DEVELOPMENT OF A CONTROL MODEL FOR A HEAD ON COLLISION AVOIDANCE SYSTEM

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently in candidature for any degree.

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ACKNOWLEDGEMENT

First of all, I would like to thank God for which has helped me went through all the circumstances, gave me determination, and encouragement for me to successfