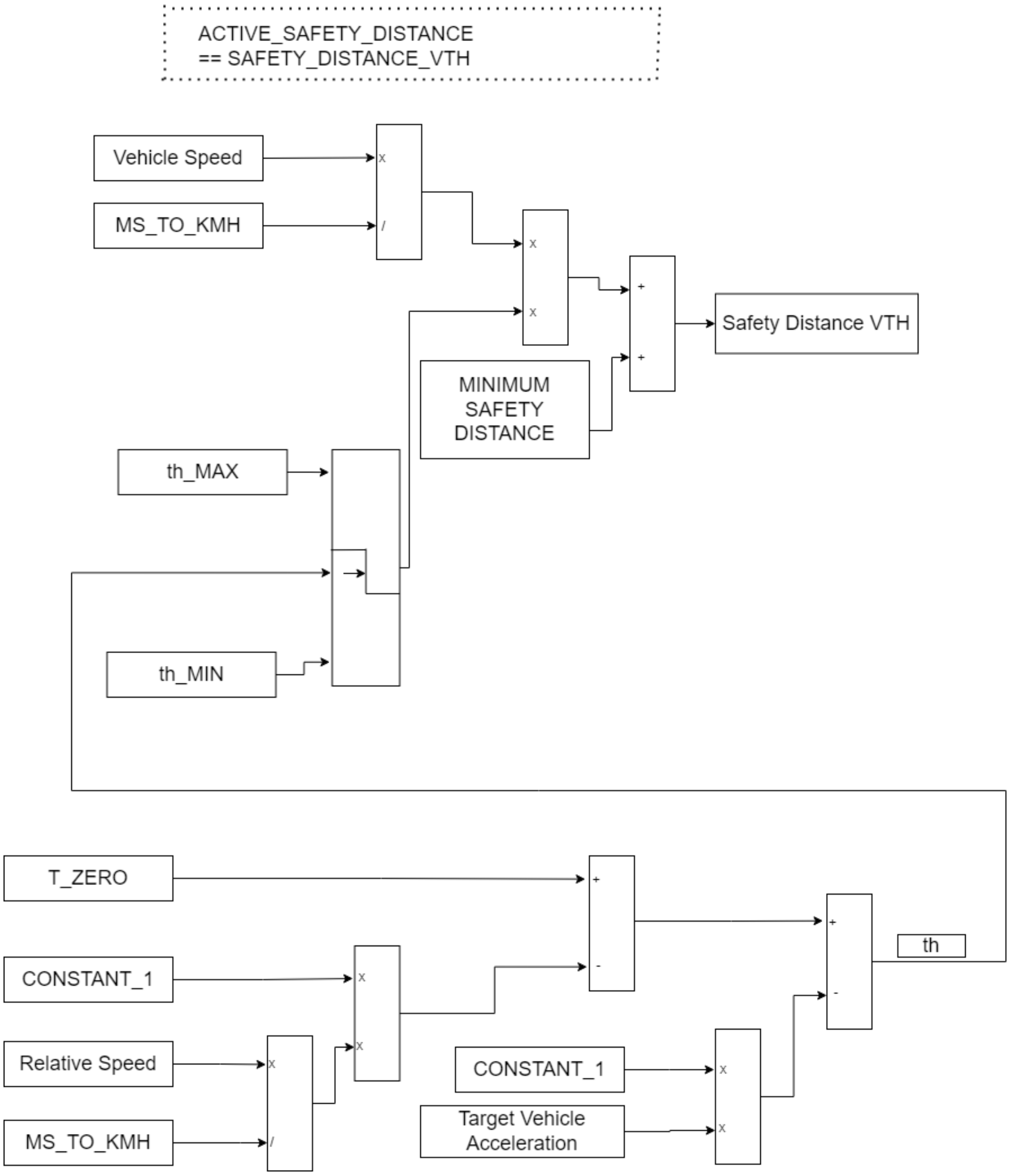

Figure 4.7 Safety Distance Calculation with VTH

4.2.2 Time-based system design

ADDS calculates the required acceleration or deceleration using a time-based brake system. Section 3.4 has been explained as to how it is modelled for an emergency brake system (Hilmi, 2019). In this study, not only the emergency brake system was modelled with a time-based system, but also other features such as collision warning avoidance, adaptive cruise control, and cruise control systems were modelled. To realize this, all sub features are located in one spectrum with their own threshold values for TTC. Also, a time-based system has been covering the virtual target model by using parameter passing between CC and ACC (Bleek, 2007). The spectrum for the time-based system for ADDS can be seen in Figure 4.8.

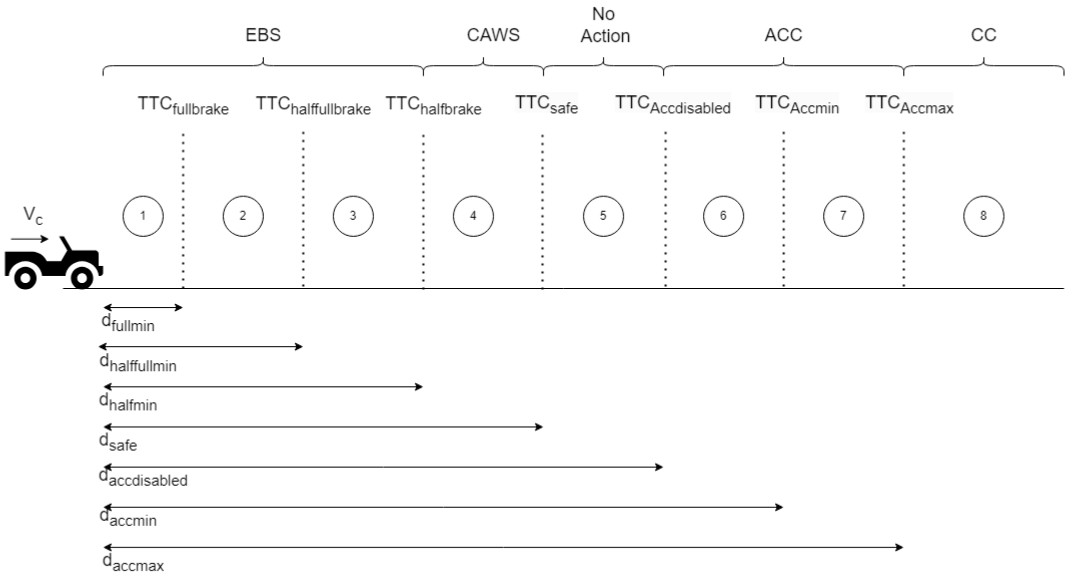

Figure 4.8 Spectrum of Time Based System for ADDS

The spectrum contains eight sections, covering from the car's current location to the furthest point within the sensor's range. Every section has its own upper and lower limits for the Time to Collision (TTC) level. The critical distance is determined based on these TTC values. Within the spectrum, section one represents a domain where collusion is inevitable. The emergency brake system should be triggered in sections two and three. The collusion warning avoidance system should be activated in section four. Section five is a field that should remain inactive, as it does not fall under any of the sub-feature fields. The activation of adaptive cruise control is applicable in section six and seven. The activation of cruise control should occur in section eight. The time to collision values can be computed for each threshold by utilizing equation 4.3.

$$TTC_{xxx} = \frac{\frac{V_c^2}{2 * a_{thresh}}}{V_{rel}} \tag{4.3}$$

where TTC_{xxx} is the time to collusion threshold for any limitation such as full-brake, half-full-brake, acc_{max}, V_c is the vehicle speed, a_{thresh} is the acceleration threshold for that area and V_{rel} is relative speed. The safety distance for each section can be calculated using equation 4.4.

$$d_{xxx} = TTC_{xxx} * V_{rel} \tag{4.4}$$

where dxxx is the critical safety distance for any limitation such as full-brake, half-full-brake, or acc_{max} TTC_{xxx} is the time to collusion threshold for the same field, and V_{rel} is relative speed.

The ADDS algorithm computes the necessary acceleration-deceleration rate and updates the section status based on the activated section. Section one is activated if the current Time to Collision (TTC) is less than $TTC_{fullbrake}$ or the relative distance is less than $d_{fullbrake}$. This section is titled "Inevitability of Collisions" due to the car's inability to stop before colliding, with the objective being to minimize harm. The system adjusted the deceleration to its highest level and indicated that it was functioning as an emergency brake system.

Section two is enabled when the current TTC is smaller than the TTC half-full brake or the relative distance is smaller than the half-full brake. This section is called the area of full brake. The system set the status of the emergency brake system and deceleration is calculated with equation 4.5.

$$a_{dec} = \frac{V_c{}^2}{2 * d_{rel}} \tag{4.5}$$

where V_c is vehicle speed and d_{rel} is relative distance between the cars.

Section three is enabled when the current TTC is smaller than the TTC half-brake or the relative distance is smaller than the half-full brake. This section is called the area of the half brake. The system sets the status of the emergency brake system, and deceleration is calculated with equation 4.5.

Section four is enabled when the current TTC is smaller than the TTC safe or the relative distance is smaller than the d_{safe} brake. This section is called the area of the collision avoidance warning system. The system sets the status of the collision avoidance warning system, and deceleration is calculated with equation 4.5.

Section five is enabled when the current TTC is smaller than the disabled $TTC_{Accdisabled}$ or the relative distance is smaller than the $d_{disabled}$. This section is called the no action area, as it is not in the field of any feature. The system sets the status of the default control, and deceleration is 0.

Section six is enabled when the current TTC is smaller than the TTC_{accmin} or the relative distance is smaller than the d_{accmin}. This section is called the adaptive cruise control decrease area, as the system needs deceleration when ACC is active. The system sets the status of the adaptive cruise control, and deceleration is calculated with equation 4.5, considering its maximum deceleration limitation.

Section seven is enabled when the current TTC is smaller than the TTC_{accmax} or the relative distance is smaller than the d_{accmax}. This section is called the adaptive cruise control in the tracking area, as the system tries to keep the relative speed at 0 while tracking the car. The system sets the status of the adaptive cruise control, and acceleration is calculated with equation 4.6, considering its maximum deceleration limitation and the desired speed set by the driver.

$$a_{need} = \frac{{V_{rel}}^2}{2 * (d_{rel} - d_{accmin})} \tag{4.6}$$

where V_{rel} is relative speed and d_{rel} is relative distance between the cars and d_{accmin} is threshold distance for acc_{min} acceleration level.

Section eight is enabled when the current TTC is greater than the TTC_{accmax} or the relative distance is greater than the d_{accmax}. This section is called the cruise control area. The system sets the status of the cruise control, and acceleration is set to maximum acceleration while considering the desired speed set by the driver.

4.3.3 Calculation of all-time collusion parameters

ADDS calculates time to collusion parameters for each threshold level of features in the Calculate All TTCs subsystem according to formula 4.3. The diagram of the Calculate All TTCs subsystem can be seen in Figure 4.9.

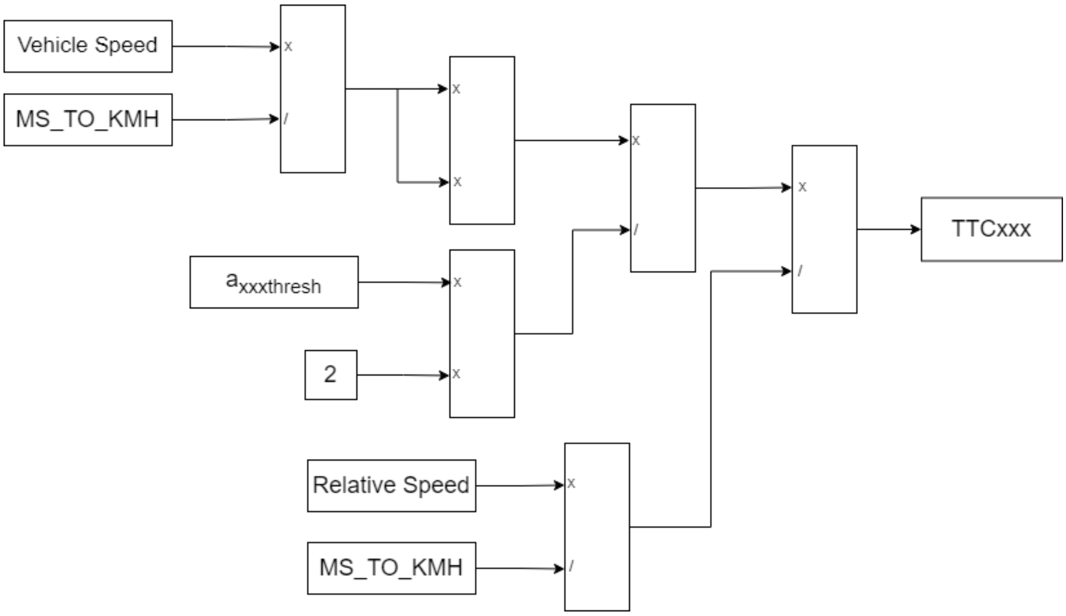

Figure 4.9 Calculation of the Time to Collusion Parameters

4.3.4 Calculation of all Safety Distance

ADDS calculates safety distance parameters for each threshold level of features in the Calculate All Safety Distance subsystem according to formula 4.4. The diagram of the Calculate All Safety Distance subsystem can be seen in Figure 4.10.

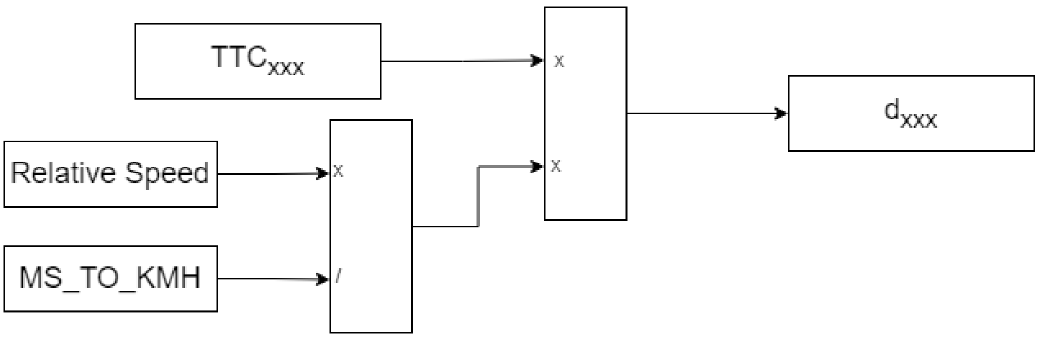

Figure 4.10 Calculation of the Safety Distance Parameters

4.3.5 Determining Acceleration Deceleration Status

The active feature is determined by ADDS by a comparison of the current Time to Collision (TTC) with all TTCs, the current relative distance, and the computed safety distance. The acceleration or deceleration rate can be determined by applying equations 4.5 and 4.6, depending on the current state of the system. Figure 4.11 displays the diagram of the Determining Acceleration Deceleration Status subsystem.

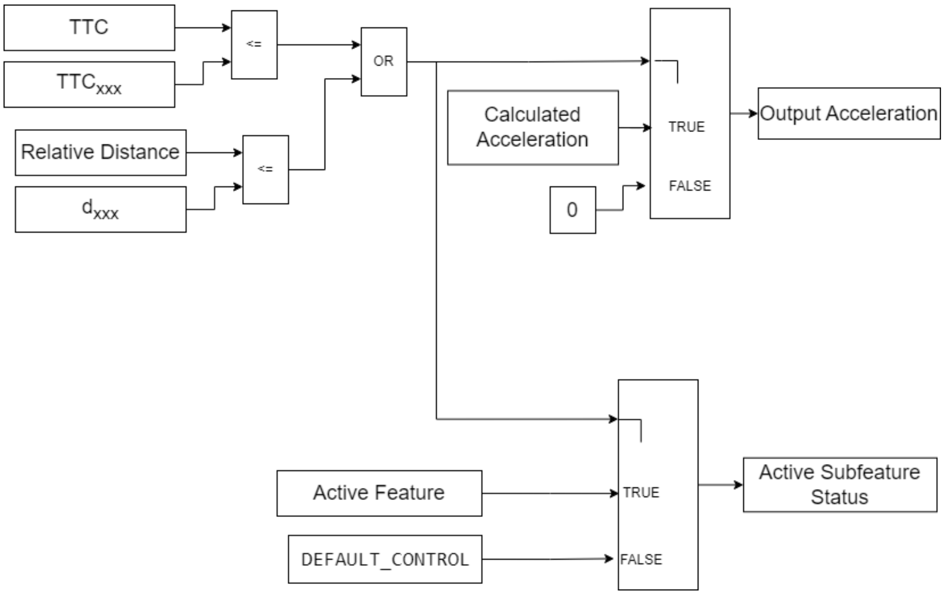

Figure 4.11 Diagram of Determining Acceleration Deceleartion System

4.3.6 Check Enable Status

Lastly, ADDS verifies the enable flag of the fields. If the enable flag is not activated, it will provide default values. Otherwise, it will provide computed values. Figure 4.12 displays the diagram of the Check Enable Status subsystem.

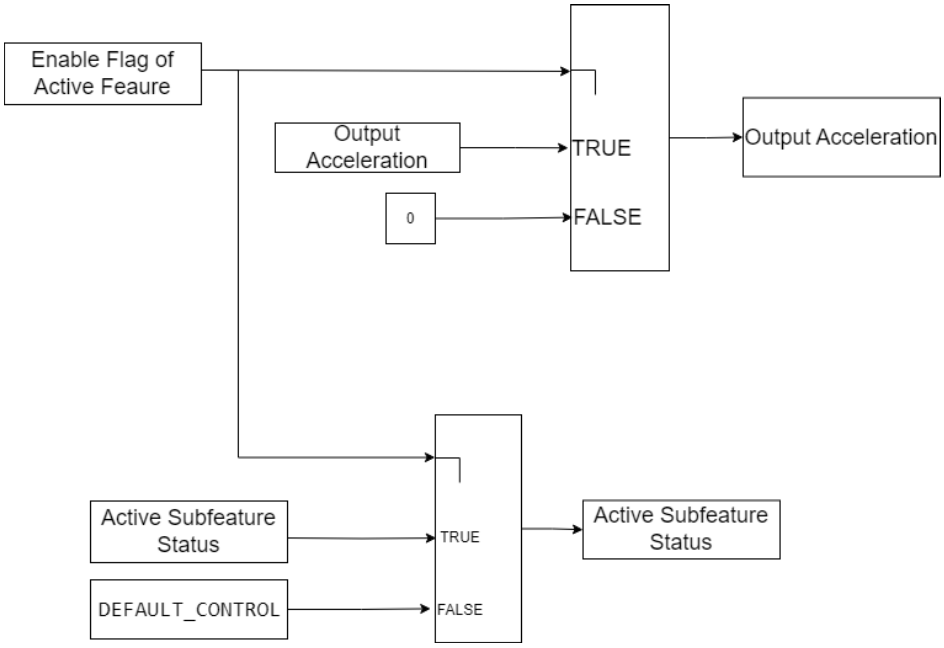

Figure 4.12 Diagram of Check Enable Status

The parameters utilized in the design and calculation of the model are presented in table 4.1. The safety distance calculation parameter is mostly derived from the work of (Yang, 2020), while the Emergency Brake Limit control is mainly based on the research of (Guo, 2020), (Hilmi, 2019), and (Bleek, 2007).

Table 4.1 All parameters used in Model Design and Calculations

Paramater	Value	Description
MS_TO_KMH	3.6	the constant to convert speed unit from m/s to km/h or vice versa
TIMER_PARAM	0.1	this is calculated from MCU timer rate
d0 (MINIMUM SAFE DISTANCE)	5	For CTH and CTH, the minimum safety distance
t0 (T ZERO)	1.423	for CTH and VTH, constant time headway
c1 (CONSTANT_1)	0.03588	for CTH and VTH, adjustment factor for relative speed
c2 (CONSTANT_2)	0.0369	for CTH and VTH, adjustment factor for acceleration of target vehicle
th_MIN	0.2	minimum threshold value for constant time headway and variable time headway
th_MAX	2.2	maximum threshold value for constant time headway and variable time headway
FUHALFFULLBRAKE_MS2	8	Threshold acceleration value to trigger full-brake, in m/s
HALFFULLBRAKE_MS2	7	Threshold acceleration value to trigger half-full brake, in m/s
HALFBRAKE_MS2	6	Threshold acceleration value to disable adaptive cruise control, in m/s
ACCMIN_MS2	2.5	Threshold acceleration minimum value for adaptive cruise control tracking, in m/s
ACCMAX_MS2	2	Threshold acceleration maximum value for adaptive cruise control tracking, in m/s
ACC_ACCEL_MAX	3	Maximum acceleration rate for adaptive cruise control, in m/s
ACC_DECEL_MAX	-3	Maximum deceleration rate for adaptive cruise control, in m/s

CHAPTER FIVE

TESTS, RESULTS AND ANALYSIS

The ADDS system has gone through testing in various circumstances. A test environment has been established to facilitate comprehensive testing of the system using various inputs and outputs. The test environment supplies inputs to the ADDS and, based on the ADDS outputs, gives inputs for the next cycle. Figure 5.1 displays the overall layout of the test environment incorporating the ADDS system.

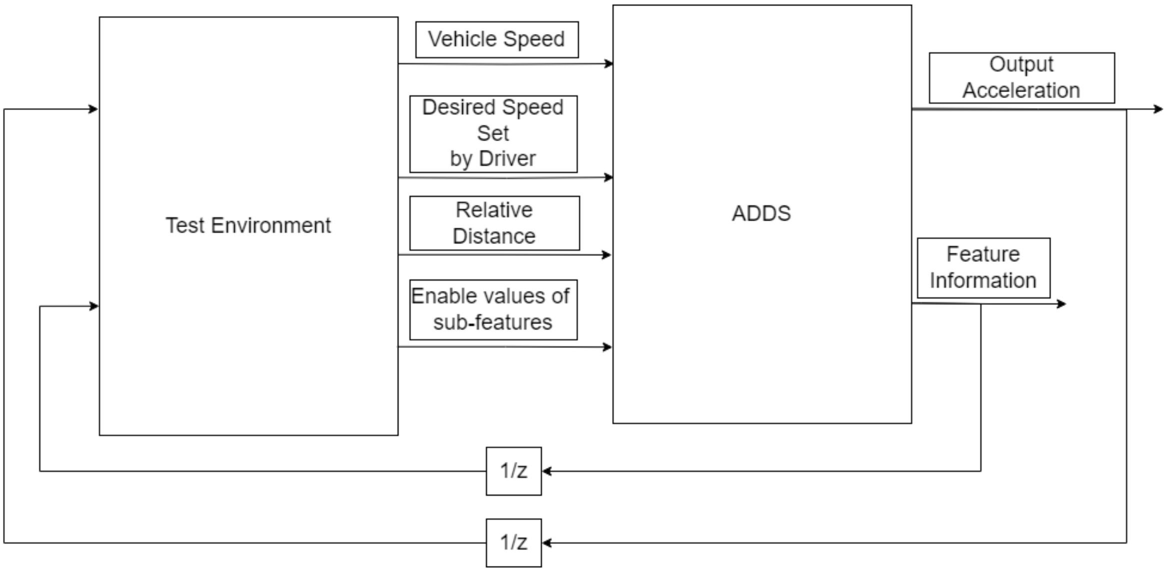

Figure 5.1 Diagram of Test Environment with ADDS

The test environment parameters and ADDS outputs have been transmitted to the MCU board via serial communication. The results are assessed using that data. The structure of the data frame is displayed in Table 5.1.

Table 5.1 Data Frame Structure

Byte Number	Data	Scale	Comment
1	“<“	N/A	Start of the frame
2-5	Relative Distance	10	Relative Distance in meter
6	“.”	N/A	Separator between values
7-9	Vehicle Speed	1	Vehicle Speed in km/h
10	“.”	N/A	Separator between values
11-15	Relative Speed	10	Relative Speed in km/h
16	“.”	N/A	Separator between values
17-20	Safety Distance	10	Safety Distance in m
21	“.”	N/A	Separator between values
22-26	Output Acceleration	1000	Acceleration value in m/s^2
27	“.”	N/A	Separator between values
28	Active Sub Feature	1	0: DEFAULT 1: EBS_FULL 2: EBS_HALF 3: CAWS 4: ACC 5: CC
29	“>“	N/A	End of the frame
30	'\0'	N/A	End of Line

A simulation has been developed using Python on a PC, utilizing the data frame as the car dashboard depicted in Figure 5.2.

The dashboard displays the velocity of the primary vehicle using both a vehicle speedometer and a numerical value. It rapidly simulates the car's position by utilizing the relative distance value. The blue automobile symbolizes the host vehicle, while the red car symbolizes the target vehicle. In addition, the numerical representation of the relative distance between the cars is displayed in this car simulation. Simultaneously, four parameters have been presented at the bottom: the relative speed between the cars, the safety distance value given the current circumstances, the acceleration-deceleration request from the ADDS system, and the status of the active sub feature (CC, ACC, CAWS, EBS, or Default).

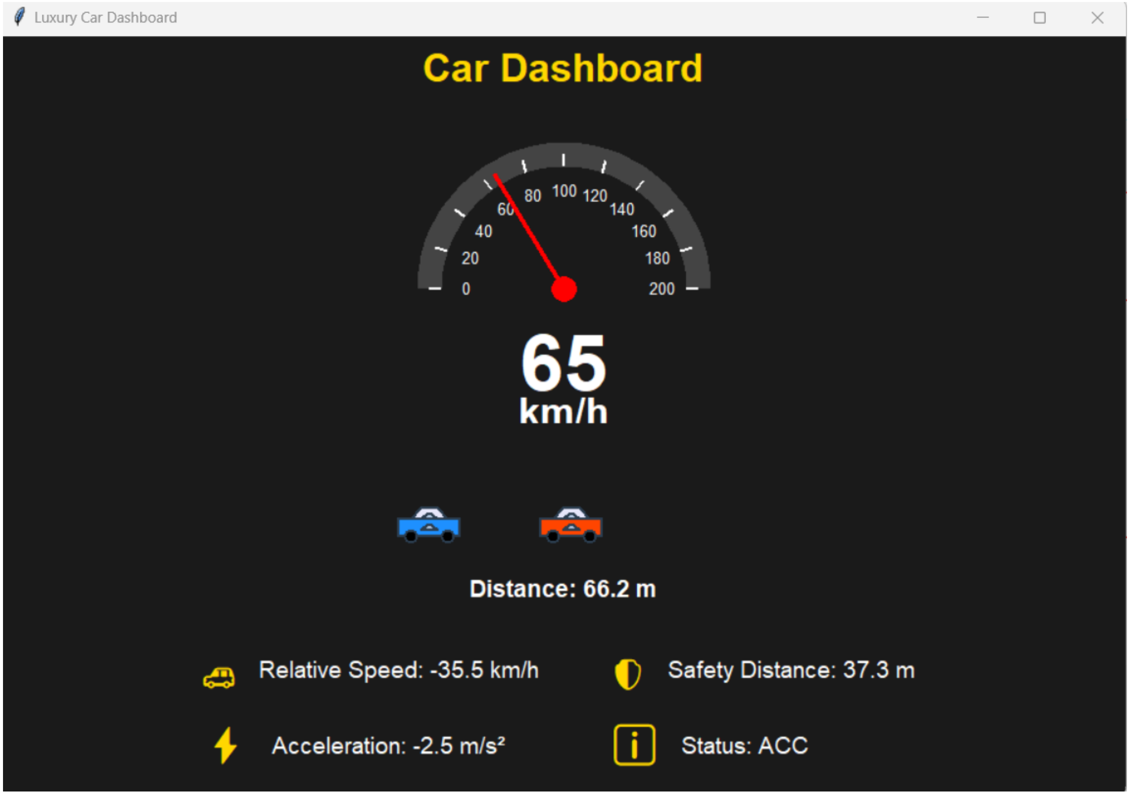

Figure 5.2 Dashboard Simulation

Six different test scenarios have been evaluated using ADDS and the test environment. There are two open-loop tests and four closed-loop tests. Open loop tests are conducted to observe safety distance measurements and assess the overall behavior of a time-based system. The close-loop tests are specifically designed to observe the system's response in simulated real-life situations.

5.1 Test-1 : Constant speed, host vehicle faster than target vehicle

The initial distance between the cars is 300 meters. The host vehicle maintains a constant speed of 70 km/h, while the target vehicle maintains a constant speed of 69 km/h. This test case is formulated as an open loop, indicating that the test environment does not utilize the outputs of the ADDS. Figure 5.3 provides a concise representation of the structure of Test-1.

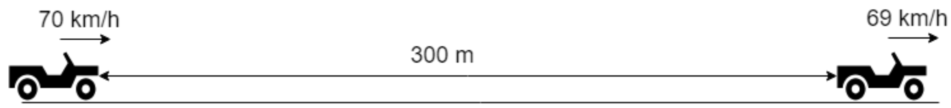

Figure 5.3 Test-1 Structure Overview

The test has been run with all safety distance methods: CSH (Constat Space Headway), CTH (Constant Time Headway), and VTH (Variable Time Headway).

5.1.1 Results of Test-1

The safety distance measurement for Test-1 can be seen in Figures 5.4 measurement with CHS, 5.5 measurement with CTH, and 5.6 measurement with VTH.

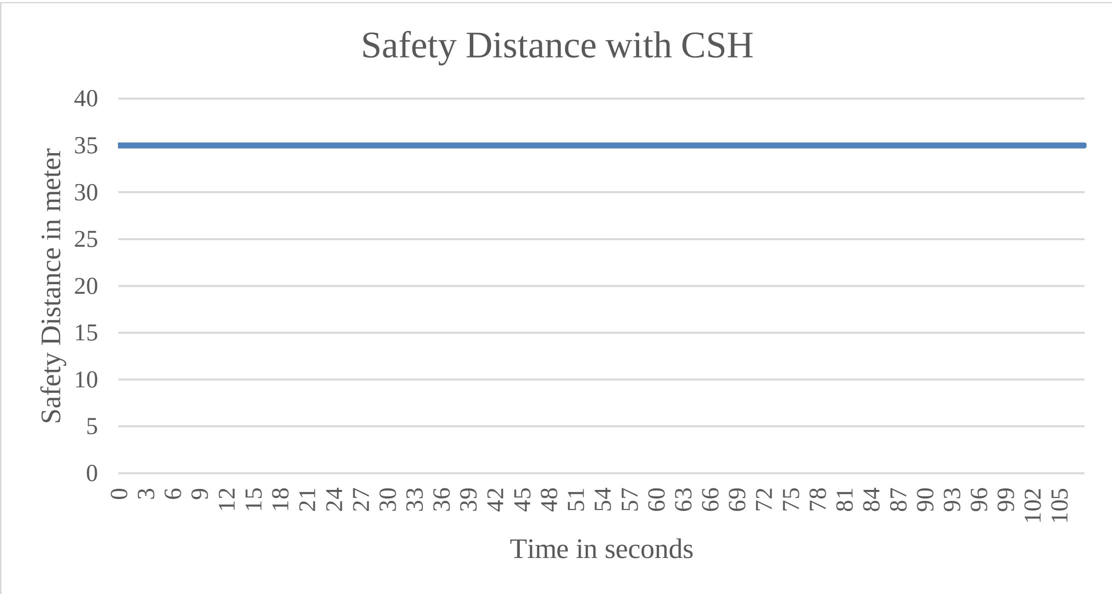

Figure 5.4 Safety Distance Measurement with CSH for Test-1

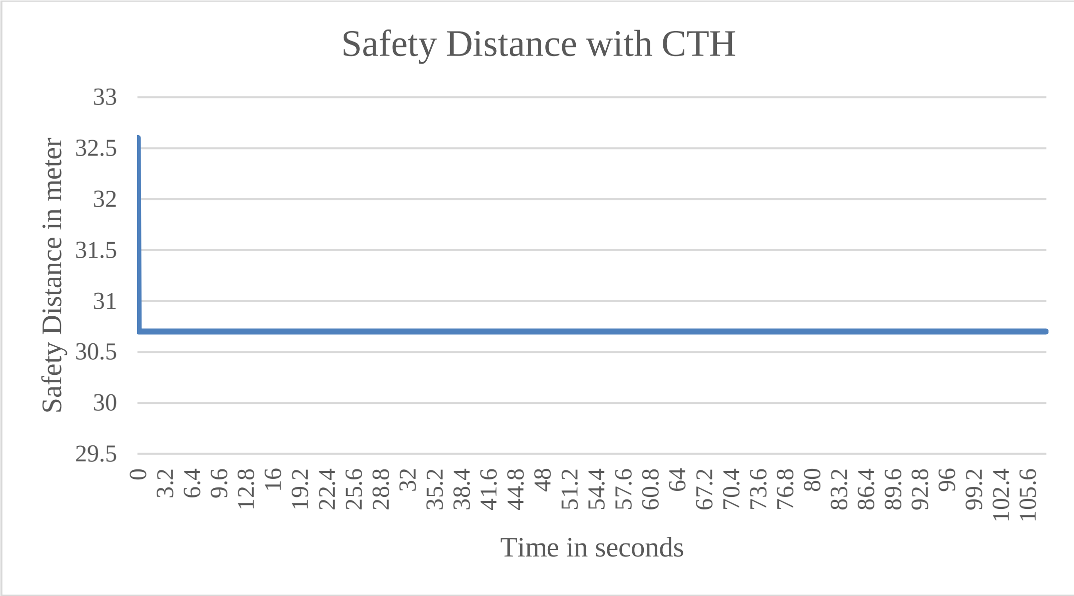

Figure 5.5 Safety Distance Measurement with CTH for Test-1

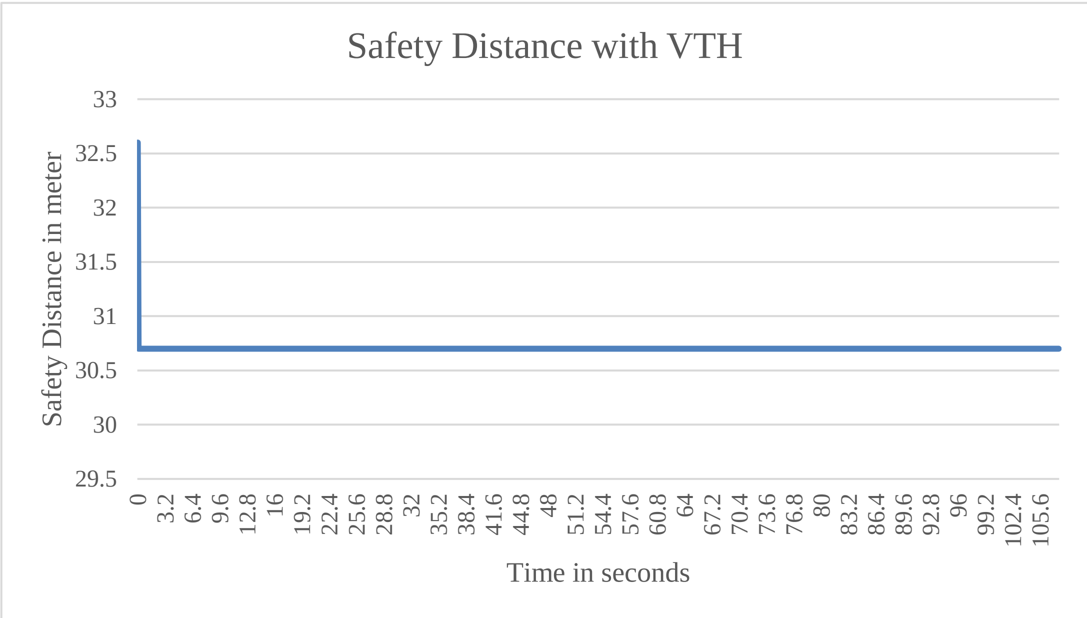

Figure 5.6 Safety Distance Measurement with VTH for Test-1

The output acceleration of the system for Test-1 can be seen in Figures 5.7 measurement with CHS, 5.8 measurement with CTH, and 5.9 measurement with VTH.

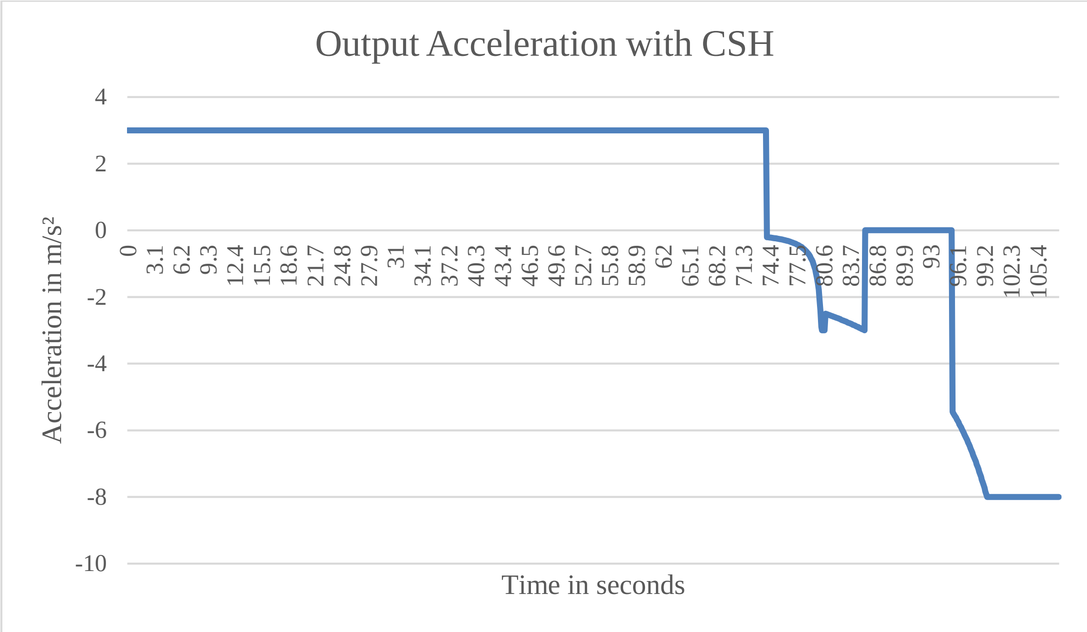

Figure 5.7 Output Accelearation of the System with CSH for Test-1

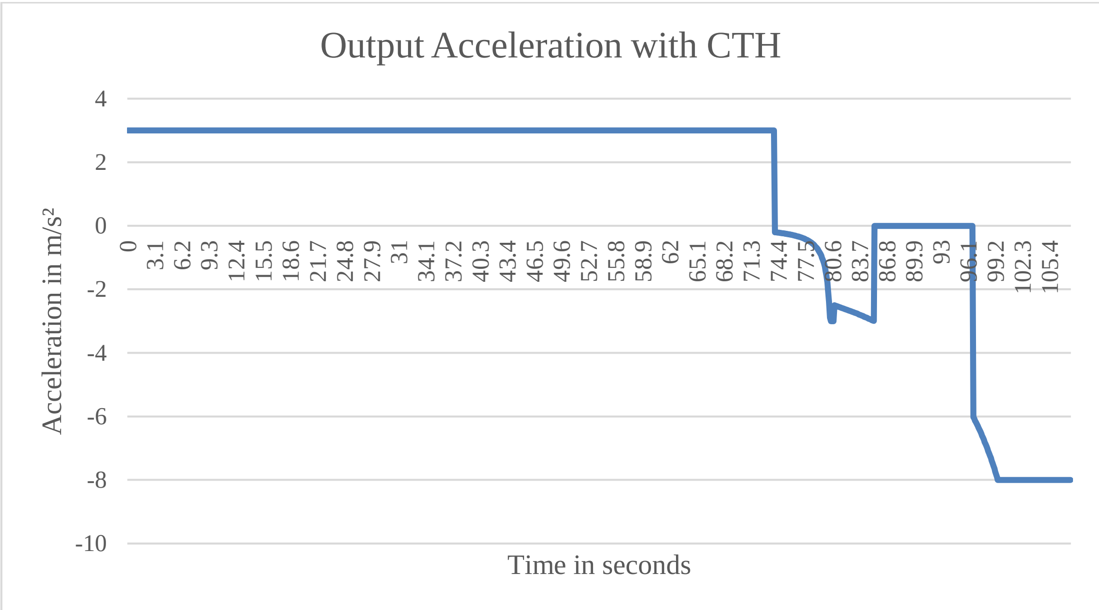

Figure 5.8 Output Accelearation of the System with CTH for Test-1

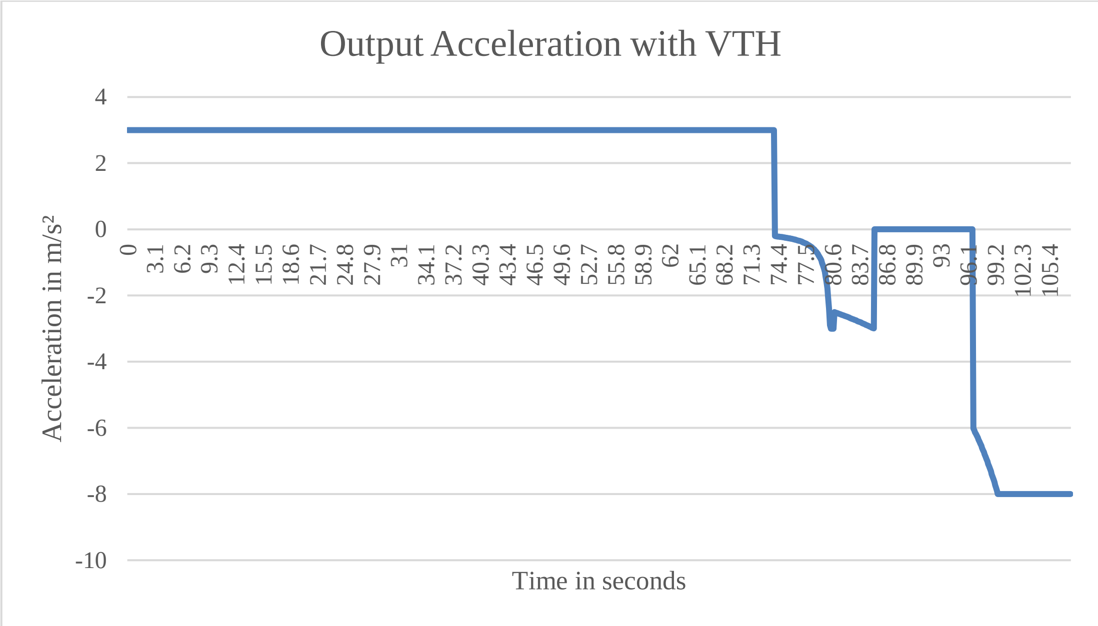

Figure 5.9 Output Accelearation of the System with VTH for Test-1

The active sub feature status for Test-1 can be seen in Figures 5.10 measurement with CHS, 5.11 measurement with CTH, and 5.12 measurement with VTH.

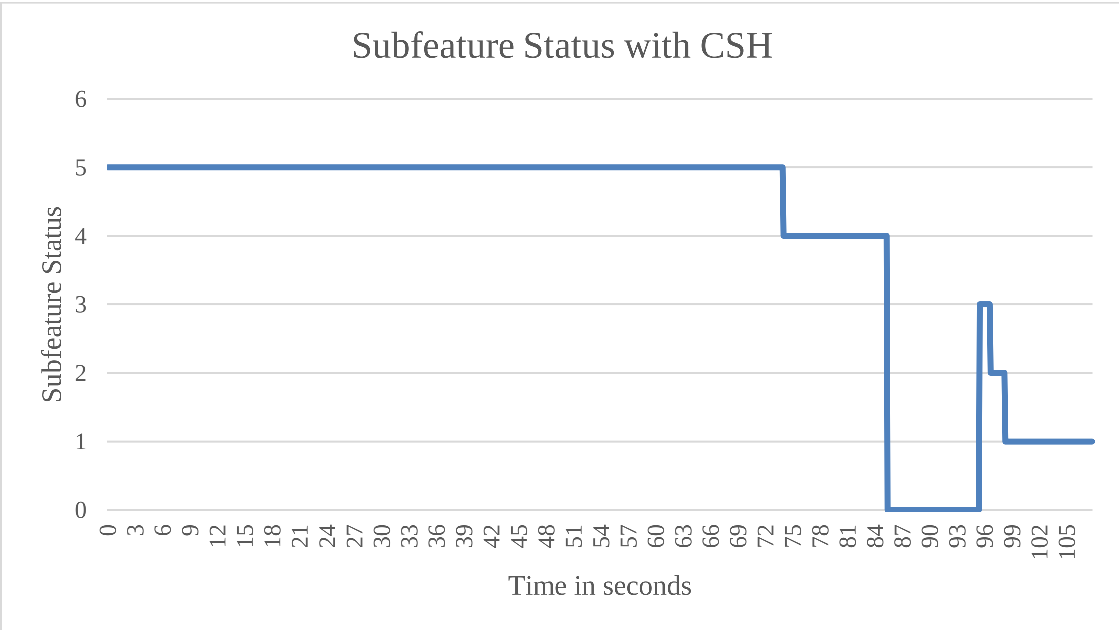

Figure 5.10 Subfeature Status with CSH for Test-1

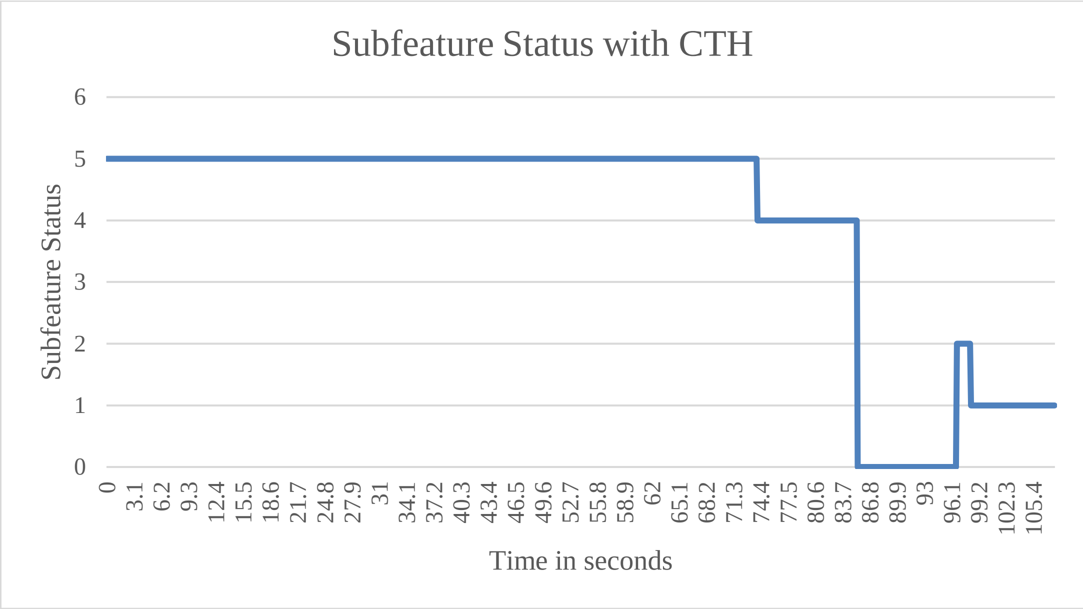

Figure 5.11 Subfeature Status with CTH for Test-1

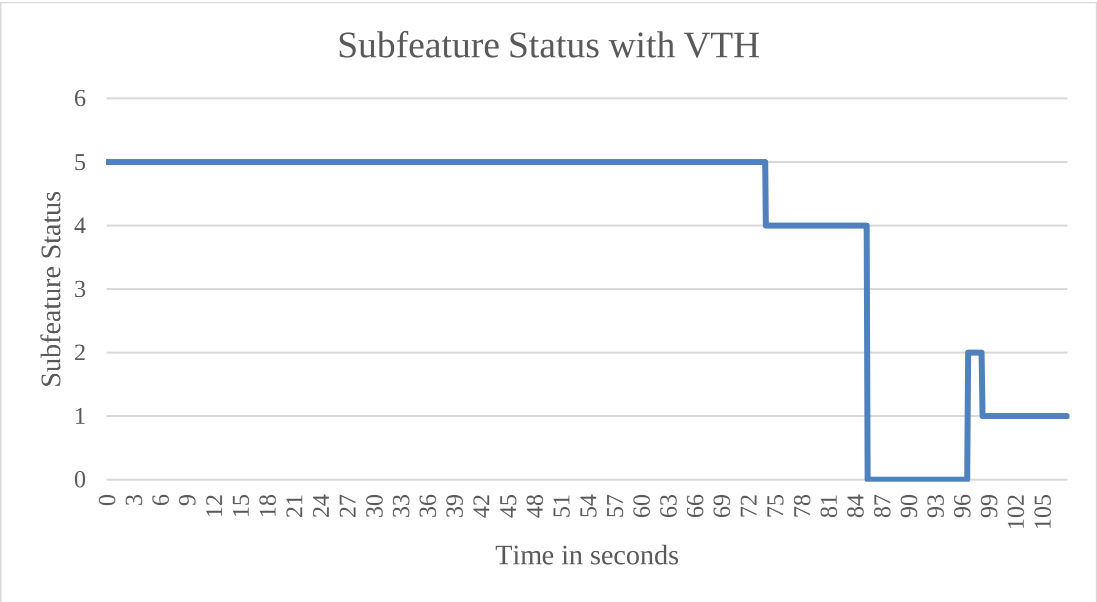

Figure 5.12 Subfeature Status with VTH for Test-1

5.1.2 Analysis of the results of Test-1

Since the test was conducted with both the host vehicle and the target vehicle maintaining a constant speed, the safety distance for CTH and VTH is expected to be the same. This is because the target vehicle does not experience any acceleration, as indicated by equations 3.3 and 3.5. Figure 5.5 and Figure 5.6 provide evidence that CTH and VTH share the same safety distance in the absence of acceleration for the target vehicle. Furthermore, it is anticipated that the output acceleration and the status of the sub features for CTH and VTH will be the same. This can be observed in Figures 5.8 and Figure 5.9 for output acceleration, and Figures 5.11 and Figure 5.12 for sub feature status. Nevertheless, CSH exhibits slightly distinct behavior compared to CTH and VTH. The safety distance is consistently equal to half of the vehicle speed, measured in meters, as demonstrated by equation 3.2 and further supported by Figure 5.4.

The Collision Avoidance Warning System (CAWS) is activated when the distance between the vehicles is less than the prescribed safety distance, as depicted in Figure 4.8. Nonetheless, the ADDS system is always changing, and if the system determines that an immediate braking action is necessary based on present data, then the Emergency Brake System (EBS) takes precedence over the Collision Avoidance Warning System (CAWS). Figure 5.10 shows that only CSH activated the CAWS system, while Figure 5.11 and 5.12 demonstrate that CTH and VTH directly activated the EBS system.

This test demonstrates that ADDS activates all the subordinate features, such as CC, ACC, CAWS, and EBS, as depicted in Figure 5.10, Figure 5.11, and Figure 5.12. Furthermore, it has the capability to effectively handle and control all of these subordinate functionalities based on the provided inputs.

5.2 Test-2: Target vehicle has constant deceleration

The initial distance between the cars is 300 meters. The host vehicle maintains a constant speed of 70 km/h, while the target vehicle also travels at 70 km/h but decelerates by 10 km/h each second. This test case is designed to operate as an open loop, indicating that the test environment does not utilize the outputs of the ADDS. Figure 5.13 provides a concise representation of the structure of Test-2.

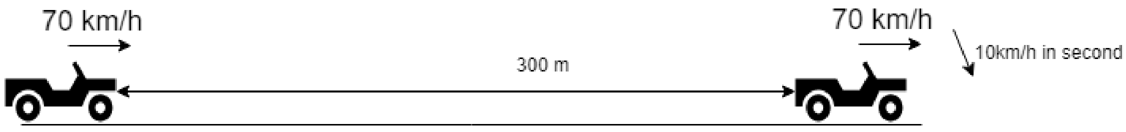

Figure 5.13 Test-2 Structure Overview

The test has been run with all safety distance methods: CSH (Constat Space Headway), CTH (Constant Time Headway), and VTH (Variable Time Headway).

5.1.2 Results of Test-2

The safety distance measurement for Test-2 can be seen in Figures 5.14 measurement with CHS, 5.15 measurement with CTH, and 5.16 measurement with VTH.

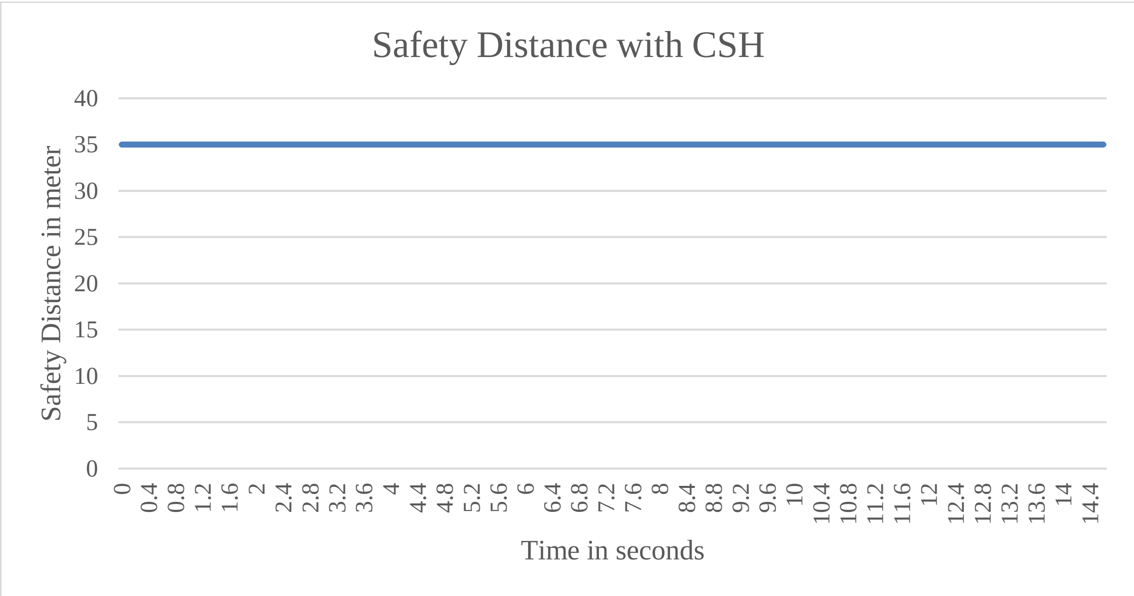

Figure 5.14 Safety Distance Measurement with CSH for Test-2

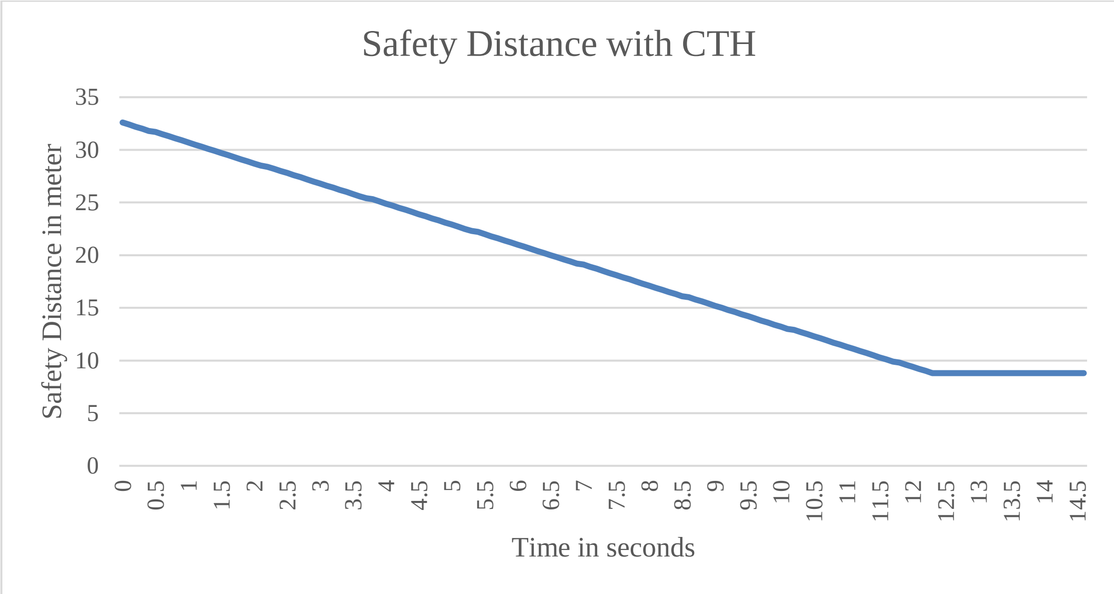

Figure 5.15 Safety Distance Measurement with CTH for Test-2

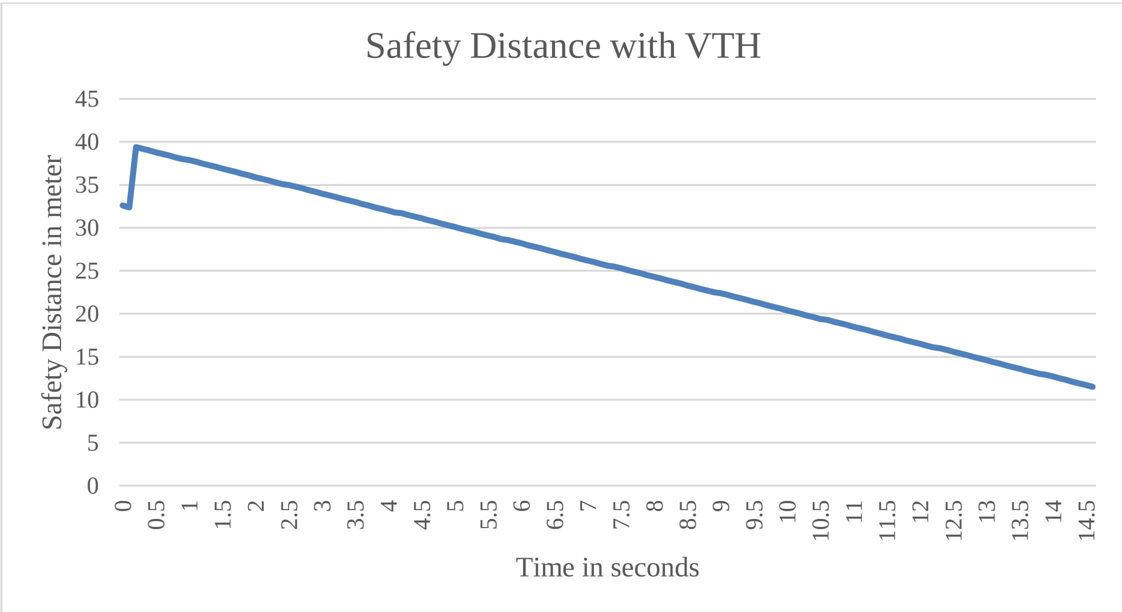

Figure 5.16 Safety Distance Measurement with VTH for Test-2

The output acceleration of the system for Test-2 can be seen in Figures 5.17 measurement with CHS, 5.18 measurement with CTH, and 5.19 measurement with VTH.

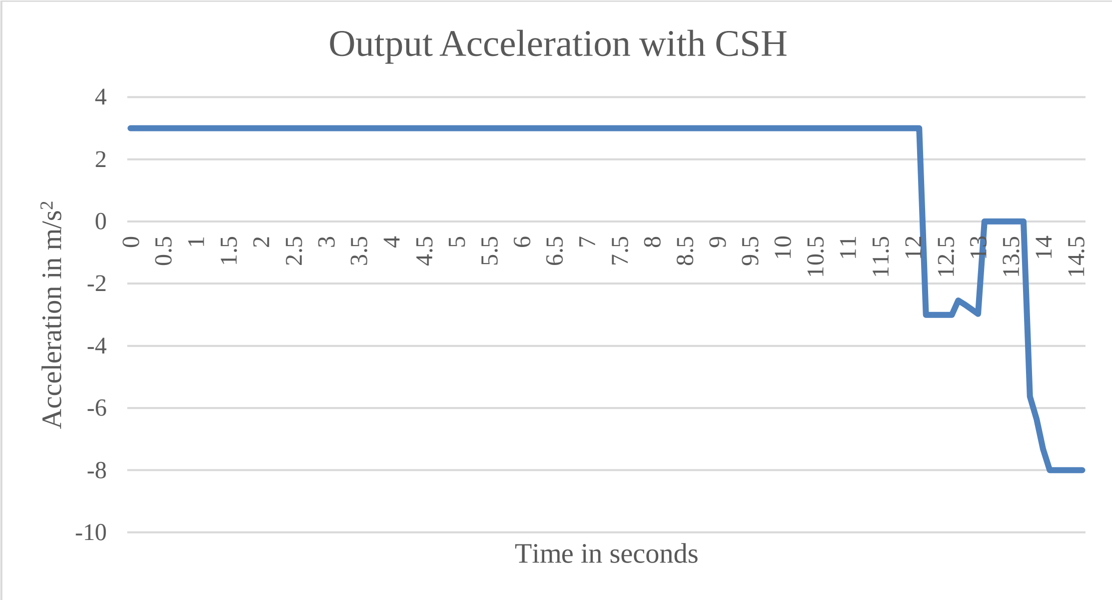

Figure 5.17 Output Accelearation of the System with CSH for Test-2

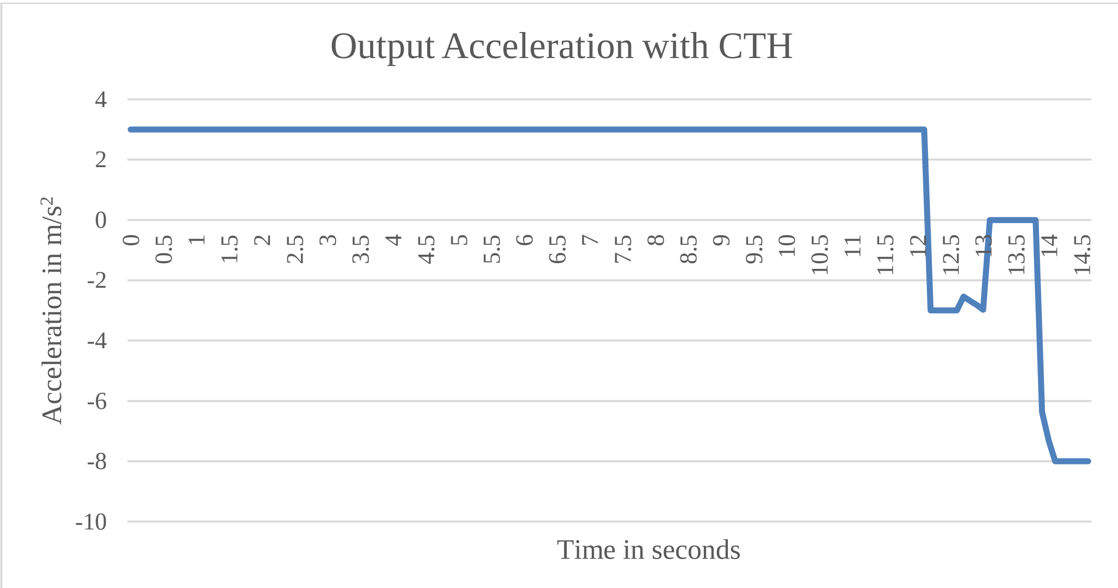

Figure 5.18 Output Accelearation of the System with CTH for Test-2

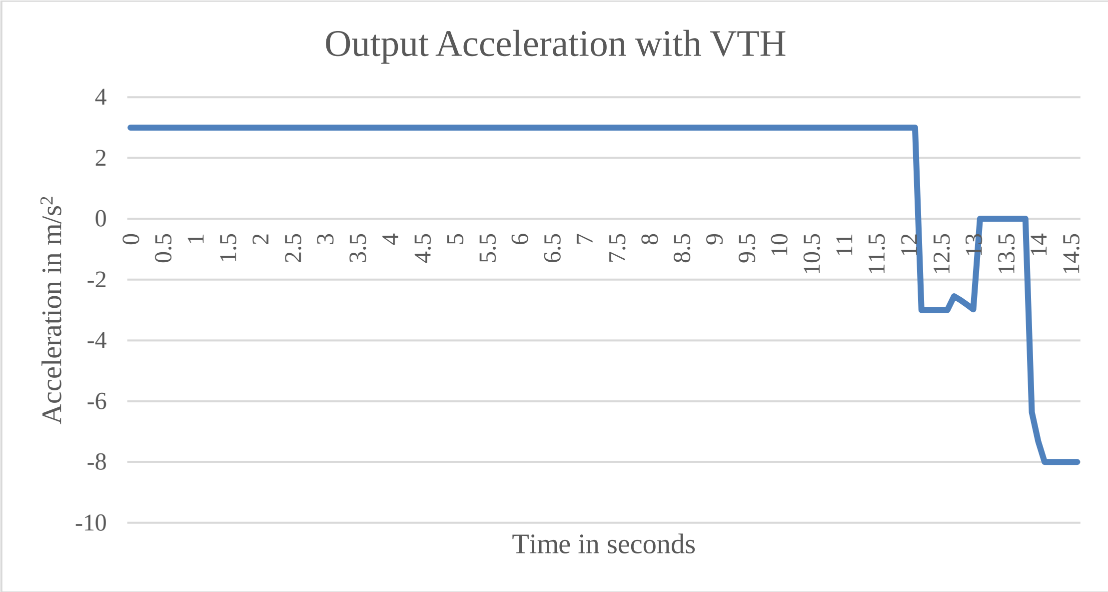

Figure 5.19 Output Accelearation of the System with VTH for Test-2

The active sub feature status for Test-2 can be seen in Figures 5.20 measurement with CHS, 5.21 measurement with CTH, and 5.22 measurement with VTH.

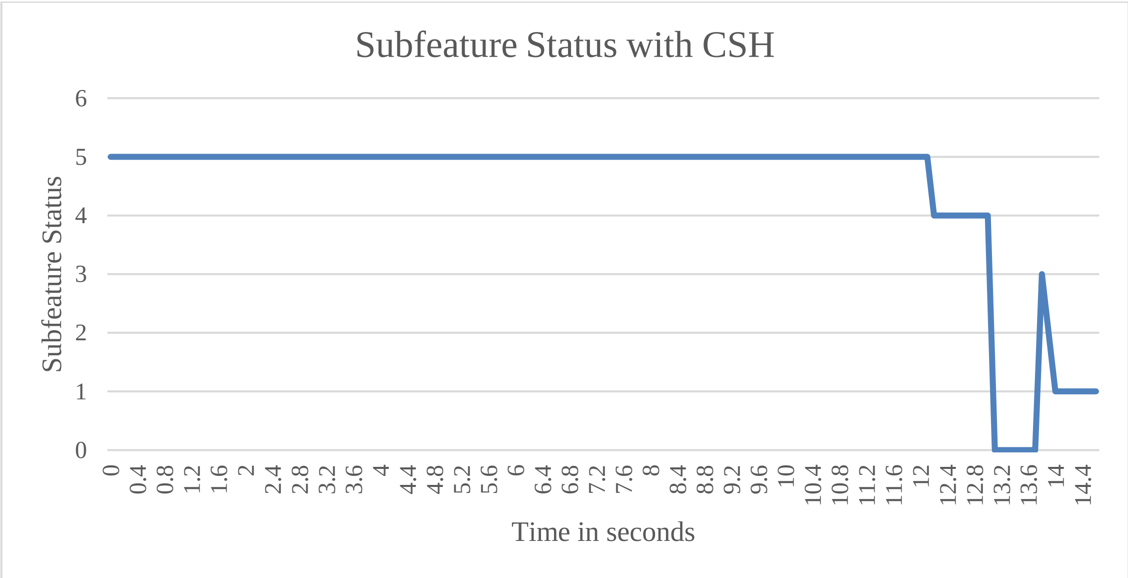

Figure 5.20 Subfeature Status with CSH for Test-2

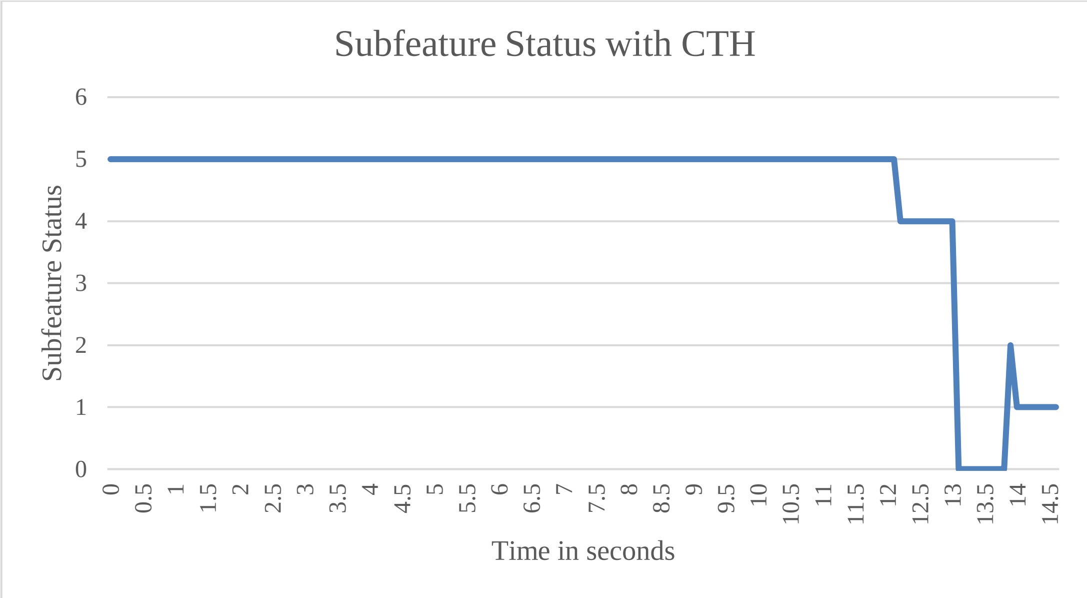

Figure 5.21 Subfeature Status with CTH for Test-2

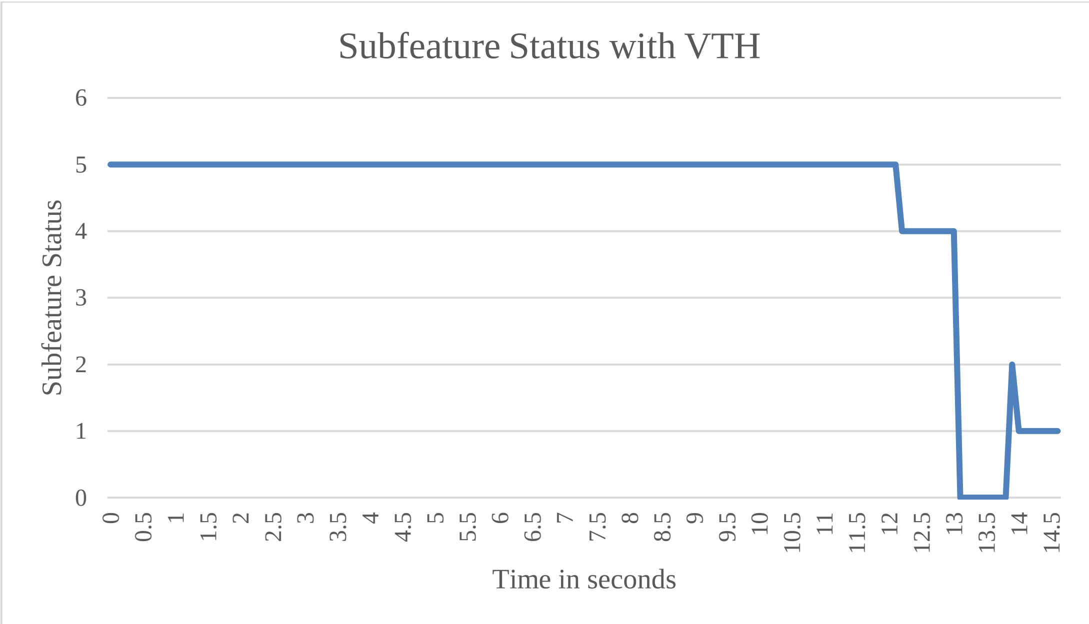

Figure 5.22 Subfeature Status with VTH for Test-2

5.2.2 Analysis of the results of Test-2

Given that the test was conducted with the host vehicle maintaining a constant speed and the target vehicle experiencing a constant deceleration, we can expect the safety distance to be VTH less than CTH, as shown by equations 3.3 and 3.5. By comparing Figure 5.15 and Figure 5.16, it is evident that VTH has a smaller safety distance than CTH.

The CAWS was activated, causing a similar response to the CSH, much like the Test-1. Due to the periodic system, the EBS threshold activates the system prior to the safety distance.

This test demonstrates the accurate calculation of safety distance methods, and successfully activates all the sub features including CC, ACC, CAWS, and EBS, as depicted in Figure 5.20, Figure 5.21, and Figure 5.22.

5.3 Test-3: Target vehicle has constant deceleration and stop

The initial distance between the cars is 100 meters. The host vehicle maintains a constant speed of 100 km/h, while the target vehicle has a speed of 50 km/h and decreases by 10 km/h every second. This test case is designed as a closed-loop system, where the test environment utilizes the outputs of the ADDS and responds accordingly based on their values. Figure 5.23 provides a concise representation of the structure of Test-3.

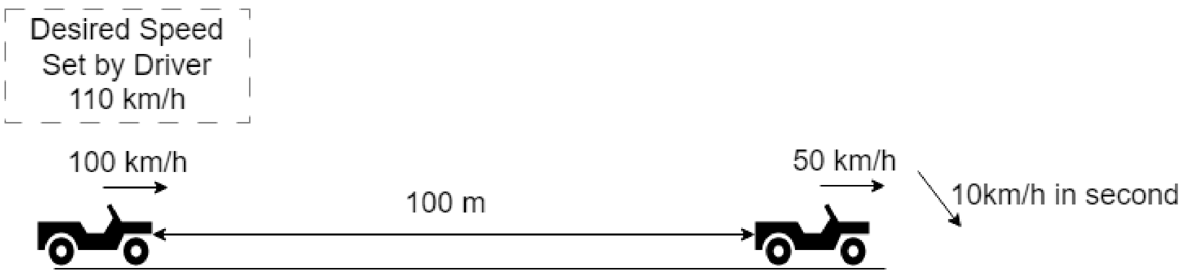

Figure 5.23 Test-3 Structure Overview

The test has been run with all safety distance methods: CSH (Constat Space Headway), CTH (Constant Time Headway), and VTH (Variable Time Headway).

5.3.1 Results of Test-3

The safety distance measurement for Test-3 can be seen in Figures 5.24 measurement with CHS, 5.25 measurement with CTH, and 5.26 measurement with VTH.

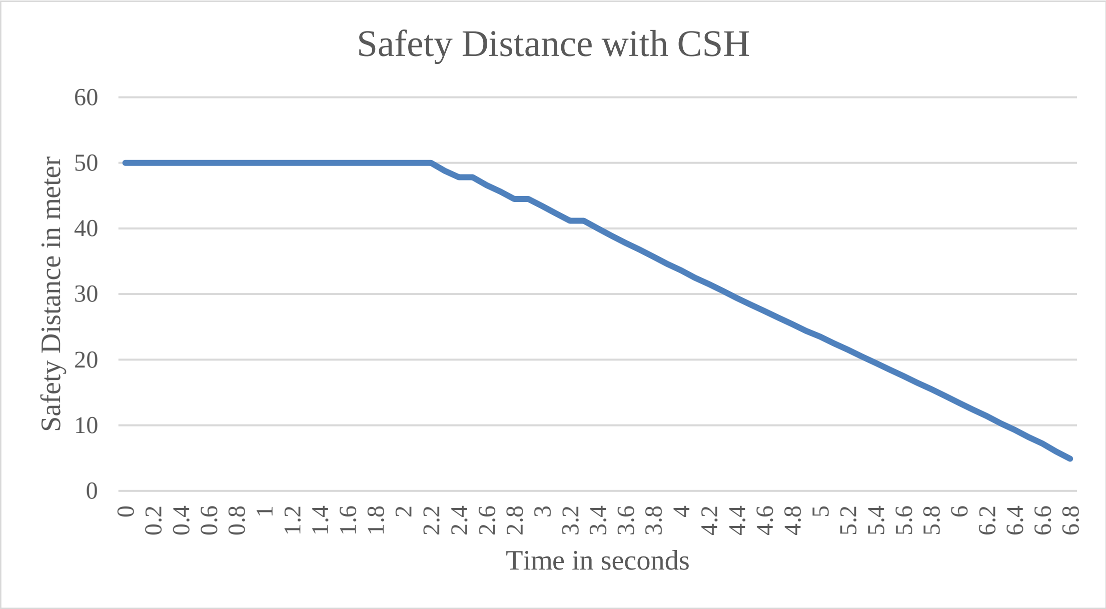

Figure 5.24 Safety Distance Measurement with CSH for Test-3

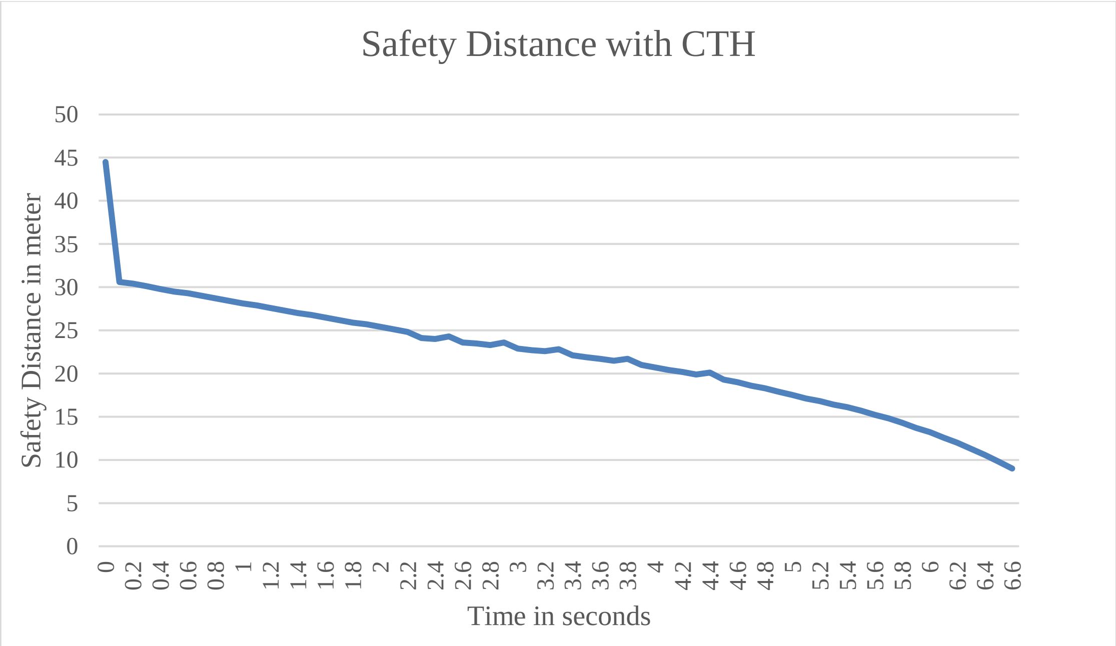

Figure 5.25 Safety Distance Measurement with CTH for Test-3

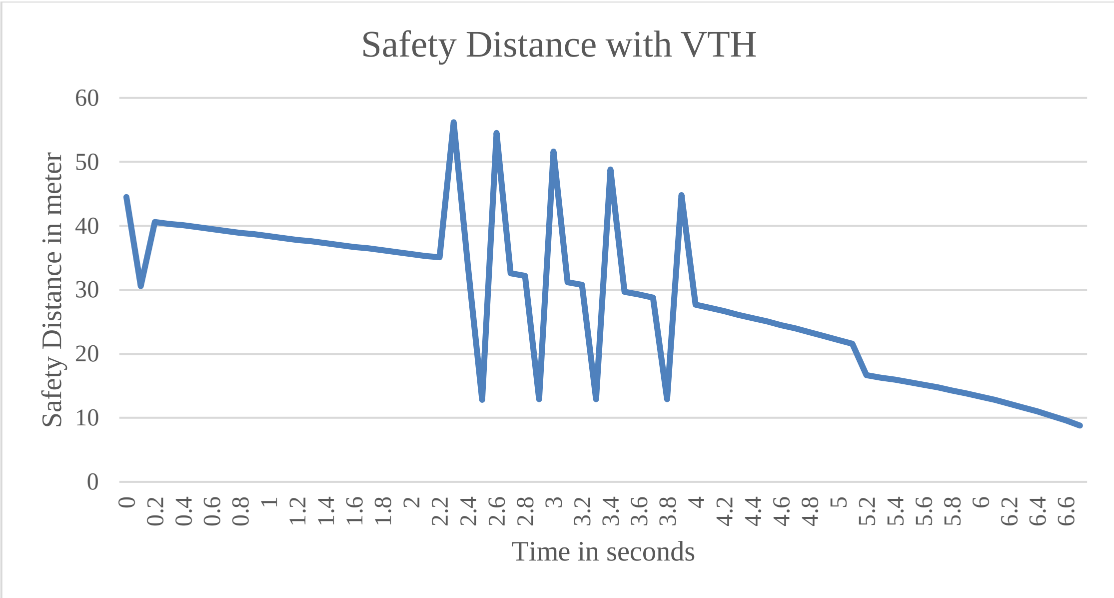

Figure 5.26 Safety Distance Measurement with VTH for Test-3

The output acceleration of the system for Test-3 can be seen in Figures 5.27 measurement with CHS, 5.28 measurement with CTH, and 5.29 measurement with VTH.

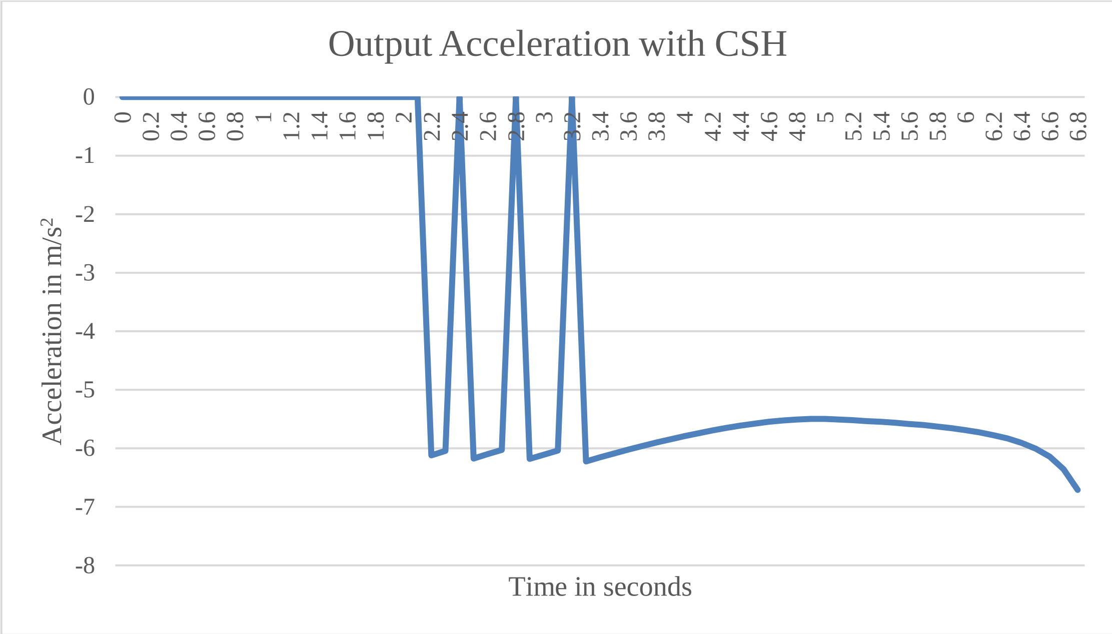

Figure 5.27 Output Accelearation of the System with CSH for Test-3

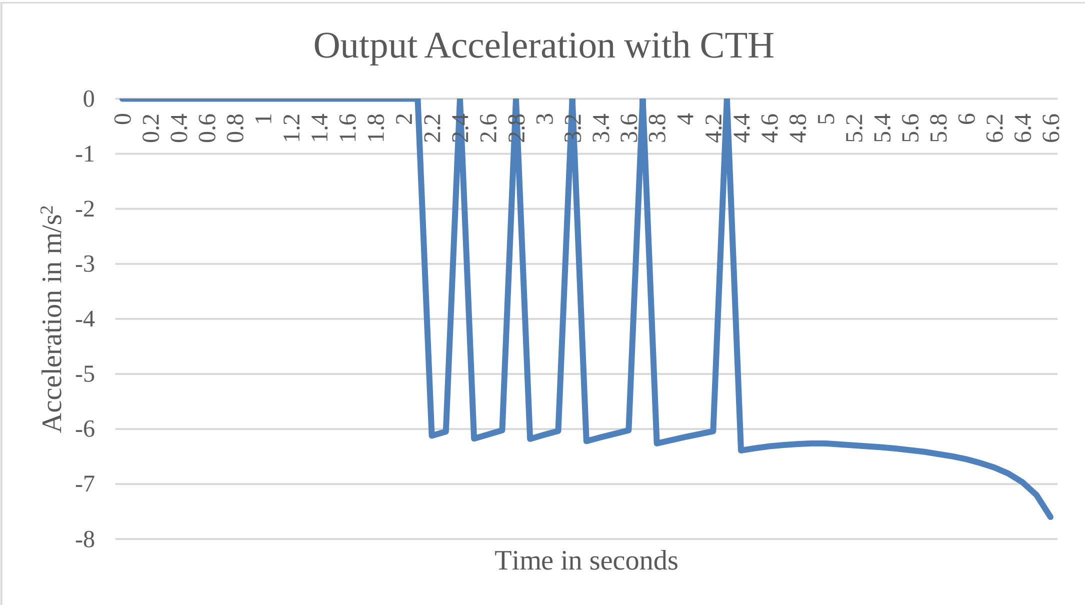

Figure 5.28 Output Accelearation of the System with CTH for Test-3

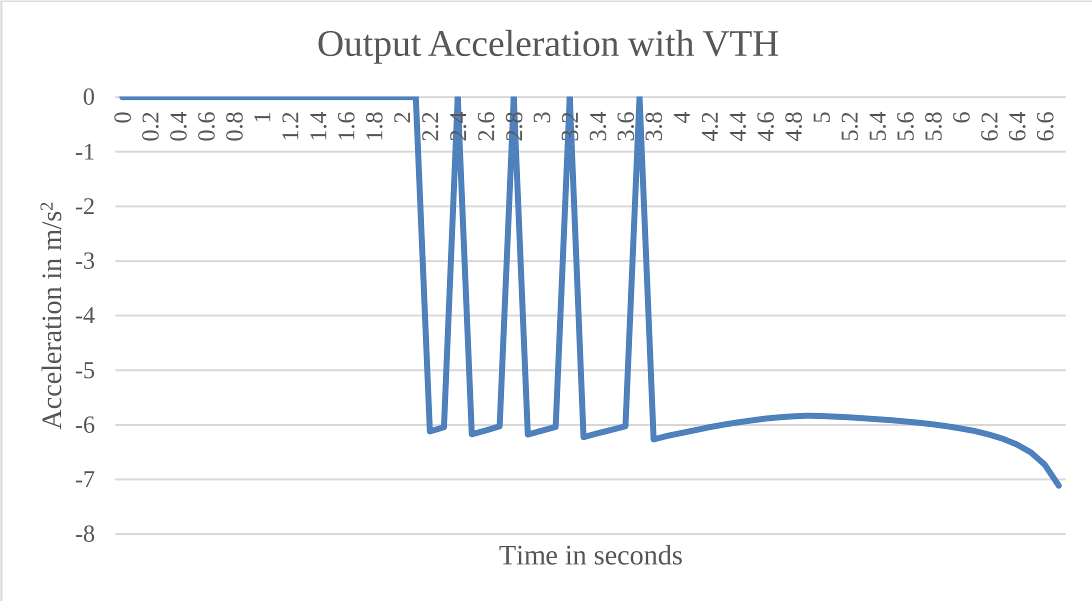

Figure 5.29 Output Accelearation of the System with VTH for Test-3

The speed of the host vehicle for Test-3 can be seen in Figures 5.30 measurement with CHS, 5.31 measurement with CTH, and 5.32 measurement with VTH.

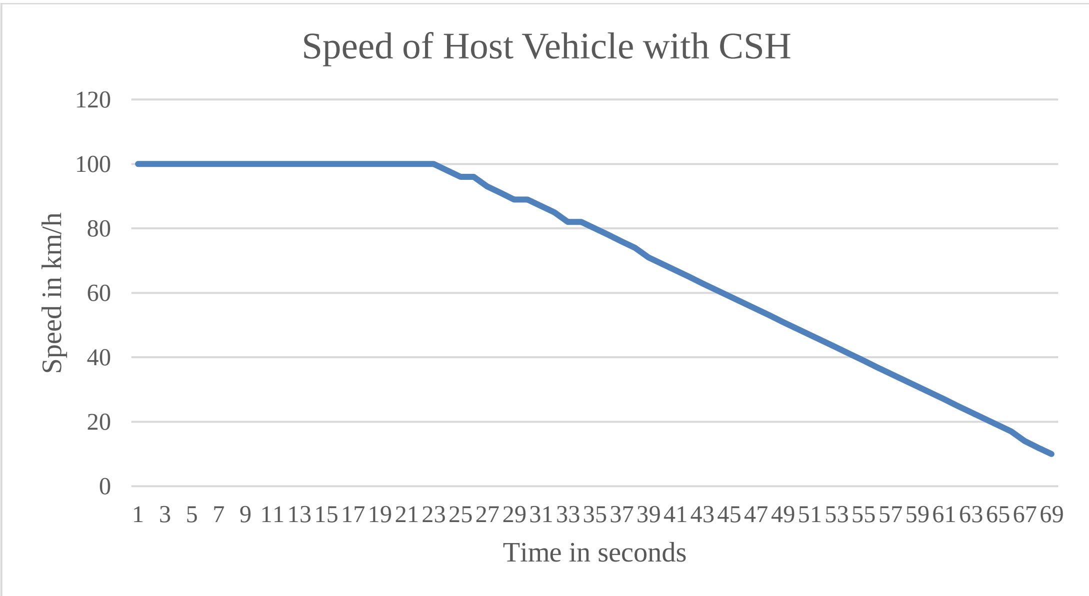

Figure 5.30 Host Vehicle Speed with CSH for Test-3

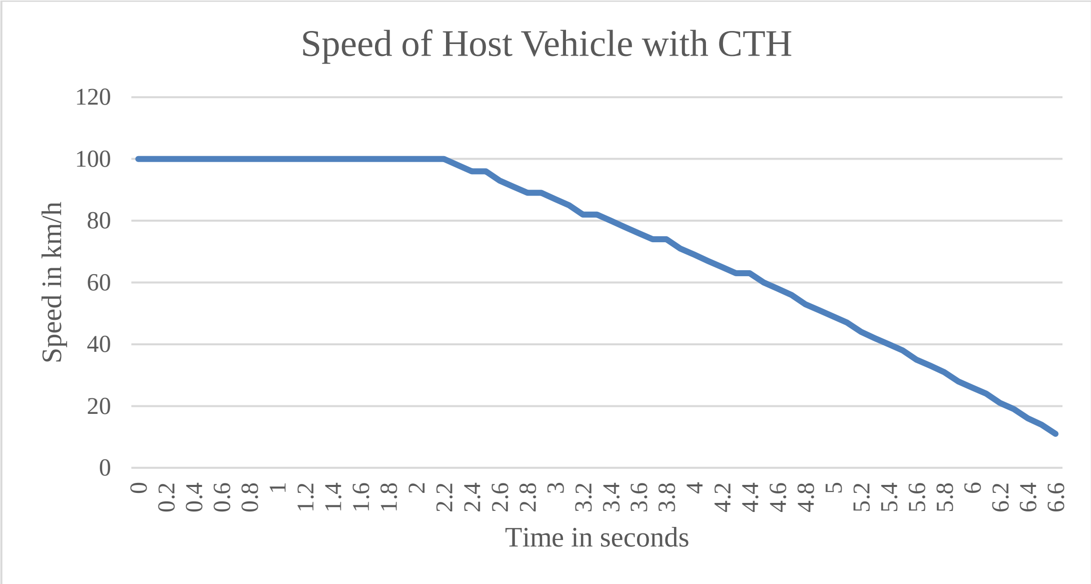

Figure 5.31 Host Vehicle Speed with CTH for Test-3

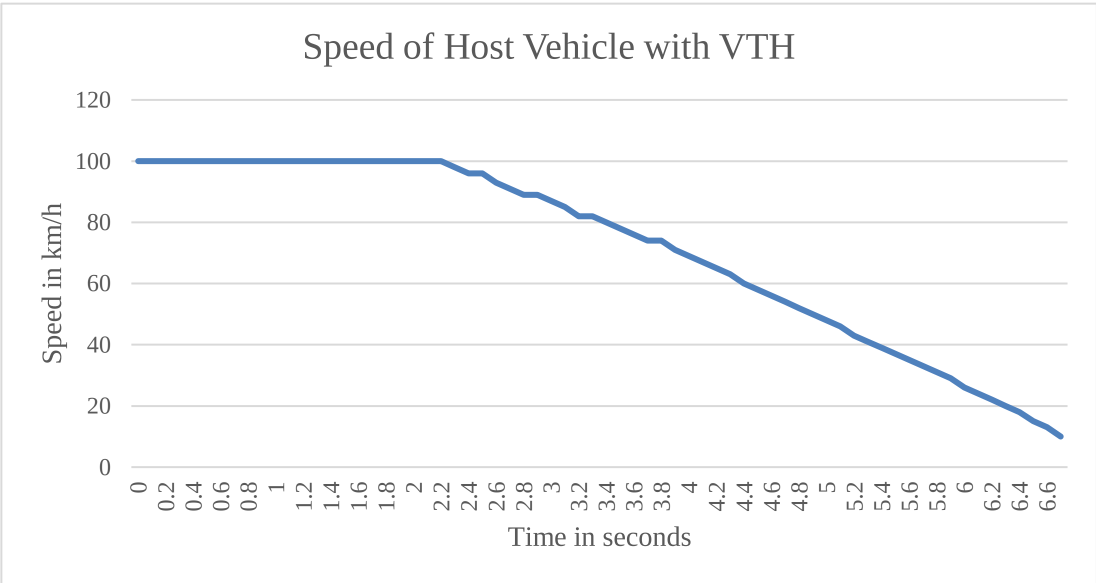

Figure 5.32 Host Vehicle Speed with VTH for Test-3

The active sub feature status for Test-3 can be seen in Figures 5.33 measurement with CHS, 5.34 measurement with CTH, and 5.35 measurement with VTH.

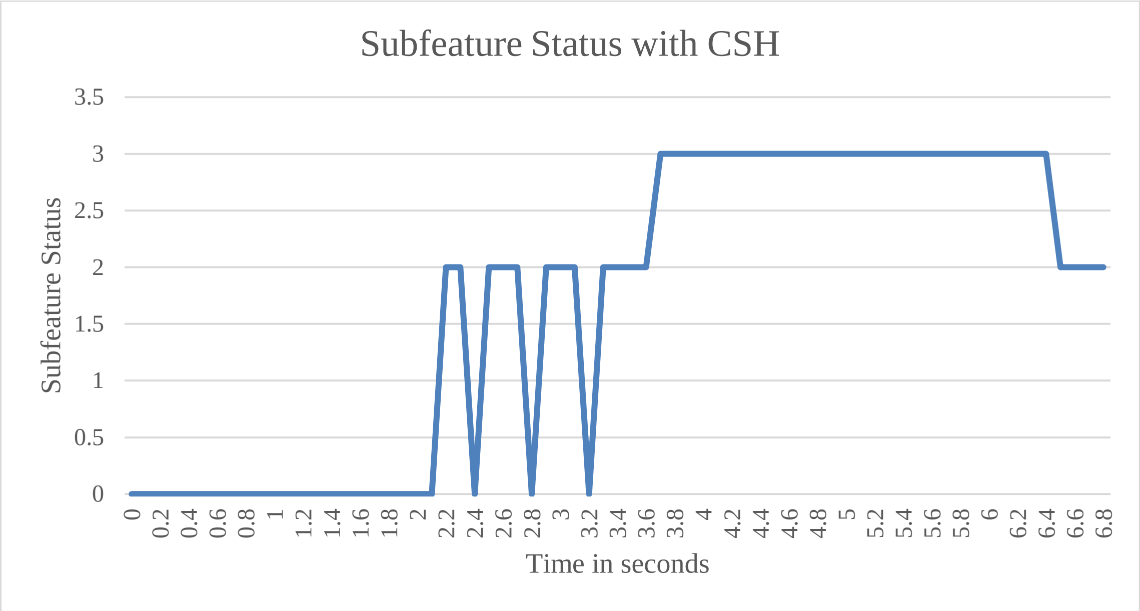

Figure 5.33 Subfeature Status with CSH for Test-3

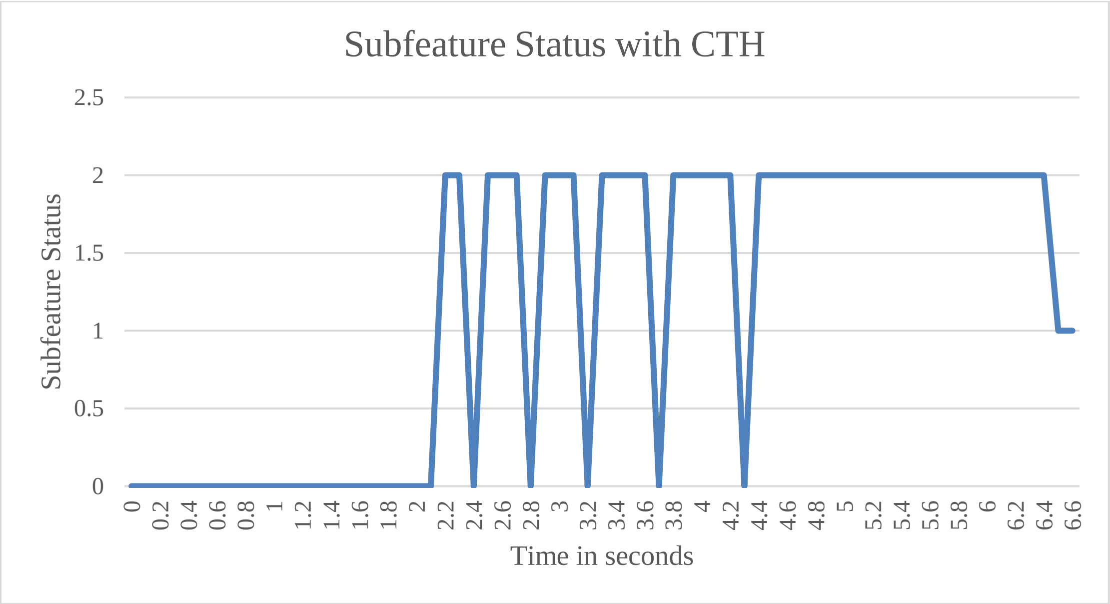

Figure 5.34 Subfeature Status with CTH for Test-3

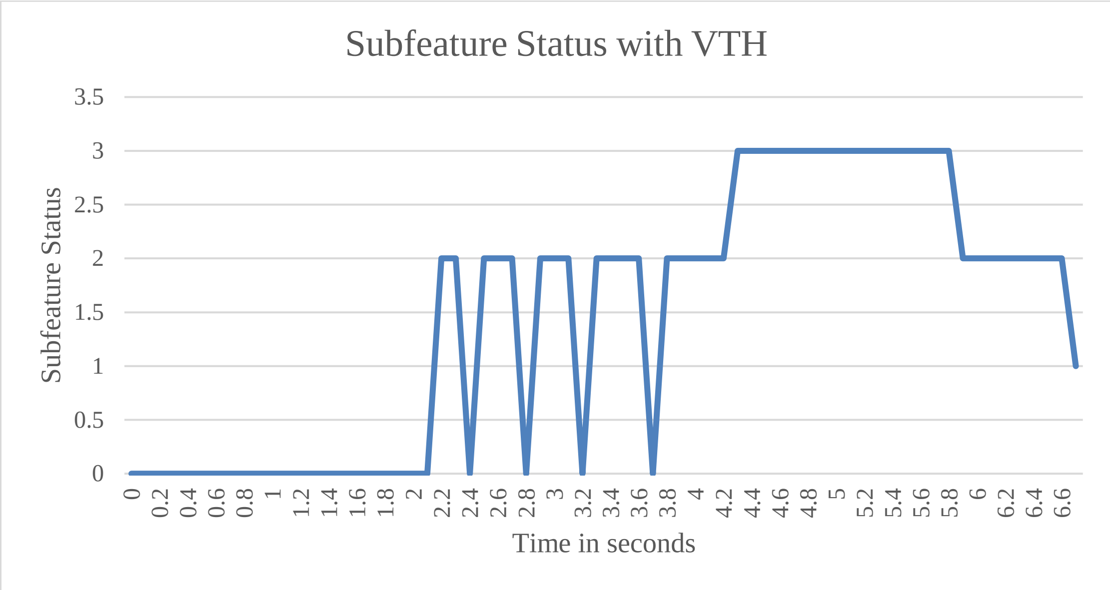

Figure 5.35 Subfeature Status with VTH for Test-3

5.3.2 Analysis of the results of Test-3

The test has been conducted in a closed loop configuration. In Figure 4.8, the target car is initially located at a position referred to as "no action". The target vehicle is decelerating until it comes to a complete halt. The host vehicle initiates braking when the target vehicle enters the emergency braking zone for all three types of safe distance management. The value of CTH is smaller than that of VTH and CSH for safety distance, as evident from the comparison of Figure 5.24, Figure 5.25, and Figure 5.26. CTH is consistently stored in either EBS or No action, as depicted in Figure 5.34. However, when EBS is closed and the distance approaches the CAWS area, VTH and CSH become active, as illustrated in Figure 5.33 and 5.35. The vehicle speed remains consistent across all safety distance control approaches, as evidenced by the comparison of Figure 5.30, Figure 5.31, and Figure 5.32. ADDS activates the Event-Based System (EBS) for all methods, while the Context-Aware System (CAWS) is only activated for the CSH and VTH methods.

This test demonstrates that, in the case of collusion, ADDS has executed EBS and CAWS in keeping with the current conditions.

5.4 Test-4: A vehicle suddenly enters the lane

Initially, there is no car ahead to focus on, and the speed of the main vehicle is 50 km/h. The driver has set the intended speed to 70 km/h. After a duration of 10 seconds, a car abruptly entered the lane, positioned 67 meters distant from the host vehicle. This test case is built as a closed loop, wherein the test environment utilizes the outputs of the ADDS and responds based on their values. Figure 5.36 provides a concise representation of the structure overview of Test-4.

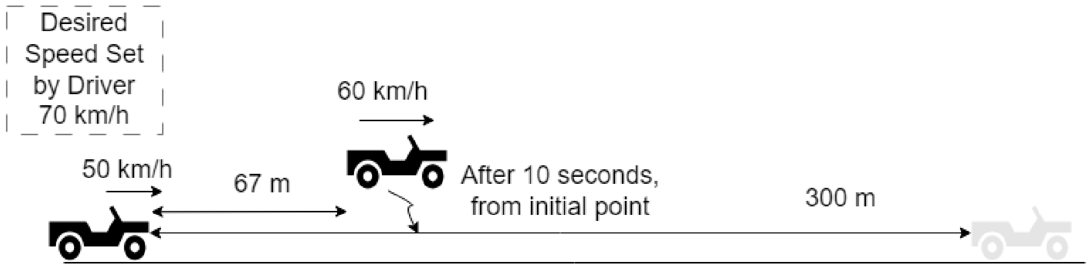

Figure 5.36 Test-4 Structure Overview

The test has been run with all safety distance methods: CSH (Constat Space Headway), CTH (Constant Time Headway), and VTH (Variable Time Headway).

5.4.1 Results of Test-4

The safety distance measurement for Test-4 can be seen in Figures 5.37 measurement with CHS, 5.38 measurement with CTH, and 5.39 measurement with VTH.

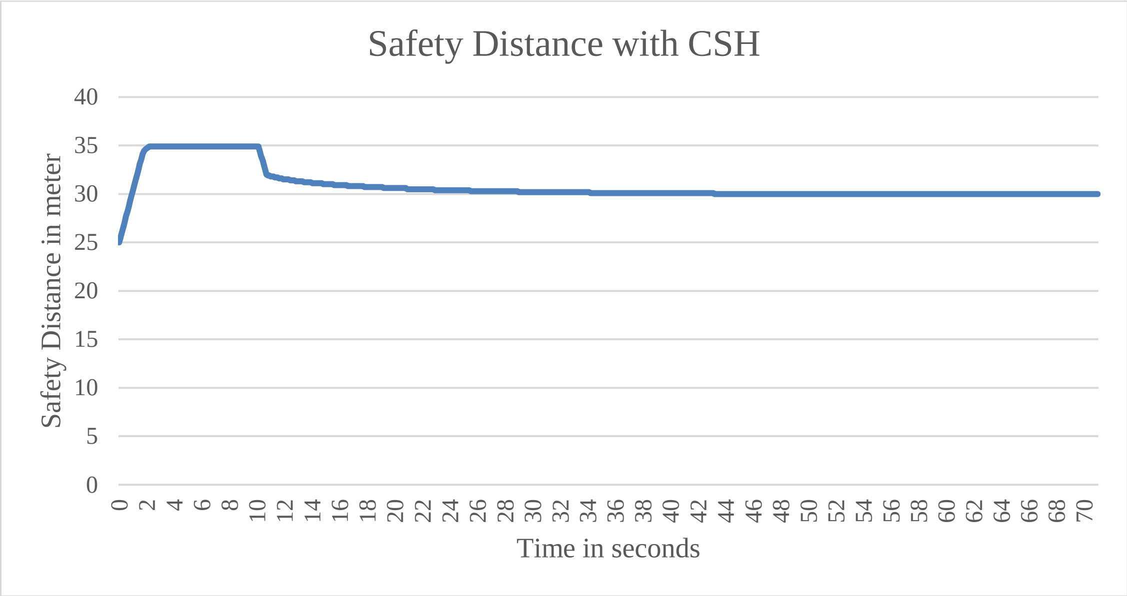

Figure 5.37 Safety Distance Measurement with CSH for Test-4

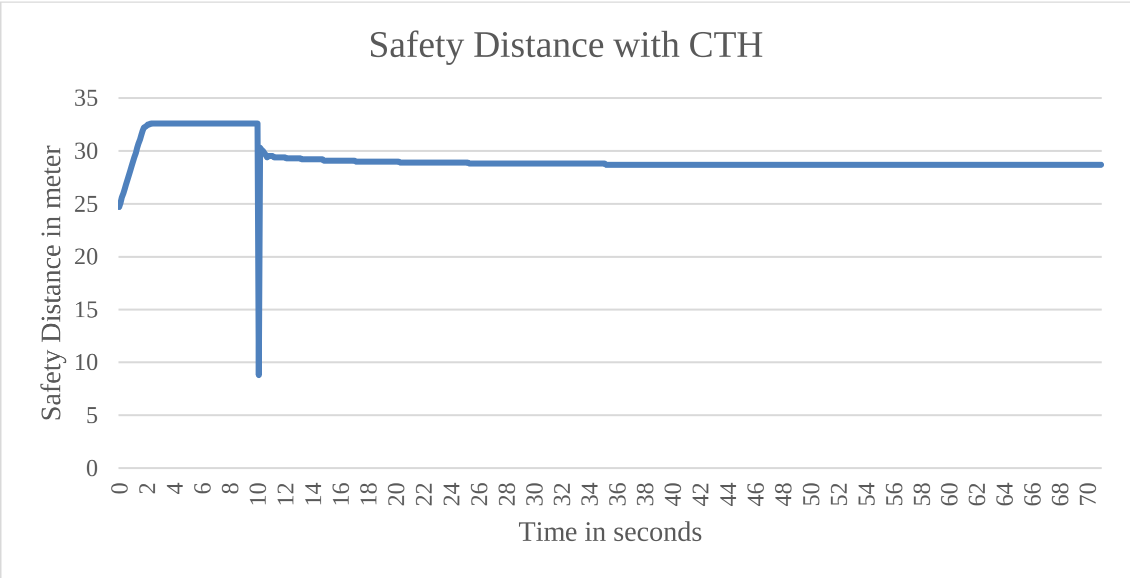

Figure 5.38 Safety Distance Measurement with CTH for Test-4

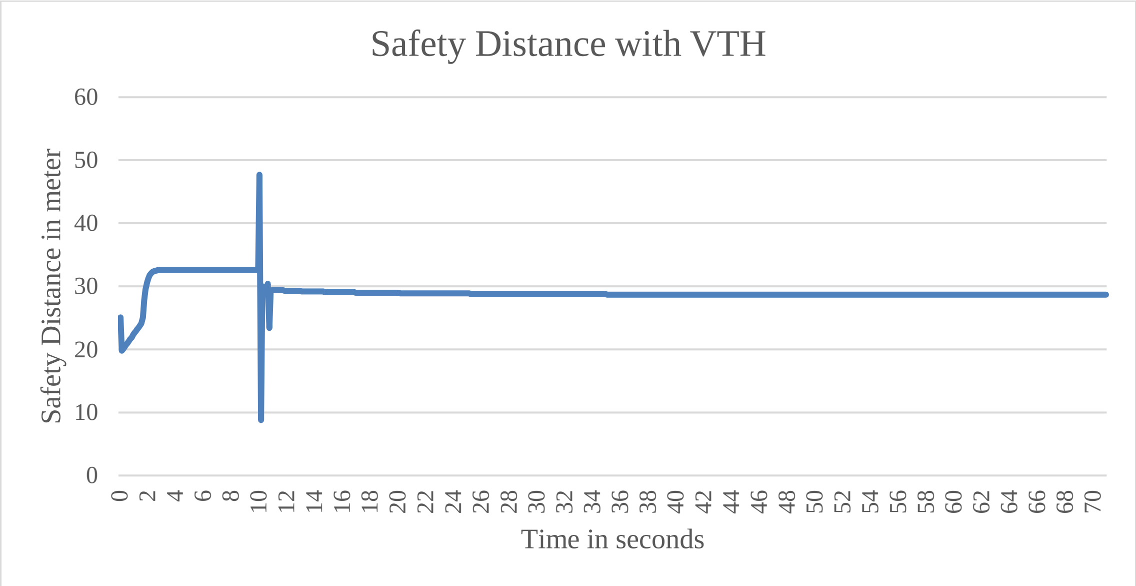

Figure 5.39 Safety Distance Measurement with VTH for Test-4

The output acceleration of the system for Test-4 can be seen in Figures 5.40 measurement with CHS, 5.41 measurement with CTH, and 5.42 measurement with VTH.

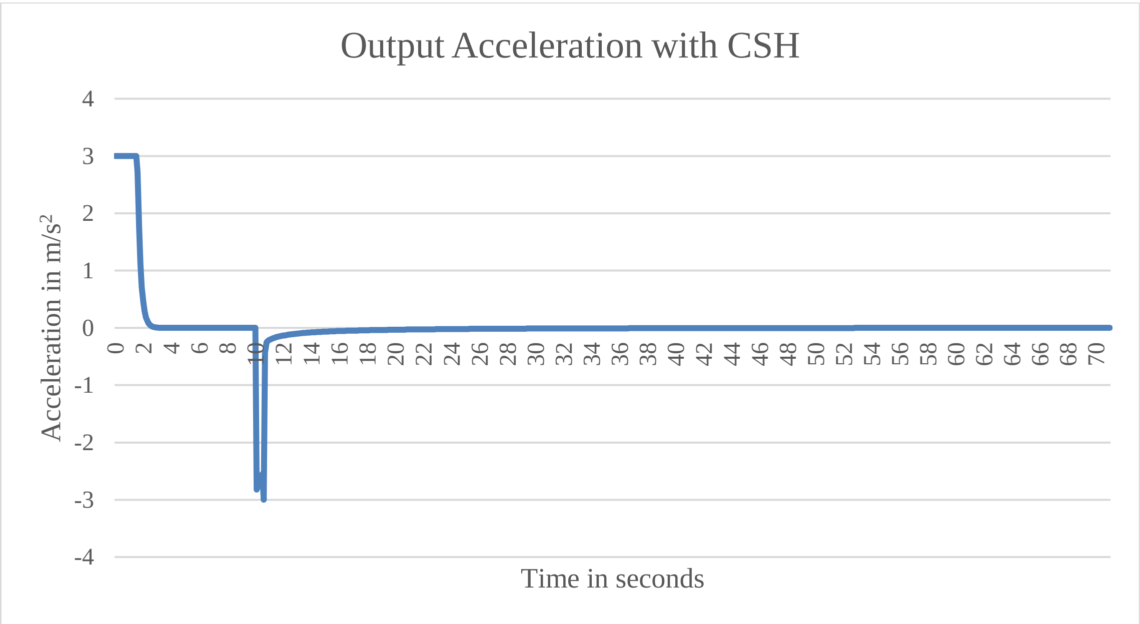

Figure 5.40 Output Accelearation of the System with CSH for Test-4

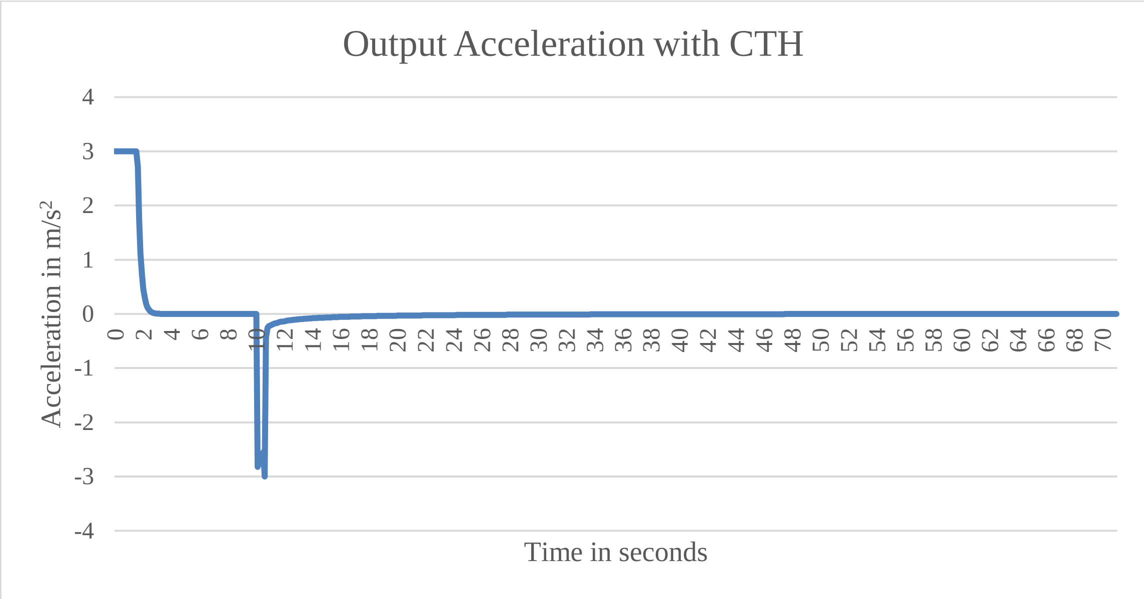

Figure 5.41 Output Accelearation of the System with CTH for Test-4

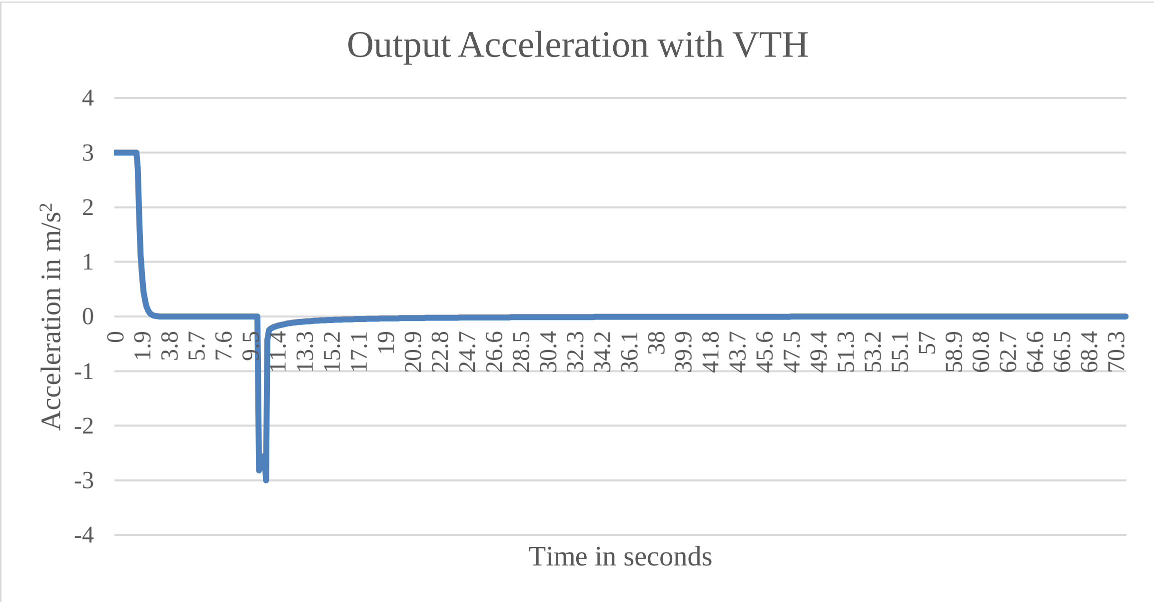

Figure 5.42 Output Accelearation of the System with VTH for Test-4

The speed of the host vehicle for Test-4 can be seen in Figures 5.43 measurement with CHS, 5.44 measurement with CTH, and 5.45 measurement with VTH.

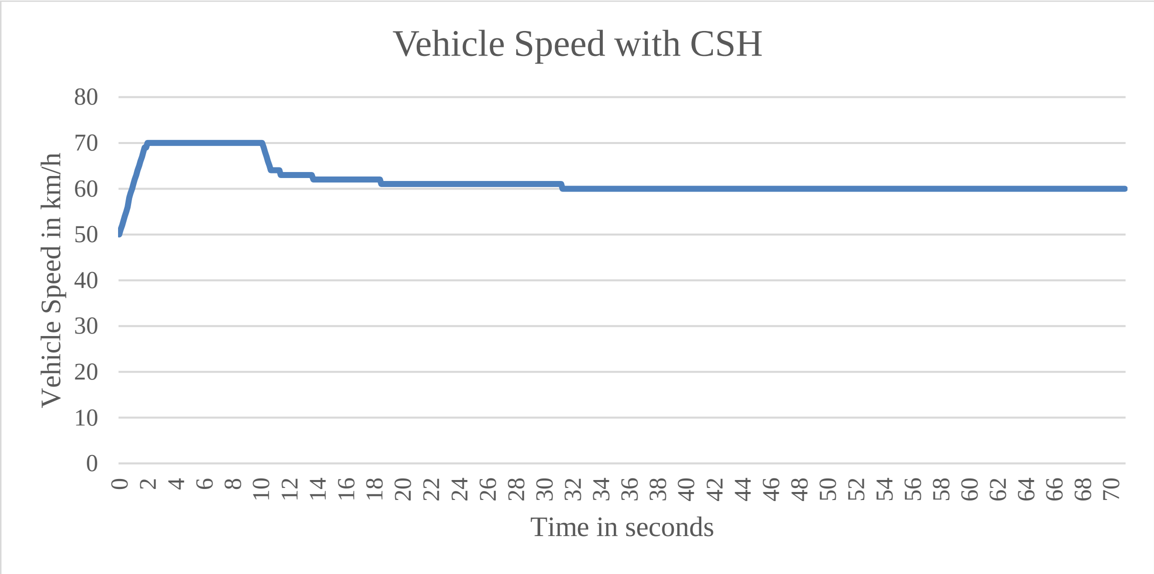

Figure 5.43 Host Vehicle Speed with CSH for Test-4

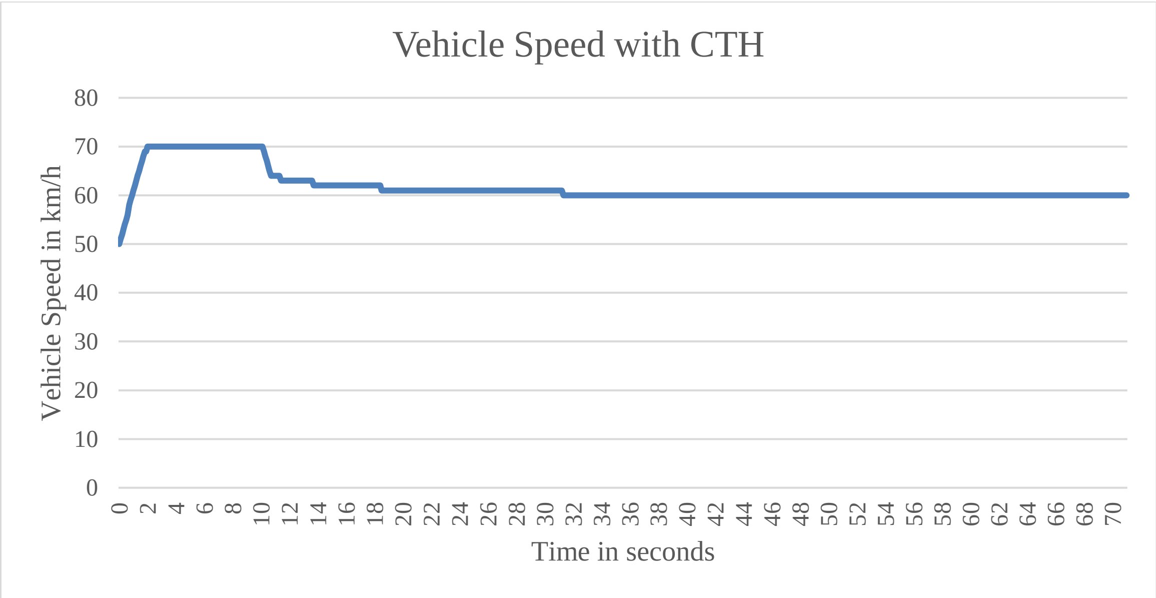

Figure 5.44 Host Vehicle Speed with CTH for Test-4

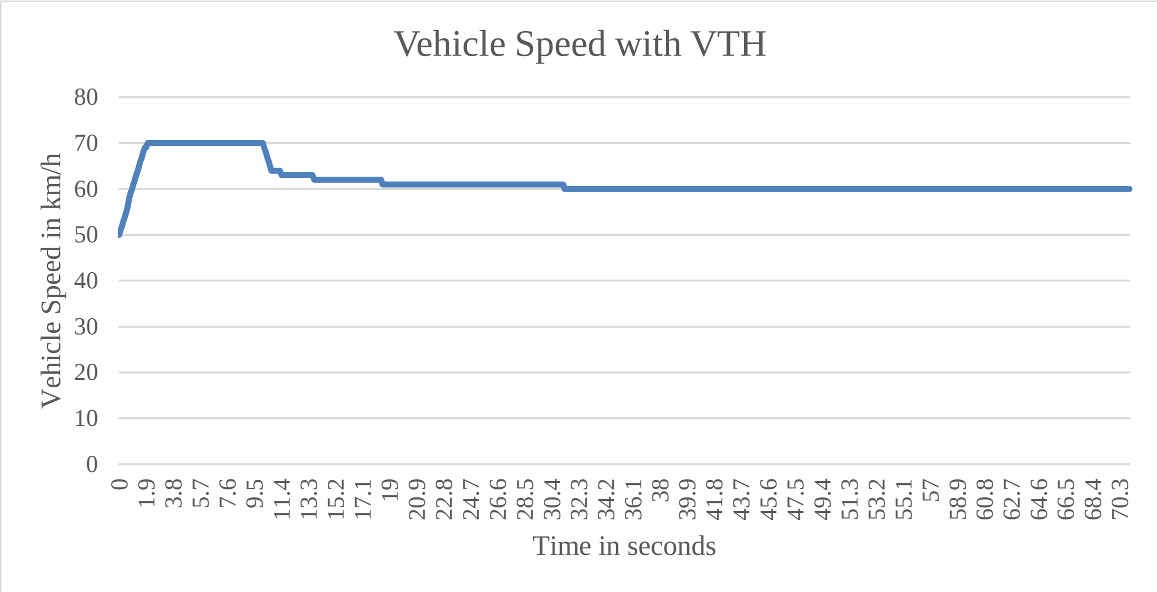

Figure 5.45 Host Vehicle Speed with VTH for Test-4

The active sub feature status for Test-4 can be seen in Figures 5.46 measurement with CHS, 5.47 measurement with CTH, and 5.48 measurement with VTH.

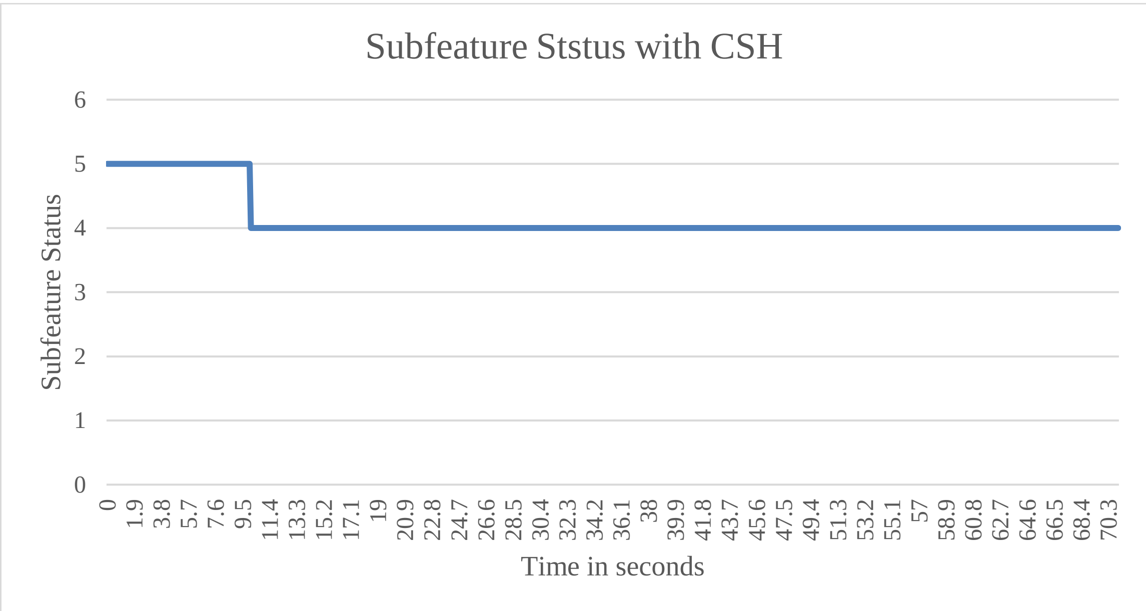

Figure 5.46 Subfeature Status with CSH for Test-4

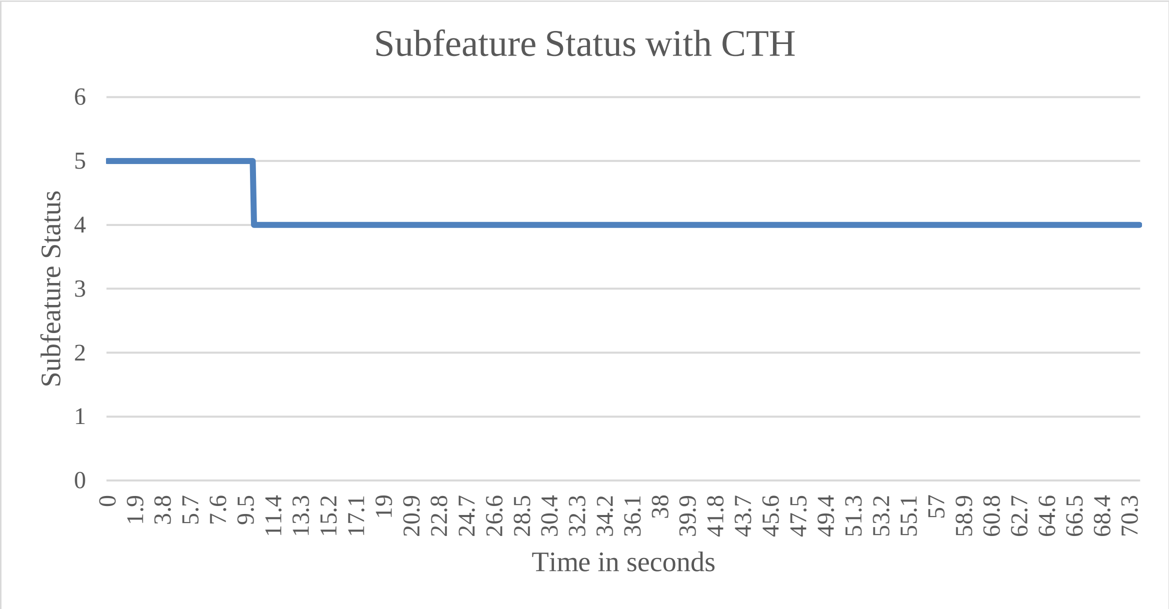

Figure 5.47 Subfeature Status with CTH for Test-4

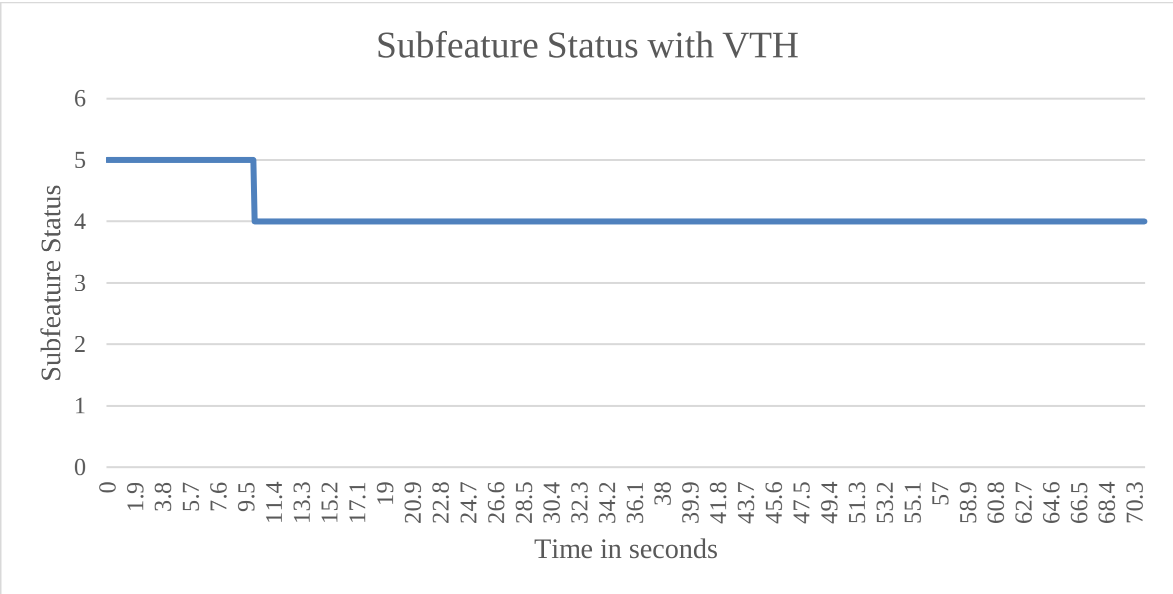

Figure 5.48 Subfeature Status with VTH for Test-4

5.4.2 Analysis of the results of Test-4

The test has been conducted in a closed loop configuration. Initially, there is no specific vehicle being targeted, and the Acceleration Deceleration Determination

System (ADDS) system begins in Cruise Control (CC) mode for all methods of measuring safety distance, as depicted in Figure 5.46, Figure 5.47, and Figure 5.48. The ADDS system initiates an increase in speed until the host automobile reaches the speed specified by the driver. The target car's position, when it abruptly moves into the lane, falls inside Section 6 of the spectrum as depicted in Figure 4.8. The distance of the target car is measured in Section 7 of the spectrum after it has decelerated. In that particular segment, the Acceleration Deceleration Determination System (ADDS) aims to maintain a consistent distance between the host vehicle and the target vehicle, while also ensuring that both vehicles maintain the same speed. This is achieved by applying the necessary acceleration, as specified in equation 4.6. In this experiment, the ADDS system has been operating in conjunction with the CC mode, but as soon as cars unexpectedly enter the lane, it switches to the ACC mode. The behavior of ADDS is consistent across all safety distance measurement methods. This is because the safety distance serves as a parameter for the likelihood of collision, as depicted in Figure 4.8. ADDS activates the Collision Avoidance Warning System (CAWS) when the relative distance is less than the safety distance. Hence, the Acceleration Deceleration Determination System (ADDS) exhibits consistent and uniform acceleration-deceleration behavior across all safety distance methods, as depicted in Figure 5.40, Figure 5.41, and Figure 5.42. In addition, the vehicle speed remains consistent for all safety distance methods as determined by the Acceleration Deceleration Determination System (ADDS), as depicted in Figure 5.43, Figure 5.44, and Figure 5.45.

This test demonstrates that ADDS is capable of maintaining a consistent relative distance when operating in ACC mode, without any decrease in speed.

5.5 Test-5: Target vehicle slow down, then gets faster

At the beginning, there is a distance of 50 meters between the host vehicle and the target vehicle. The host vehicle is traveling at a speed of 70 kilometers per hour, while the target vehicle is traveling at a speed of 60 kilometers per hour. The driver has set the intended speed to 90 km/h. The target vehicle decelerates at a rate of 3 m/s^2 until it reaches a speed of 35 km/h, after which it accelerates at a rate of 3 m/s^2 until it reaches a speed of 100 km/h. This test case is structured as a closed loop, wherein the test environment utilizes the outputs of ADDS and responds based on their values. Figure 5.49 provides a concise representation of the structure of Test-5.

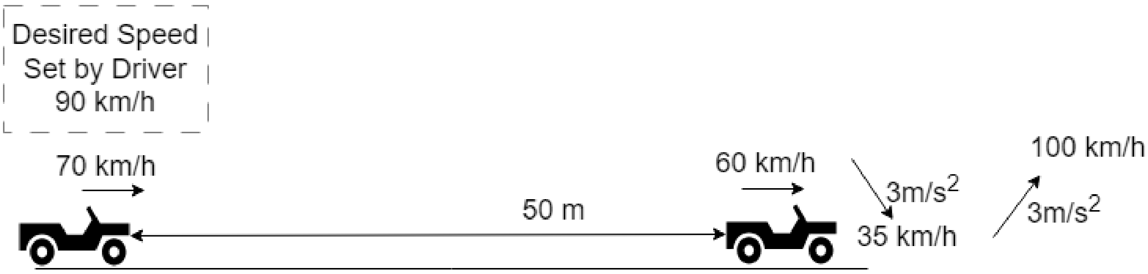

Figure 5.49 Test-5 Structure Overview

The test has been run with all safety distance methods: CSH (Constat Space Headway), CTH (Constant Time Headway), and VTH (Variable Time Headway).

5.5.1 Results of Test-5

The safety distance measurement for Test-5 can be seen in Figures 5.50 measurement with CHS, 5.51 measurement with CTH, and 5.52 measurement with VTH.

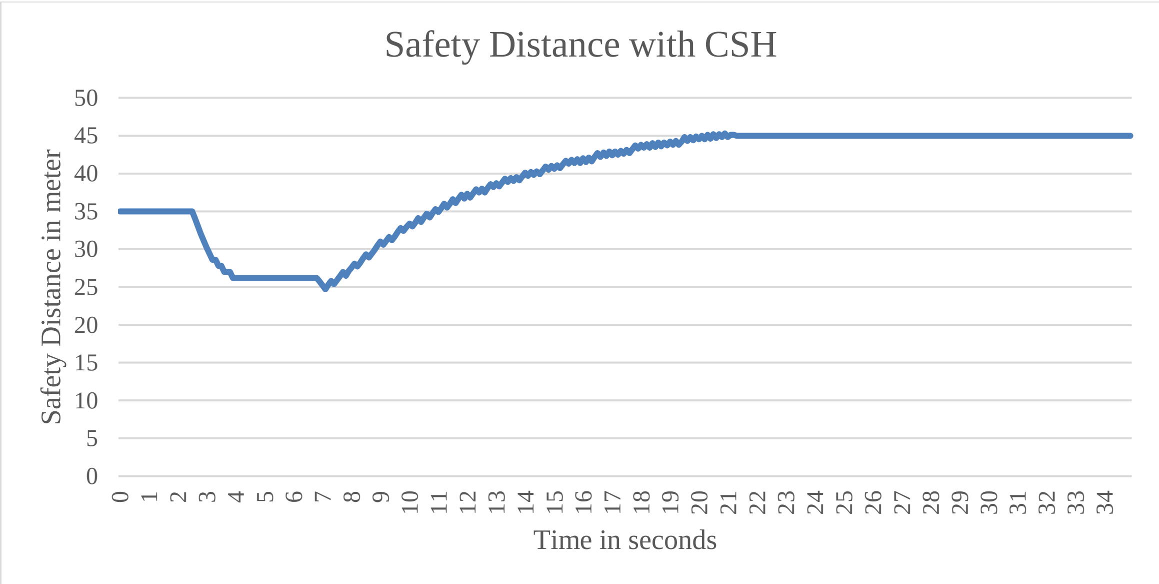

Figure 5.50 Safety Distance Measurement with CSH for Test-5

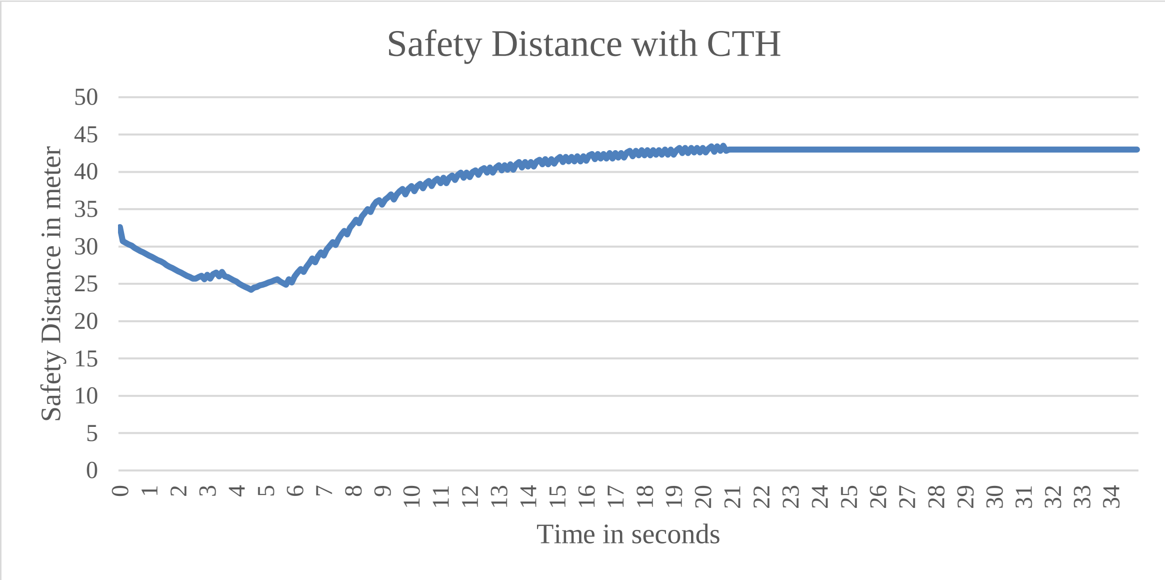

Figure 5.51 Safety Distance Measurement with CTH for Test-5

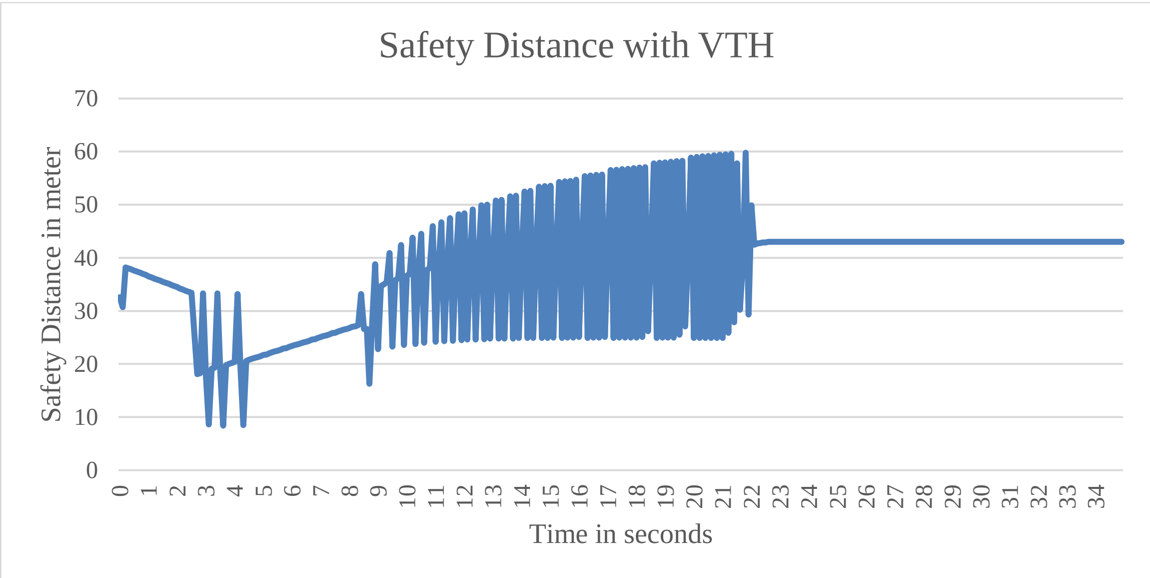

Figure 5.52 Safety Distance Measurement with VTH for Test-5

The output acceleration of the system for Test-5 can be seen in Figures 5.53 measurement with CHS, 5.54 measurement with CTH, and 5.55 measurement with VTH.

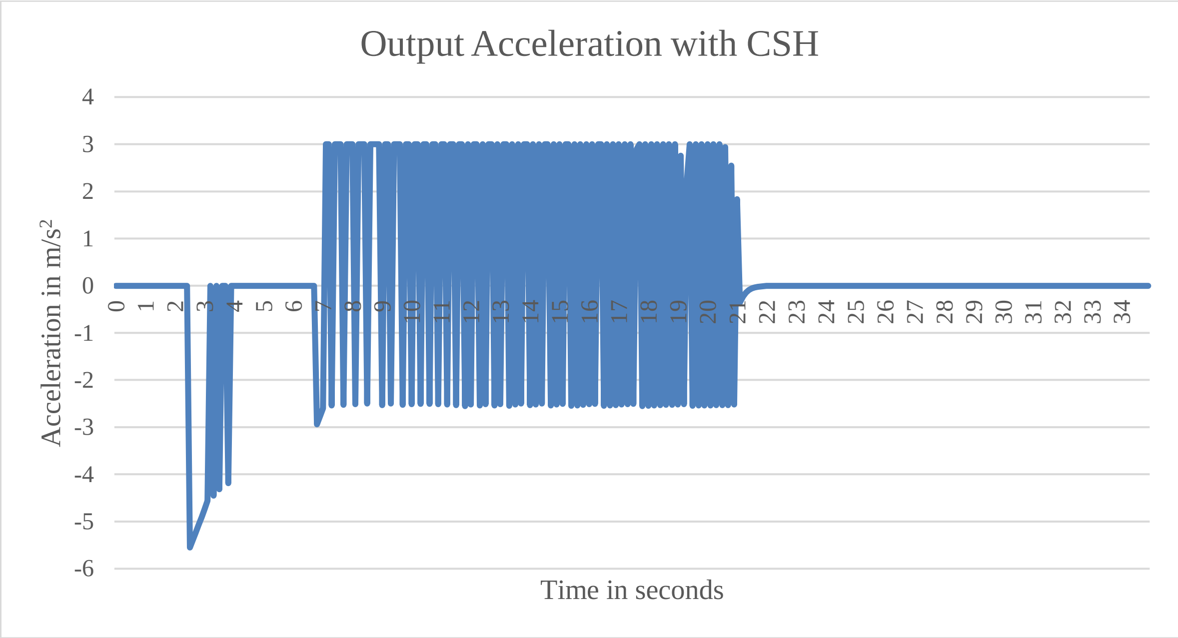

Figure 5.53 Output Accelearation of the System with CSH for Test-5

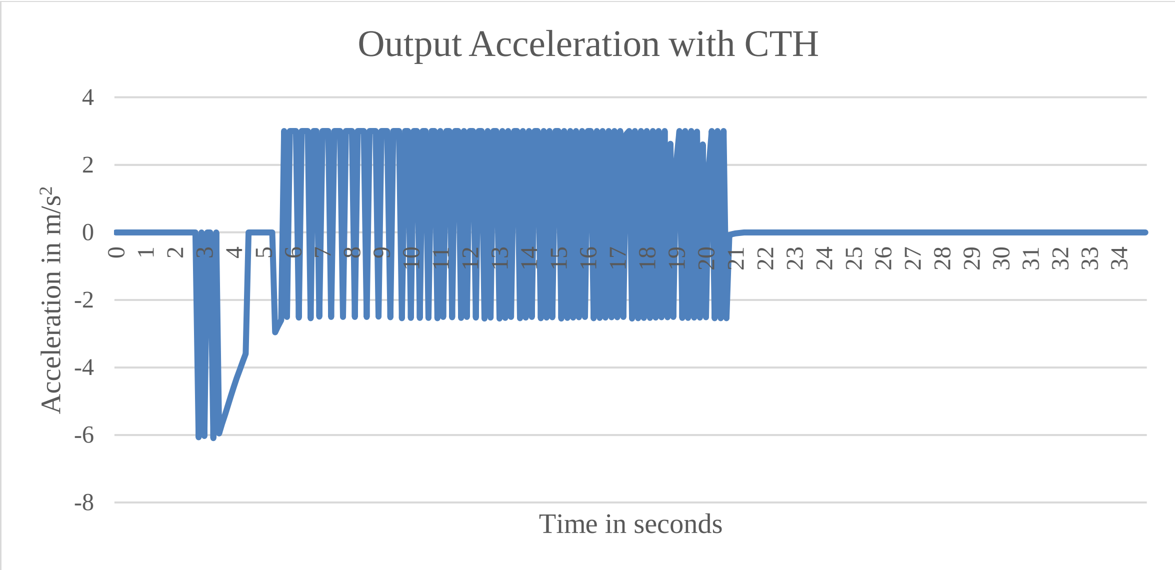

Figure 5.54 Output Accelearation of the System with CTH for Test-5

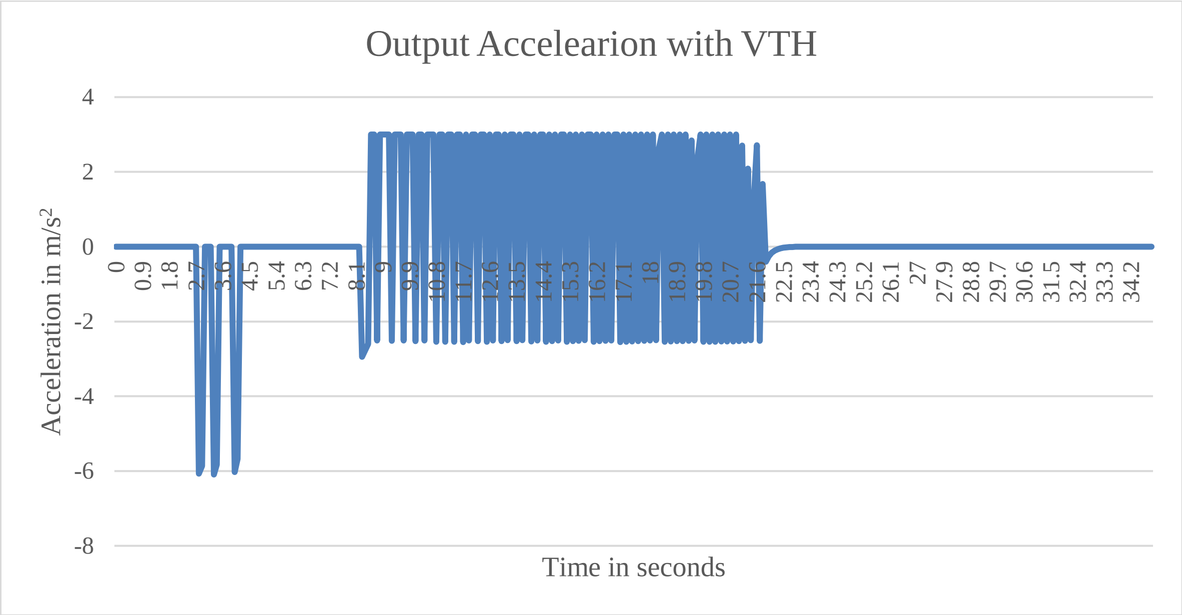

Figure 5.55 Output Accelearation of the System with VTH for Test-5

The speed of the host vehicle for Test-5 can be seen in Figures 5.56 measurement with CHS, 5.57 measurement with CTH, and 5.58 measurement with VTH.

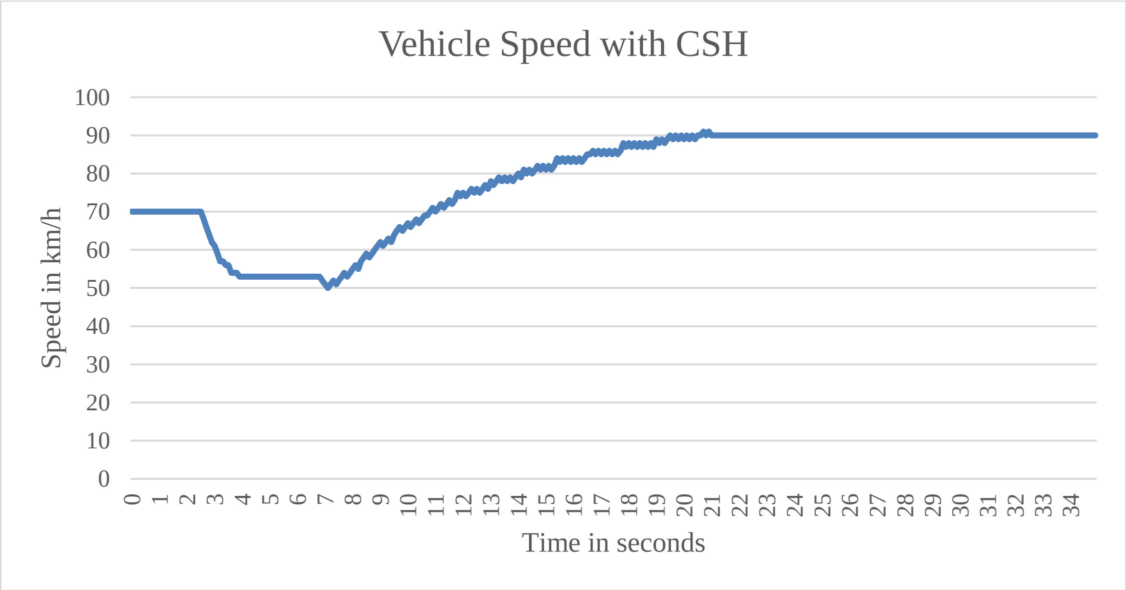

Figure 5.56 Host Vehicle Speed with CSH for Test-5

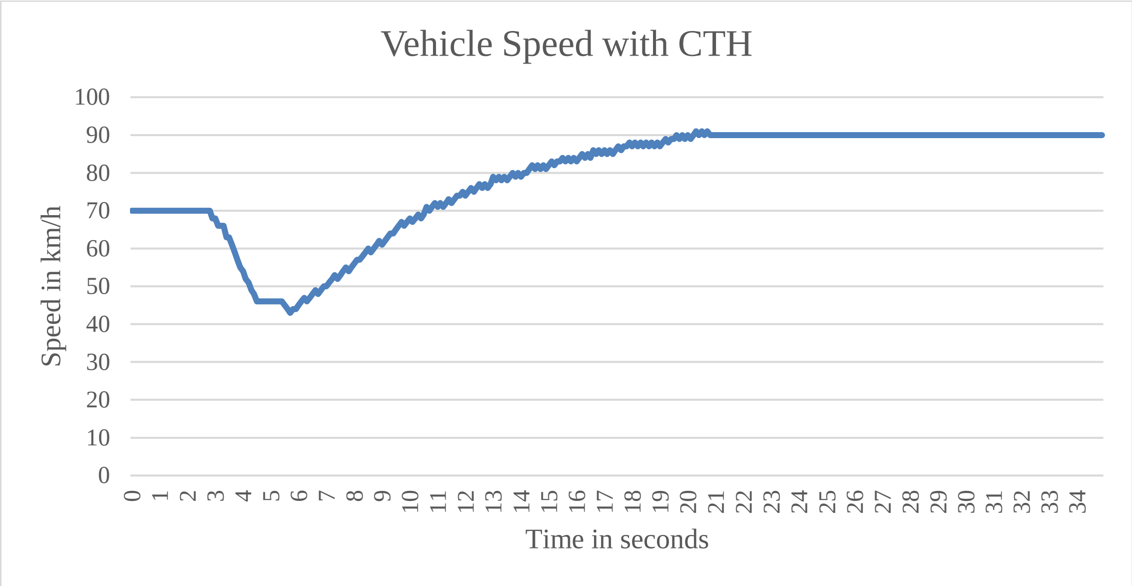

Figure 5.57 Host Vehicle Speed with CTH for Test-5

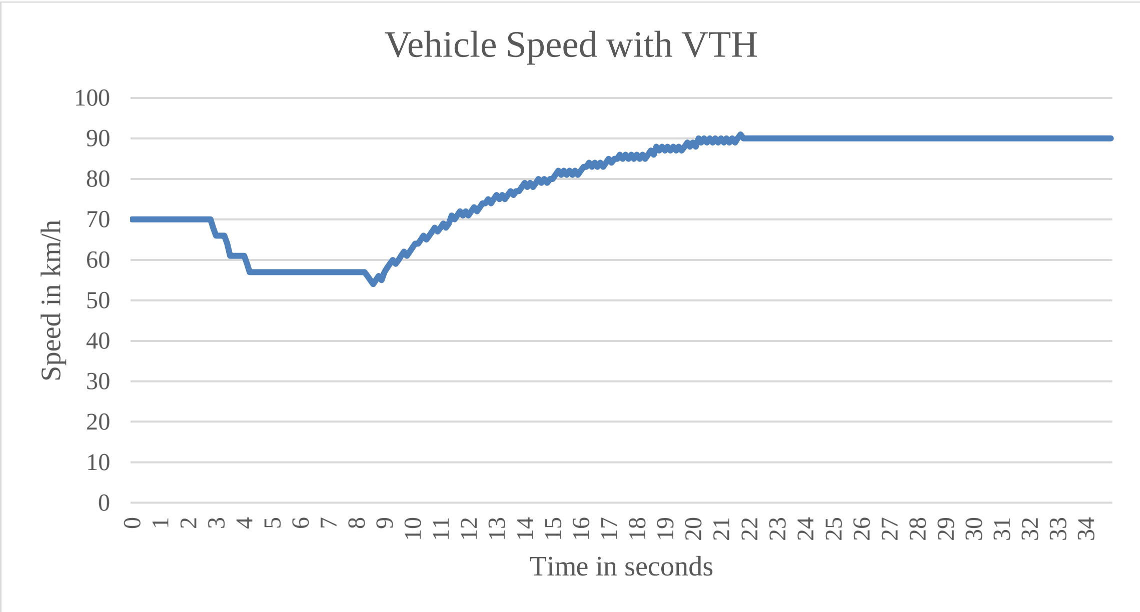

Figure 5.58 Host Vehicle Speed with VTH for Test-5

The active sub feature status for Test-5 can be seen in Figures 5.59 measurement with CHS, 5.60 measurement with CTH, and 5.61 measurement with VTH.

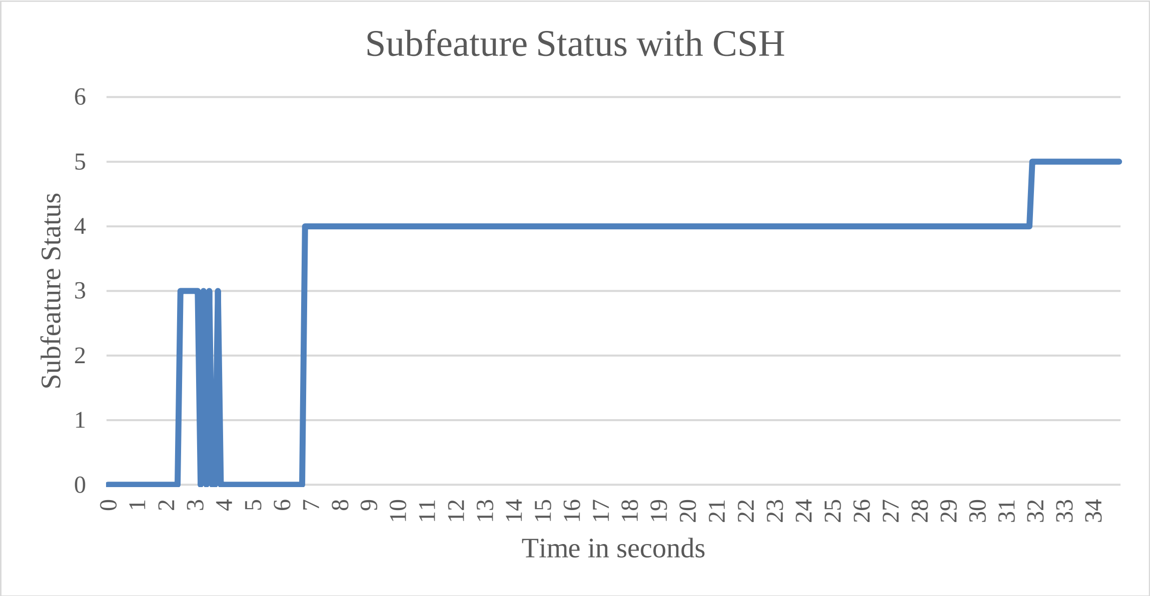

Figure 5.59 Subfeature Status with CSH for Test-5

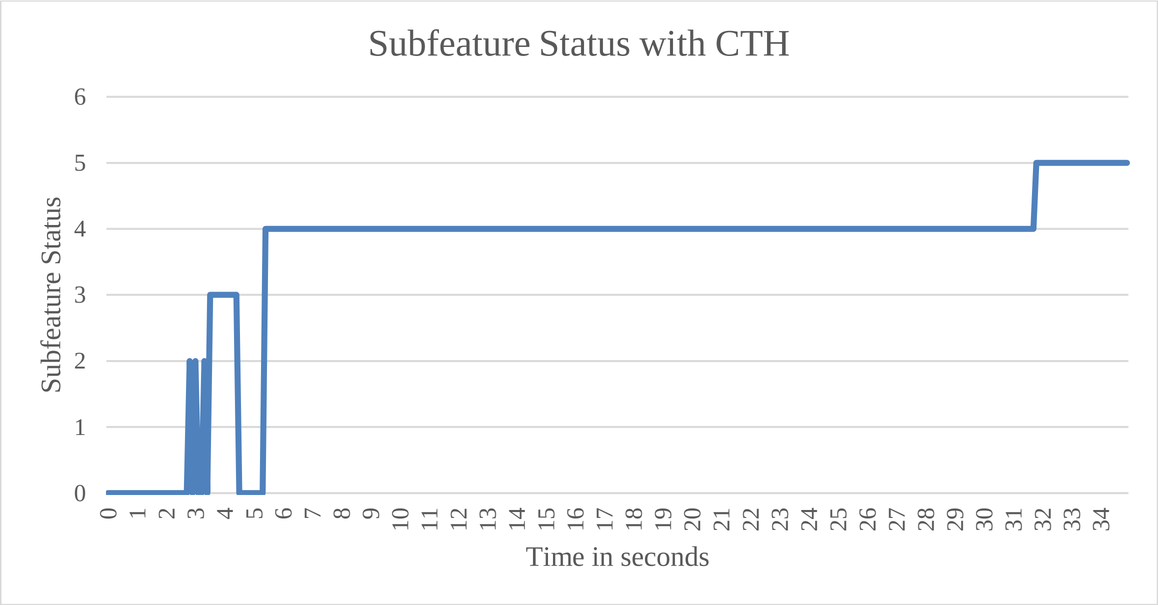

Figure 5.60 Subfeature Status with CTH for Test-5

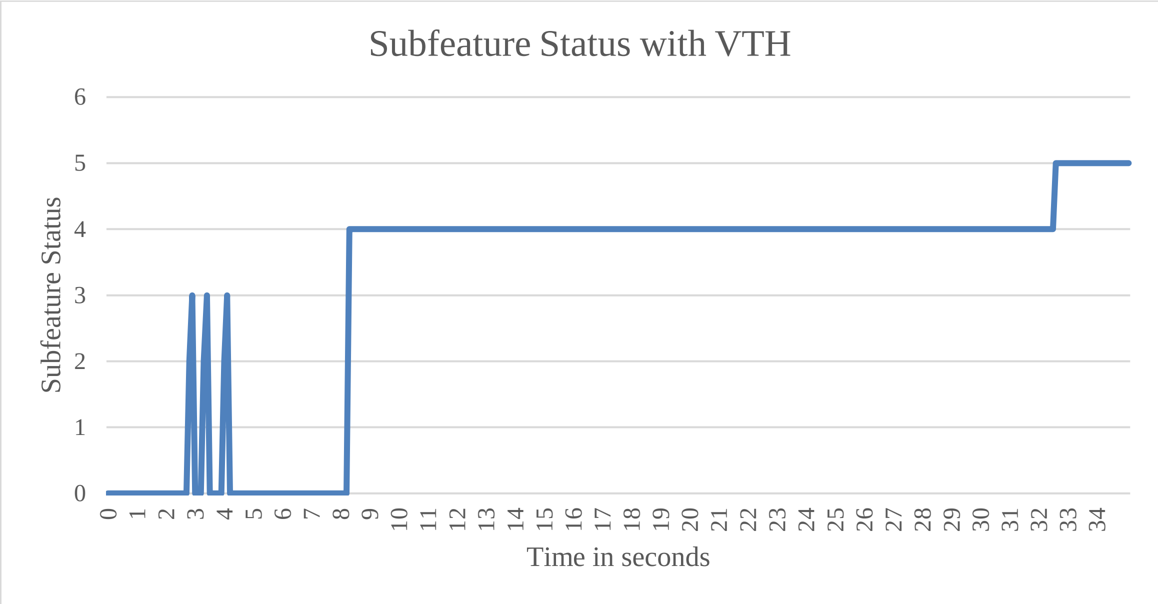

Figure 5.61 Subfeature Status with VTH for Test-5

5.5.2 Analysis of the results of Test-5

The test has been conducted in a closed loop configuration. In Figure 4.8, the target vehicle is initially in the No Action state. Subsequently, it begins to decelerate. As the distance between the vehicles decreases, the target vehicle activates either the Collision Avoidance Warning System (CAWS) or the Emergency Braking System (EBS) based on the safety distance technique. CSH and VTH initially activate the CAWS, as depicted in Figure 5.59 and Figure 5.61, while CTH activates the EBS first, followed by the CAWS, as shown in Figure 5.60. The speed of the host vehicle decreases significantly when the Collision Threat Handling (CTH) system is activated. This is evident from the higher deceleration rate observed in Figure 5.56, Figure 5.57, and Figure 5.58. Additionally, it is evident that due to the CSH being open before the CTH, the velocity of the host vehicle in the CTH is decreasing compared to the VTH. Over time, the velocity of the target vehicle increases. The target vehicle transitions through the No Action state, followed by ACC, and finally CC, based on the TTC level of the target vehicle, as depicted in Figure 5.59, Figure 5.60, and Figure 5.61.

This test demonstrates that ADDS has the capability to dynamically execute EBS in the event of a potential collision. When the threat is not yet there, it can switch between ACC and CC according on the prevailing circumstances.

5.6 Test-6 : Target vehicle gets faster

At the beginning, there is a distance of 14 meters between the host vehicle and the target vehicle. The host vehicle is traveling at a speed of 50 kilometers per hour, while the target car is traveling at a speed of 40 kilometers per hour. The driver has set the intended speed to 70 km/h. The target vehicle is accelerating from 3 m/s^2 to a speed of 100 km/h. This test case is structured as a closed loop, wherein the test environment utilizes the outputs of ADDS and responds based on their values. Figure 5.62 provides a visual representation of the structure overview of Test-6.

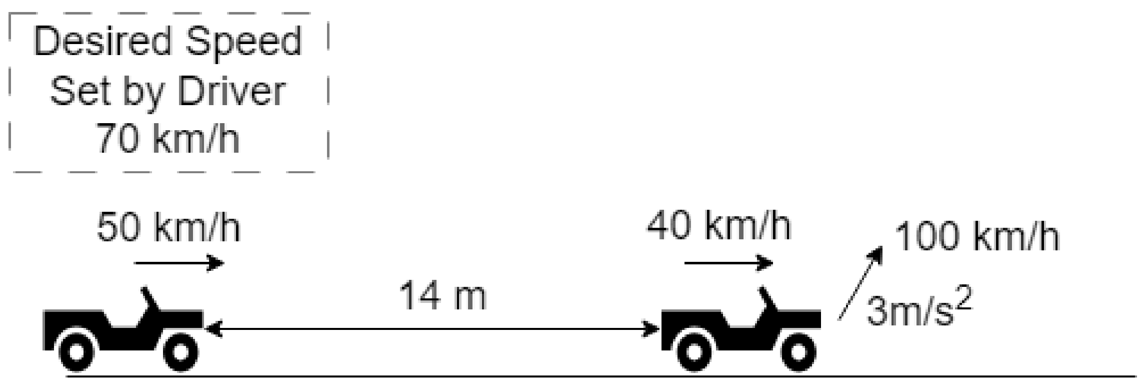

Figure 5.62 Test-6 Structure Overview

The test has been run with all safety distance methods: CSH (Constat Space Headway), CTH (Constant Time Headway), and VTH (Variable Time Headway).

5.6.1 Results of Test-6

The safety distance measurement for Test-6 can be seen in Figures 5.63 measurement with CHS, 5.64 measurement with CTH, and 5.65 measurement with VTH.

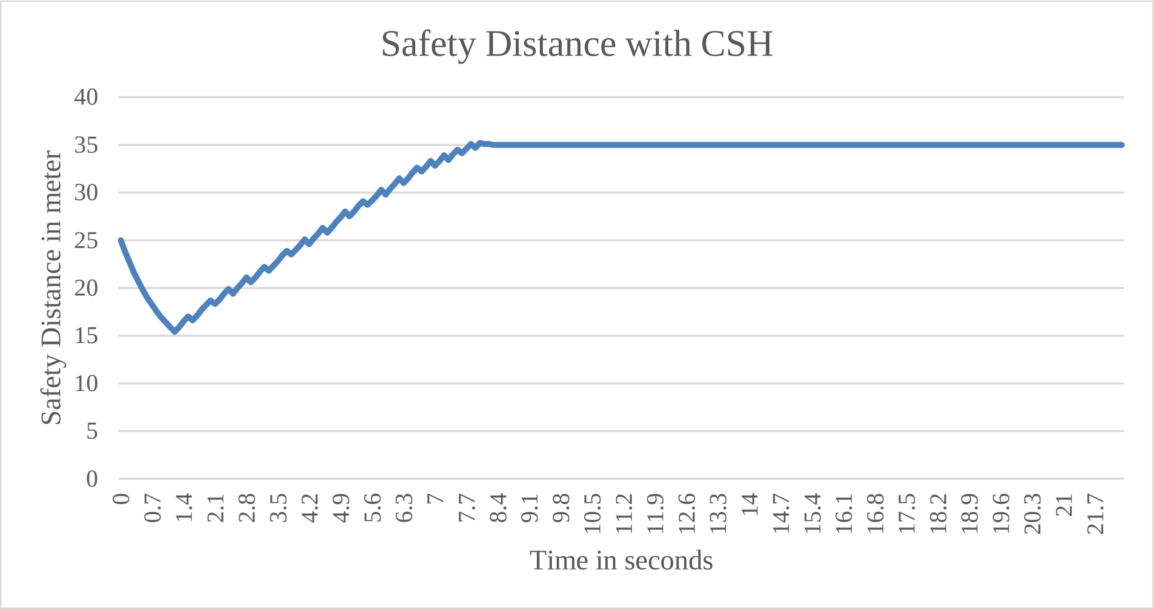

Figure 5.63 Safety Distance Measurement with CSH for Test-6

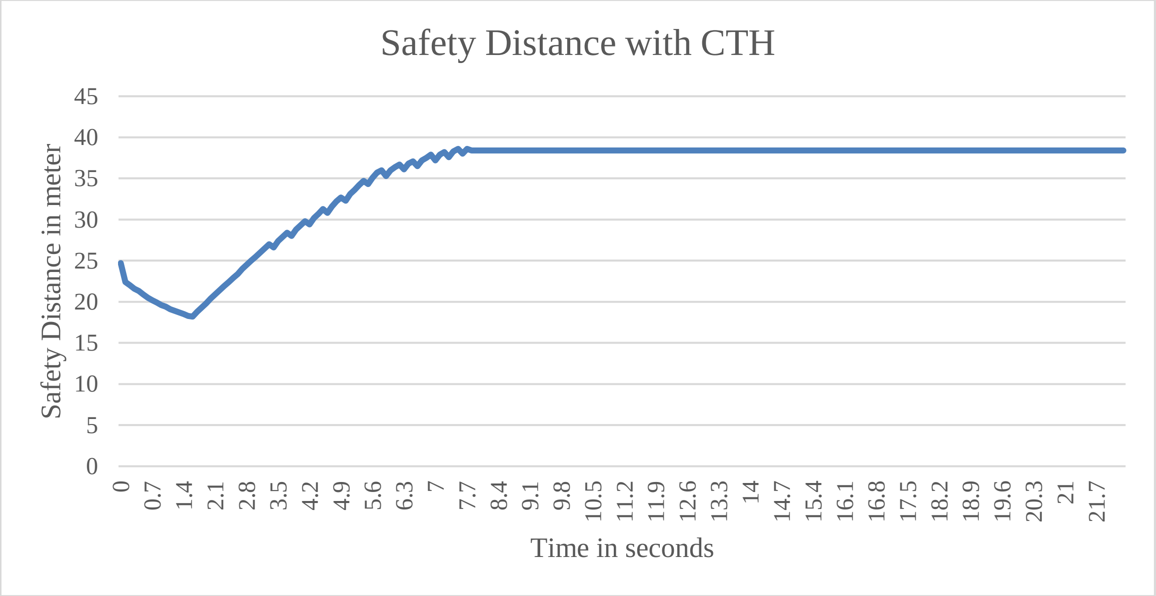

Figure 5.64 Safety Distance Measurement with CTH for Test-6

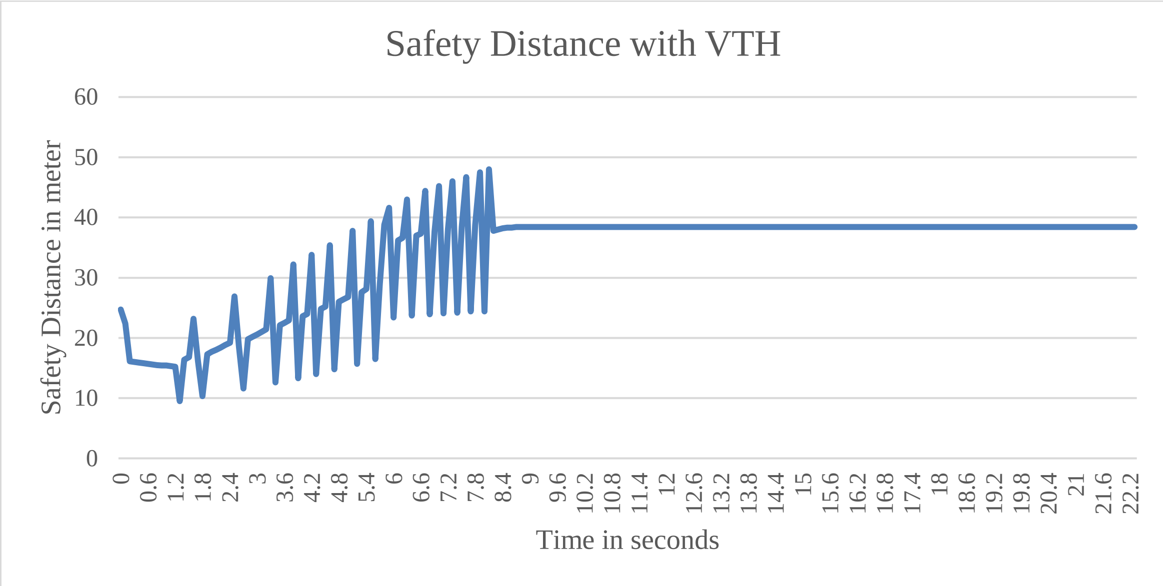

Figure 5.65 Safety Distance Measurement with VTH for Test-6

The output acceleration of the system for Test-6 can be seen in Figures 5.66 measurement with CHS, 5.67 measurement with CTH, and 5.68 measurement with VTH.

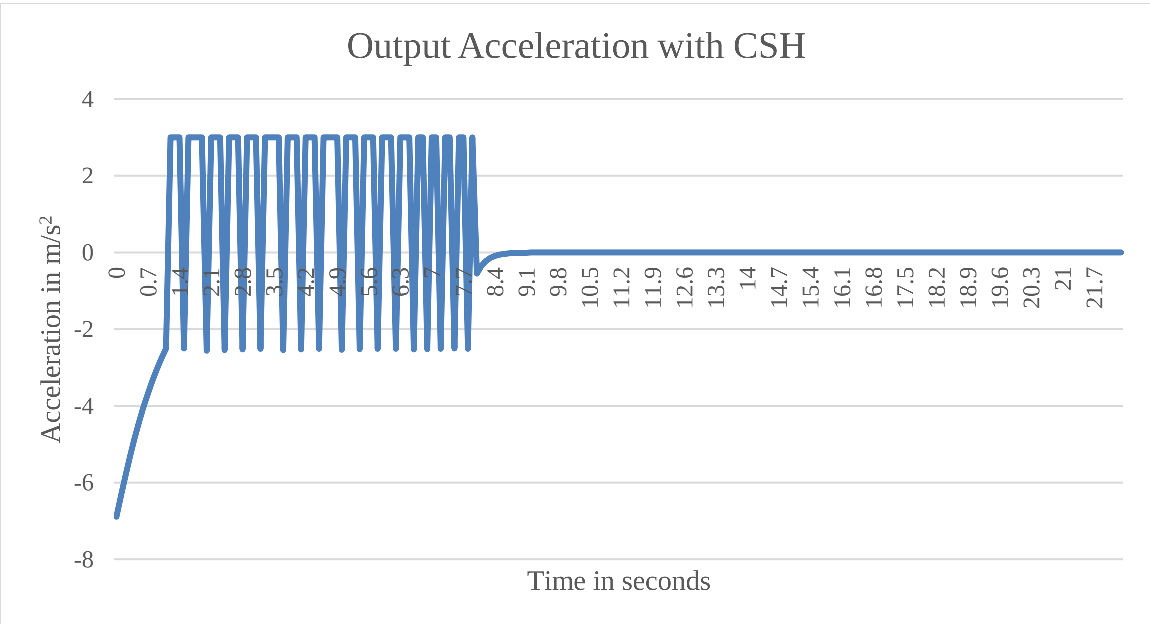

Figure 5.66 Output Accelearation of the System with CSH for Test-6

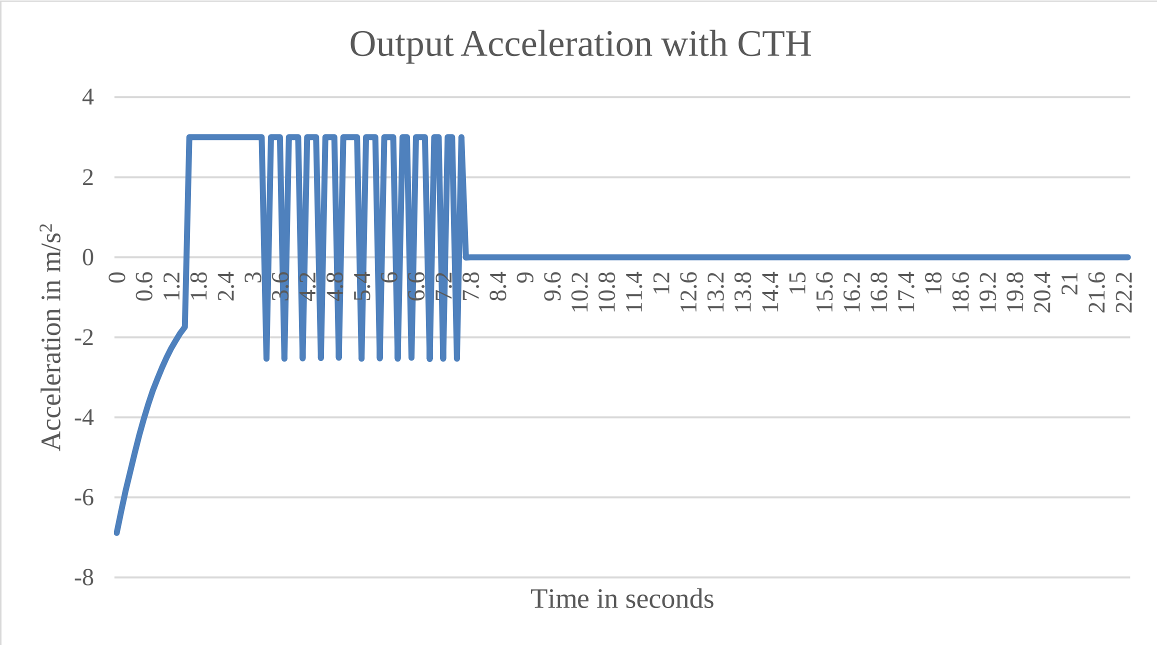

Figure 5.67 Output Accelearation of the System with CTH for Test-6

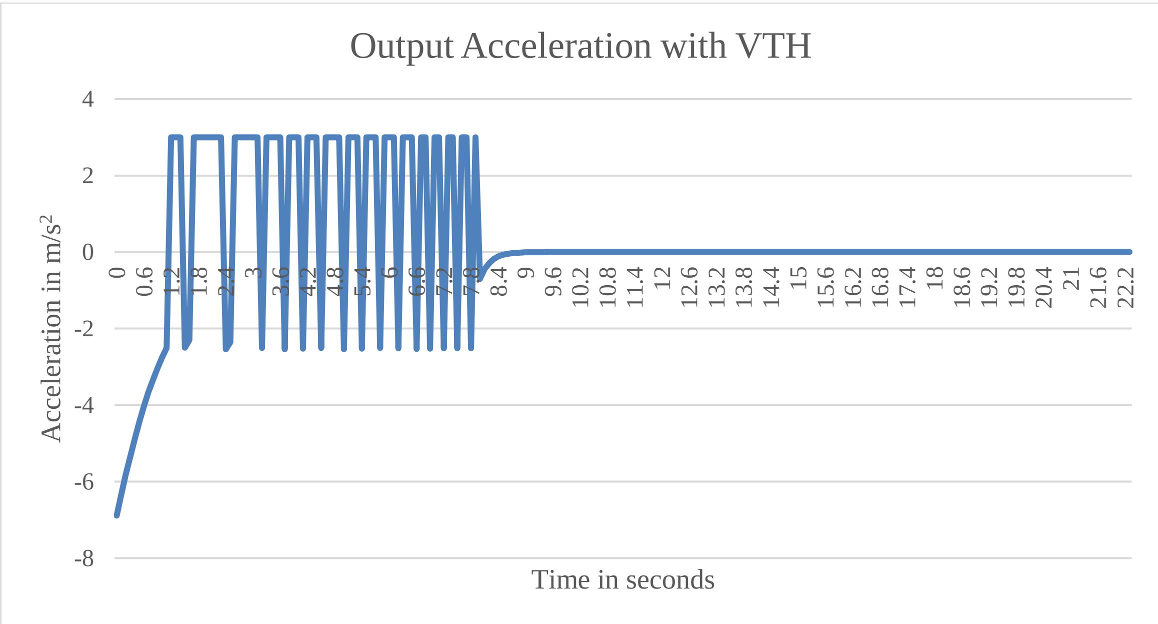

Figure 5.68 Output Accelearation of the System with VTH for Test-6

The speed of the host vehicle for Test-6 can be seen in Figures 5.69 measurement with CHS, 5.70 measurement with CTH, and 5.71 measurement with VTH.

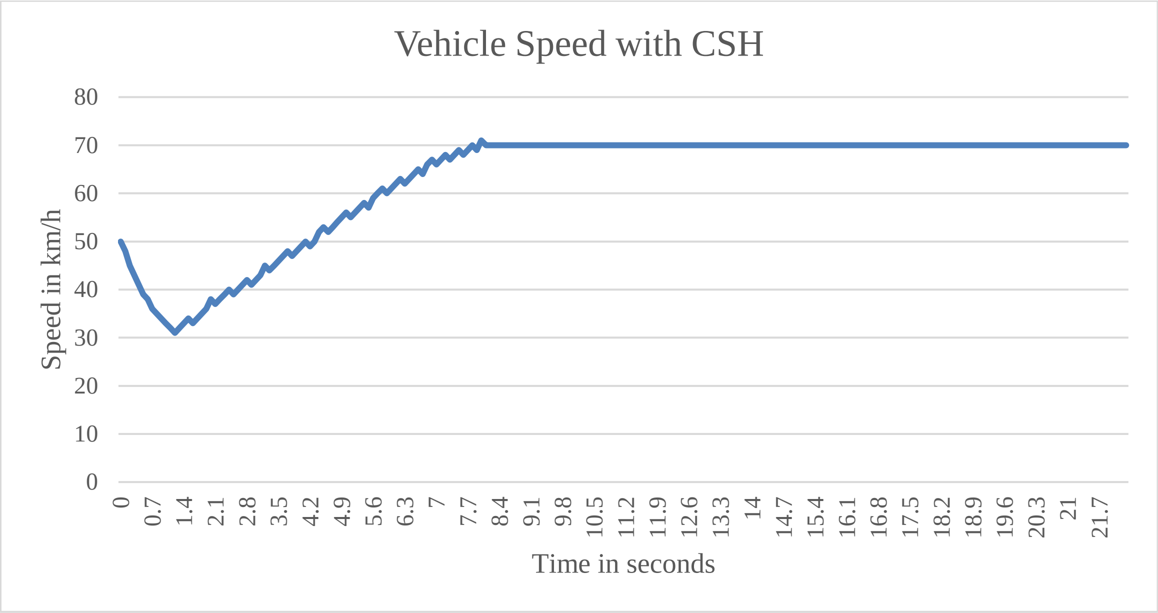

Figure 5.69 Host Vehicle Speed with CSH for Test-6

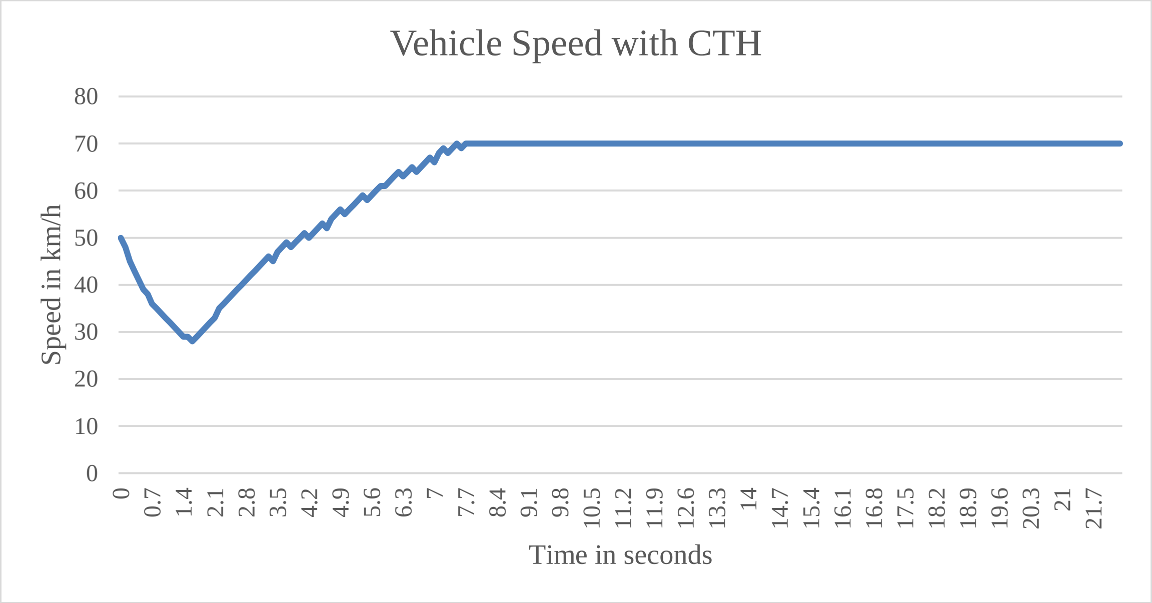

Figure 5.70 Host Vehicle Speed with CTH for Test-6

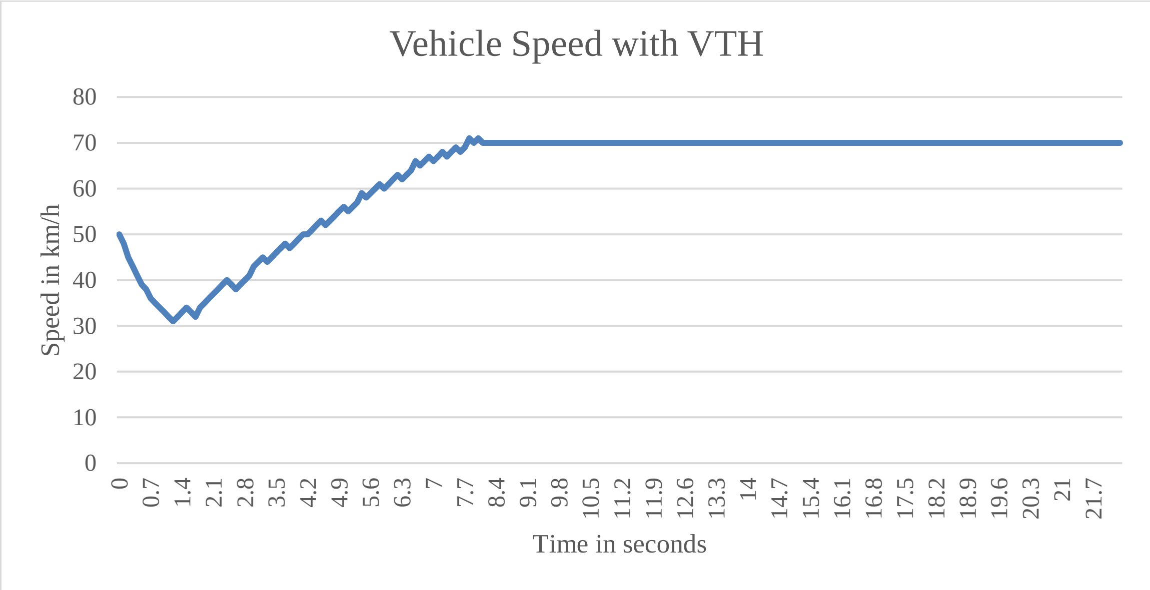

Figure 5.71 Host Vehicle Speed with VTH for Test-6

The active sub feature status for Test-6 can be seen in Figures 5.72 measurement with CHS, 5.73 measurement with CTH, and 5.74 measurement with VTH.

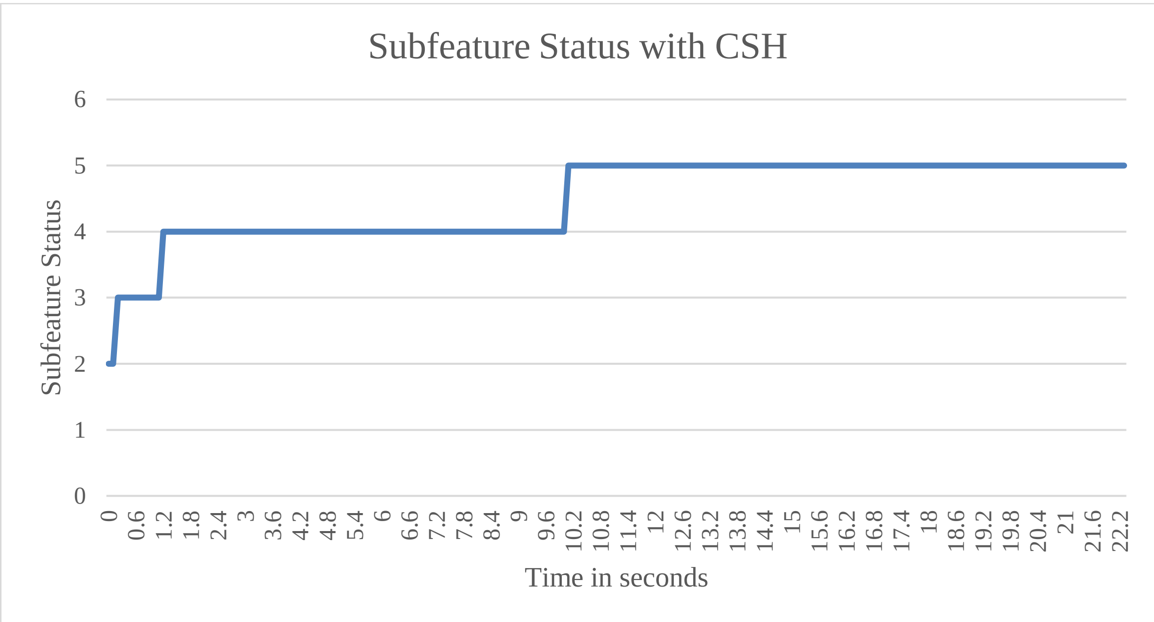

Figure 5.72 Subfeature Status with CSH for Test-6

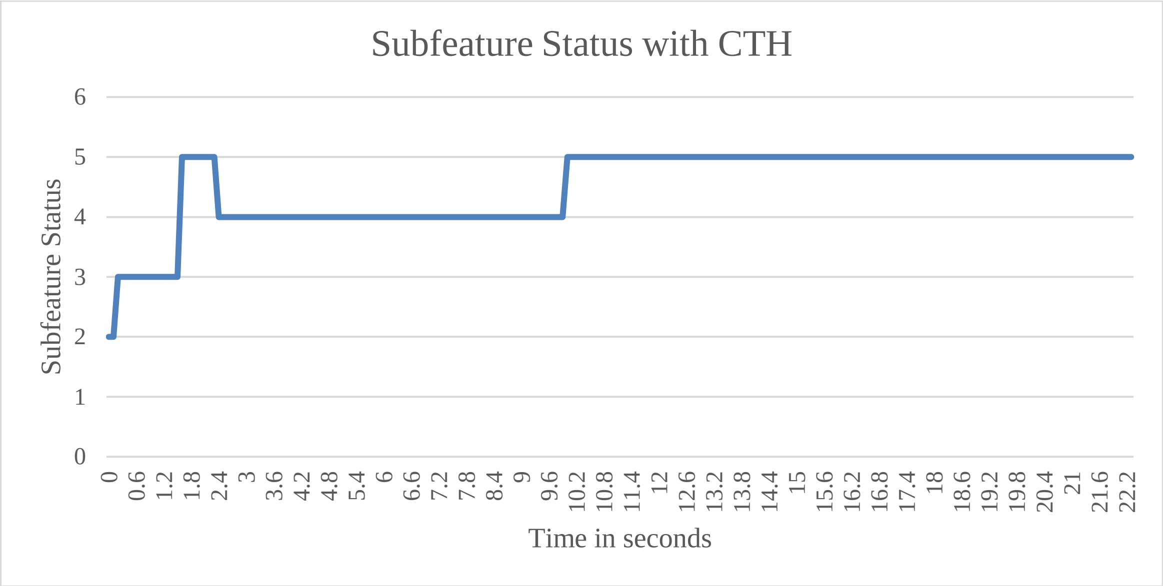

Figure 5.73 Subfeature Status with CTH for Test-6

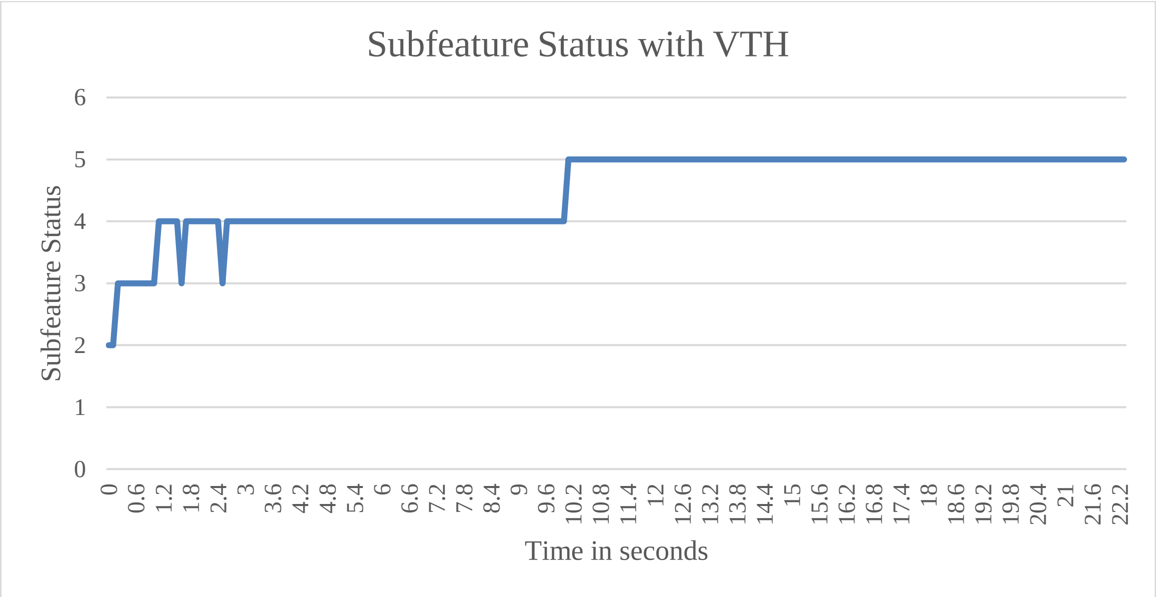

Figure 5.74 Subfeature Status with VTH for Test-6

5.6.2 Analysis of the results of Test-6

The test has been conducted in a closed loop configuration. Initially, the target vehicle is in the Emergency Brake System (EBS) condition for all safety distance measures. Comparing Figure 5.64 and Figure 5.65, it is evident that the VTH safe method safety distance is greater than the CTH safe method due to the target vehicle's acceleration. Furthermore, it is evident that VTH and CSH exhibit comparable safety distance values. This can be observed by comparing Figure 5.63 and 5.65. Additionally, both scenarios demonstrate similar acceleration requests, as depicted in Figure 5.66 and Figure 5.68. Similarly, the vehicle speed control is also similar, as shown in Figure 5.69 and Figure 5.71. CTH exhibits a larger safety distance value compared to other ways, as depicted in Figure 5.64. On the other hand, ADDS prolongs the system's duration with the CAWS method and applies a greater amount of braking. This can be observed by comparing Figure 5.72, Figure 5.73, and Figure 5.74. ADDS eventually executes the ACC and CC algorithms for all safety distance techniques.

This test also demonstrates that ADDS has effectively and automatically adjusted its features and executed them based on the circumstances at the time.

5.7 Comprehensive Analysis of Test Results

The ADDS consists of two primary components: the first component involves the computation of the target vehicle's relative distance and acceleration, while the second component involves the determination of the required acceleration and active sub feature, as depicted in Figure 3.2. The initial step involves calculating the relative speed between the automobiles by utilizing the derivative of the relative distance, as described in equation 4.1. Once the relative speed is known, together with the speed of the host vehicle, the acceleration of the target vehicle may be estimated using equation 4.2. In the Application and Design section, Figures 4.2 and 4.3 demonstrate the practical implementation of their computations in a real-time embedded system. These calculations are mostly utilized in the determination of the safety distance. In the technique section, three primary safety distance methods are commonly employed in the automotive industry. One approach is Constant Space Headway (CSH), which relies solely on the speed of the host vehicle, as indicated in equation 3.2. The second method is known as Constant Time Headway (CTH), which utilizes the speed of the host vehicle and the relative speed of the automobiles, as represented by equations 3.3 and 3.4. The third factor is known as Variable Time Headway (VTH), which is determined by the host vehicle speed, the relative speed between the automobiles, and the acceleration of the target vehicle. These relationships are described by equations 3.5 and 3.6.

All tests evaluate the methods of determining the safety distance. Experimental data demonstrates that CSH and CTH have more stability than VTH throughout all of the experiments. The system initially calculates the relative velocity and subsequently determines the acceleration of the target vehicle based on the estimated values. Thus, the VTH approach exhibits greater variance compared to the other methods. In order to mitigate variability, the computation of the time headway in the application section has been enhanced by incorporating upper and lower thresholds, referred to as th_{max} and th_{min} respectively (Yang, 2020).

The second part of the ADDS was focused on determining the necessary rate of acceleration and deceleration, as well as identifying the active sub feature associated with that acceleration. Figure 4.8 primarily illustrates the process of designing sub feature determination throughout eight sections on a single frame. Equations 4.5 and 4.6 are used by ADDS to calculate the necessary acceleration rate, as stated in the section. The features performed by ADDS in the subsystem Determining Acceleration Deceleration Status can be observed in Figures 4.9, 4.10, 4.11, and 4.12.

Test-1 and Test-2 have been designed as open-loop systems. The test environment shown in Figure 5.1 does not assess the outputs of the ADDS. The purpose of these two tests is to examine the results of the safety distance method and verify that ADDS has executed all sub features based on their range. As the target car approaches the host vehicle, ADDS determines which sub feature should be activated by comparing the current relative distance and TTC parameter with the upper and lower thresholds of the sub features, as depicted in Figure 4.8. Test-1 includes Figure 5.10, Figure 5.11, and Figure 5.12, while Test-2 includes Figures 5.20, Figure 5.21, and Figure 5.22. These figures demonstrate that ADDS has executed all sub features when the current relative distance and TTC (Time to Collision) fall within their respective ranges.

Test-3 was designed to assess the system's sensitivity to collusion. By comparing Figure 5.24, Figure 5.25, and Figure 5.26, it is evident that CTH has the smallest safety distance value. Additionally, CTH does not activate CAWS (Collision Avoidance Warning System) since its Time to Collision (TTC) for the safety distance is smaller than the $TTC_{half\text{-}brake}$. Instead, CTH directly transitions from EBS (Emergency Brake System) to No Action, as depicted in Figure 5.34. Nevertheless, the system maintains a similar speed for the host vehicle in all of the safety distance approaches depicted in Figure 5.30, Figure 5.31, and Figure 5.32. This is because the necessary acceleration is almost identical for all ways, as shown in Figure 5.27, Figure 5.28, and Figure 5.29.

Table 5.2 shows that in all safety distance methods, ADDS triggers EBS at the same time after 2.2 seconds from the initial point because the TTC of the safety distance is smaller than the $TTC_{halfbrake}$. However, it can also be seen that CTH is the most protective method, as ADDS keeps the system in EBS for 4.5 seconds and then the car is stopped. The second protective method is VTH, as seen in Table 5.2. ADDS keeps the system in EBS for 2 seconds, then triggers the CAWS at 4.3 seconds after the initial point and keeps the system in CAWS for 1.5 seconds. Then it triggers EBS again at 4.3 seconds after the initial point, and the car is stopped. CSH is the least protective method compared to CTH and VTH; the ADDS keeps the system in EBS for 1.4 seconds, and it triggers CAWS for 3.7 seconds after the initial point. Then, ADDS keeps the system in CAWS for 2.7 seconds, and at 6.5 seconds after the initial point, it triggers EBS again, and during 0.3 seconds, it keeps the system in EBS, and the car is stopped.

Table 5.2 Timings for Test-3

	Trigger Time for EBS	**Duration of EBS**	**Trigger Time for CAWS**	**Duration of CAWS**
CSH	2.2 6.5	2.2 to 3.6 (1.4 sec) 6.5 to 6.8 (0.3 sec)	3.7	3.7 to 6.4 (2.7 sec)
CTH	2.2	2.2 to 6.7 (4.5 sec)	N/A	N/A
VTH	2.2 5.9	2.2 to 4.2 (2 sec) 5.9 to 6.7 (0.8 sec)	4.3	4.3 to 5.8 (1.5 sec)

Test-3 shows us that ADDS is able to protect cars from accidents in the event that the target vehicle slows down and stops.

Test-4 is designed to test the system with instant change for the target vehicle. During the test, the target vehicle suddenly shifts lanes. The primary focus of this test was on evaluating the ADDS and its Adaptive Cruise Control (ACC) sub feature. The test specifically examined the behavior of the system when the target vehicle entered the lane, specifically in Section 6, as shown in Figure 4.8. In this section, the Acceleration Deceleration Determination System (ADDS) mandates a decrease in speed, accompanied by the additional feature of Adaptive Cruise Control (ACC). Subsequently, the specific specifications of the target vehicle must be transferred to Section 7. Section 7 of the document outlines the design of ADDS (Acceleration Deceleration Determination System) to provide a consistent distance between vehicles while keeping a speed of zero relative to each other. This is achieved by requesting acceleration and deceleration based on equation 4.6. In all safety distance calculation techniques, the management of acceleration and vehicle speed by ADD is essential, as the safety distance method primarily impacts the CAWS and EBS components. However, it does not have any effect on the CC and ACC components. According to Figures 5.46, 5.47, and 5.48, the Adaptive Cruise Control (ACC) is activated when there is no car in front of the host vehicle. The host vehicle's speed gradually increases until it reaches the speed specified by the driver. Once a target vehicle enters the lane, the Acceleration Deceleration Determination System (ADDS) reduces the car's speed by applying a deceleration of up to -3 m/s^2 when the target vehicle is in section six. Once the target vehicle reaches section seven, ADDS maintains a relative speed of zero and a constant relative distance. According to Figures 5.43, 5.44, and 5.45, the speed of the host vehicle is adjusted to match the speed of the target vehicle.

Table 5.3 shows that ADDS handles the system in the same way for all safety distance techniques. As indicated, ADDS first ensures that the system and the host vehicle achieve the required speed chosen by the driver within 3.3 seconds after the initial point. At 10 seconds after the initial point, a target car abruptly changes lanes, and the autonomous driving system promptly responds by activating the Adaptive Cruise Control (ACC) at 10.1 seconds after the first point. For a duration of 21.2 seconds, the ADDS system maintains the vehicle in ACC mode in order to achieve a relative speed of 0. After that, ADDS keeps the system in ACC with no acceleration or deceleration as the relative speed is 0 as required.

Table 5. 3 Timings for Test-4

	Reach Time to Desired Speed	Trigger Time for ACC	Duration of ACC until V_{rel} is 0
CSH	3.3 sec	10.1 sec	10.1 – 31.3 (21.2 sec)
CTH	3.3 sec	10.1 sec	10.1 – 31.3 (21.2 sec)
VTH	3.3 sec	10.1 sec	10.1 – 31.3 (21.2 sec)

This test shows us that ADDS is able to reach the speed set by the driver in CC mode, and when a sudden development occurs, ADDS is able to keep the relative distance constant and the relative speed at 0 with the system in ACC mode.

Test-5 is designed to test the system with the target car first slowing down and then speeding up. In the initial point, the target vehicle is in No Action (section 5) in Figure 4.8. While it is slowing down, ADDS first detects that the target vehicle is in CAWS (Section 4) and EBS (Section 3 or Section 2). Then, after it starts to speed up, ADDS detects that the target vehicle is in No Action (Section 5), ACC, and CC in order. All safety distance methods run EBS and CAWS according to their safety distance measurements. It can be seen that VTH has a higher variance than the other safety distance calculations because of the acceleration estimation. With the help of the maximum and minimum thresholds, ADDS still maintain the acceleration at accepted rate even in VTH. When comparing Figure 5.56, Figure 5.57, and Figure 5.58, CTH is more protected when collusion possibilities occur. It has slowed down the host vehicle more than other safety distance calculation methods. And CSH is more protective from VTH in this circumstance, and host vehicle speed is slowing down, as seen in Figure 5.58. However, as the relative distance is passed in the safety area first CTH and then CSH and VTH, ADDS first runs ACC with CTH, second for CSH, and last for VTH. Because of this situation, host vehicle speed first starts to speed up in CTH, second CSH and last VTH. As seen in Figures 5.56, 5.57, and 5.58, the host vehicle speed is nearly the same after a while for all safety distance calculation methods. It stays the same when the host vehicle reaches the speed set by the driver.

According to Table 5.4, CTH is the only technique that incorporates triggers for EBS. The system initiates EBS after 2.8 seconds and maintains it for a duration of 0.6 seconds. The initial CAWS is triggered by the ADDS when running using the CSH and VTH techniques. By comparing Figures 5.50 and 5.52, it can be observed that the safety distance of the CSH is greater than that of the VTH. The CSH triggers the CAWS 2.5 seconds after the initial point, whereas the VTH triggers it 2.9 seconds after the initial point. When the target vehicle begins to accelerate, it activates the adaptive cruise control (ACC) and cruise control (CC) in sequence. ADDS exhibits consistent behavior across all safety distance measurement methods. Nevertheless, the CTH technique mitigates the risk by triggering ACC 5.5 seconds after the initial point. In contrast, the CSH method triggers ACC at 6.8 seconds, and the VTH method triggers ACC at 8.3 seconds after the first point.

Table 5. 4 Timings for Test-5

	Trigger Time for EBS	**Duration of EBS**	**Trigger Time for CAWS**	**Duration of CAWS**	**Tigger Time of ACC**	**Duration of ACC**	**Trigger Time of CC**
CSH	N/A	N/A	2.5 sec	2.5 to 3.8 (1.3 sec)	6.8 sec	6.8 to 31.8 (25 sec)	31.9 sec
CTH	2.8	2.8 to 3.4 (0.6 sec)	3.5	3.5 to 4.4 (0.9 sec)	5.5 sec	5.5 to 31.7 (26.2 sec)	31.8 sec
VTH	N/A	N/A	2.9	2.9 to 4.1 (1.2 sec)	8.3	8.3 to 32.5 (24.2 sec)	32.6 sec

This test demonstrates that the ADDS is capable of responding when collision avoidance is necessary, activating either the Collision Avoidance Warning System (CAWS) or the Emergency Brake System (EBS), depending on the circumstances.

However, after the risk is reduced, the ADDS can adjust to the situation and activate either the Adaptive Cruise Control (ACC) or the Cruise Control (CC).

Test-6 is specifically developed to evaluate the system's performance when the target vehicle accelerates. Initially, the target vehicle is activated in the Electronic Braking System (EBS) at the specified locations mentioned in Section 2 and Section 3 of Figure 4.8. Subsequently, the ADDS detects the target vehicle and transfers control to the Collision Avoidance Warning System (CAWS), as shown in Section 4 of Figure 4.8. After a period of time, ADDS has identified that the target vehicle is located in the ACC (section 6 or section 7 in Figure 4.8) and CC (section 8 in Figure 4.8). CTH is more protective than CSH and VTH due to its larger safety distance measurement, similar to Test-5. Comparing Figure 5.63, Figure 5.64, and Figure 5.65 reveals that this way of calculating safety distance has a greater impact on slowing down the host vehicle than previous methods. As the speed of the vehicle increases, the distance between the vehicles also increases due to the increased speed of the target vehicle. ADDS initially implemented the Cruise Control (CC) feature in the CTH method. However, due to the host vehicle's accelerated speed in comparison to other ways, ADDS has also incorporated the Adaptive Cruise Control (ACC) feature in the CTH method. This is consistent with the utilization of ACC in other techniques, such as CSH and VTH. After a certain period of time, when the relative distance has sufficiently exceeded the system's critical distance, ADDS has operated almost simultaneously with the system CC for all safety distance techniques. The velocity of the host vehicle is elevated to the speed designated by the driver.

As seen in Table 5.5, at the initial point, ADDS starts in EBS mode; however, it is a short time (0.1 seconds) for all safety distance methods. Then, ADDS triggers CAWS at 0.2 seconds after the initial point for all safety distance methods. ADDS keeps the system in CAWS for the longest time with the CTH method, lasting 1.3 seconds. For CSH, ADDS keeps the system in CAWS for 0.9 seconds, and it is 0.8 seconds for VTH. As the host vehicle speed is getting slower in CTH than other methods, and the relative distance is increased in this method because of that, ADDS triggers CC for a while with the CTH method at 1.6 seconds after the initial point during 0.7 seconds. Then, ADDS triggers ACC for CTH method as it speeds fast and reduces relative distance during 7.4 seconds at 2.4 seconds after initial point. The situation proceeds in slightly different ways when using the CSH and VTH methods. With both methods, ADDS behaves very similarly. ADDS triggers CAWS during 0.9 seconds for CSH and 0.8 seconds for VTH at 0.2 seconds after initial point. Then, ADDS triggers ACC at 1.2 seconds after initial point for CSH and at 1.1 seconds after initial point with VTH. ADDS keeps system in ACC during 8.8 seconds for CSH and 8.9 seconds with VTH. ADDS triggers CC at 10.2 seconds after initial point with CSH and 10.1 seconds after initial point with VTH.

Table 5.5 Timings for Test-6

	Trigger Time for EBS	**Duration of EBS**	**Trigger Time for CAWS**	**Duration of CAWS**	**Tigger Time of ACC**	**Duration of ACC**	**Trigger Time of CC**	**Duration of CC**
CSH	Initial Point	0-0.1 (0.1 sec)	0.2 sec	0.2 to 1.1 (0.9 sec)	1.2 sec	1.2 to 10 (8.8 sec)	10.1 sec	10.2 sec to end of test
CTH	Initial Point	0-0.1 (0.1 sec)	0.2 sec	0.2 to 1.5 (1.3 sec)	2.4 sec	2.4 to 9.9 (7.5 sec)	1.6 sec 10sec	1.6 to 2.3 (0.7 ses) 10 sec to end of test
VTH	Initial Point	0-0.1 (0.1 sec)	0.2 sec	0.2 to 1 (0.8 sec)	1.1	1.1 to 10 (8.9 sec)	10.1	10.1 sec to end of test

This test shows us that ADDS can take action when collusion avoidance occurs, and it triggers CAWS or EBS according to circumstances; however, when the risk is eliminated, ADDS can adapt the situation and trigger ACC or CC.

ADDS, from a general perspective, is capable of preserving the velocity of a vehicle and computing the necessary changes in acceleration and deceleration as necessary.

ADDS consistently maintains acceleration and executes sub features as anticipated in all test cases. ADDS has consistently maintained the acceleration rate for all safety distribution techniques, including sub features CC and ACC, as demonstrated in Test-4. If EBS or CAWS is activated prior to CC or ACC, the activation time of CC or ACC is adjusted based on the immediate evaluation results using the values at that moment. In Test-3, it is evident that ADDS has consistently maintained the same deceleration rate for all safety distance measures in relation to the sub components EBS. ADDS has implemented distinct acceleration rates for all safety measures in the sub feature CAWS, as seen by Test-5 and Test-6. The trigger point of the CAWS is found using the dsafe method, which is considered the safest detection method. The TTCsafe is calculated based on the dsafe approach. As a result, the computation of the safety distance has been modified based on a greater number of parameters compared to the other parameters shown in Figure 4.8. Based on the findings, the safety distances can be ranked in descending order as CTH, CSH, and VTH in situations when the likelihood of an accident is high, such as in Test-5 and Test-6. Thus, the systems' protectionism can be categorized as CTH, CSH, and VTH. The host's velocity decelerates the CTH more significantly than the CSH and VTH due to the aforementioned circumstances. Nevertheless, ADDS consistently ensures the security of the system, regardless of the safety measures employed.

5.8 Budget Analysis

The ADDS system was implemented using an Arduino Uno as the microcontroller unit (MCU). All the remaining components of the system have been simulated. Inputs are reproduced in a controlled testing environment, as outlined in Graph 5.1. In addition, the outputs are replicated using a console simulation, as depicted in Graph 5.2. Therefore, the main reason for this project is in the MCU unit, and the entire cost is presented in Table 5.6.

Table 5.6 Budget of the project

Material	Cost
Arduino Uno	220 TL
Total	**220 TL**

5.9 Political, Health, Environmental, and Ethical Consequences

5.9.1 Political Consequences

The implementation of the ADDS must adhere to the regulations for environmental and safety standards, particularly those set by the Economic Commission for Europe (ECE) under the framework of the United Nations Economic Commission for Europe (UNECE). Furthermore, the European Union has established its own distinct set of legislation and directives pertaining to automobile safety. Since Turkey is a participant in the customs union agreement, it is obligated to adhere to the requirements set by the European Union. Furthermore, Turkey has its own regulations established by Türk Standardları Enstitüsü (TSE).

These laws consist of globally accepted criteria and procedures for ensuring vehicle safety, safeguarding the environment, promoting energy efficiency, and implementing anti-theft measures. These regulations are recognized by many countries around the world and cover a wide range of vehicle components and systems, such as ECE R13: Braking, ECE R79: Steering Equipment, ECE R94: Protection of the Occupants in the Event of a Frontal Collision, and ECE R95: Protection of the Occupants in the Event of a Lateral Collision.

5.9.2 Health Consequences

The purpose of the ADDS is to lower the probability of collusion with the longitudinal control of the vehicle; therefore, it is aimed at increasing vehicle safety. By reducing accidents that cause injuries and fatalities, the ADDS system can enhance public health generally. In addition, drivers may have less stress and fatigue as the ADDS system has automated the speed control with automated and adaptive driving assistance system features.

5.9.3 Environmental Consequences

ADDS may reduce fuel consumption and greenhouse gas emissions by improving the driver's driving behaviour. Also, in an autonomous vehicle, it can be more efficient as the algorithm can be more effective. This will be efficient for internal combustion engine vehicles, such as cars with gasoline or diesel motors. In electrical vehicles (EVs), by managing acceleration or deceleration effectively, ADDS can improve battery efficiency, make it more useful in the long term, and reduce the environmental footprint of the vehicle.

5.9.4 Ethical Consequences

As ADDS may collect data about the driver's behaviour and use it, it may cause ethical concerns about the privacy of the data. It must cover the data protection protocols established by the government. The system also must be designed to protect itself from any errors in the algorithm used to make decisions and to be ready for all kinds of driving circumstances according to security. Especially in autonomous vehicles, it is important to analyse the ethical consequences of machine decision-making in high-risk situations, and it is also needed in industry to establish some standards about accountability and responsibility

5.9.5 Standards Consideration and Usage

ADDS should be designed and implemented according to industry standards for safety, reliability, and compability. The safety standards ensure that the system is functionally correctly implemented and address both functional failures and performance limitations. ISO 26262 is a safety standard for the automobile industry. The security standards protect systems from cyberthreats and ensure secure software flash and updates in different ways, such as off-board flashing in service or automated updates with On the Air (OTA). The JASPAR document provides cybersecurity for automotive. Also, robust communication protocols should be used for system updates, such as CAN (Controller Area Network), which is a communication protocol used for in-vehicle communication, and FlexRay, which is a communication protocol that provides more capacity and reliable data transfer.

CHAPTER SIX
CONCLUSION

The Advance Driver Assistant System (ADAS) has many sub-features to make driving easy, increase the comfort of drivers, and increase the safety of all passengers. ADAS can perform for road parameters such as speed control, lane tracking, etc. Also, it can support the driver inside the car, such as with driver fatigue systems. On the road, ADAS mainly controls in two directions: one is lateral control and the other is longitudinal control. Lateral control is generally used to detect cars, bicycles, or pedestrians in a parallel lane or pedestrian route. The longitudinal control mainly manages vehicle speed and distance between the front vehicles. These systems adjust acceleration or braking to maintain distance between the cars and vehicle speed.

In this study, four longitudinal control feature in ADAS have been developed and implemented in an embedded system. Cruise Control (CC), Adaptive Cruise Control (ACC), Collusion Avoidance Warning Systems (CAWS), and Emergency Brake System (EBS) have been collected in one unified system called Acceleration Deceleration Determination System (ADDS). This module mainly calculates the instant needed acceleration or deceleration value and which subfeature is active at that time from CC, ACC, CAWS, and EBS.

ADDS has a spectrum using Time to Collusion (TTC) parameters and the critical distance point. It has calculated these parameters dynamically according to instant circumstances, vehicle speed, the relative distance between the host vehicle and the target vehicle, etc. According to instant TTC and relative distance, it detects which subfeature should be active and calculates the acceleration or deceleration value. ADDS has been implemented with three different safety distance calculation methods: constant space headway (CSH), constant time headway (CTH), and variable time headway (VTH). The system can be configured, and just one of them can run in the system.

ADDS has been tested with six scenarios to show its capability and behaviour under different conditions. The results show that ADDS is able to manage all the sub-features mentioned for longitudinal control, such as CC, ACC, CAWS, and EBS. It manages vehicle speed and maintains relative distance between the cars with all safety distance calculation methods. The test shows that CTH is the more protective safety distance calculation method; it triggers the first EBS or CAWS when collusion possibility occurs; the second is CSH; and the last is VTH. As CTH first triggers vehicle speed, it slows down most when ADDS is configured with CTH. For the CC or ACC part, all safety distance methods behave the same because the safety distance is mainly used for trigger CAWS in the spectrum of ADDS.

There are two main points open for improvement. The first is that ADDS estimates the relative speed and acceleration of the target vehicle to calculate CTH and VTH. It first estimate relative speed with relative distance and then estimates acceleration of target vehicle with relative speed. Therefore, the acceleration of the target vehicle is not stable at all times. It may be improved by using other sensors or cameras or sharing information between the cars with the Internet of Things (IOT). The second point is the variation of the spectrum interval change, especially in CAWS and ACC, where the output acceleration has variance. It can also be improved with new technological methods, such as machine learning algorithms for predictive control and advanced sensor fusion techniques.

In this study, longitudinal control features such as Cruise Control (CC), Adaptive Cruise Control (ACC), Collision Avoidance Warning System (CAWS), and Emergency Brake System (EBS) have been implemented in one unified system called Acceleration Deceleration Determination System (ADDS). When all the tests and results are examined, ADDS is able to make longitudinal control by determining the acceleration or deceleration value to manage vehicle speed and the relative distance between the vehicles, as well as providing which subfeature is an active subfeature in instant circumstances such as CC, ACC, CAWS, and EBS.

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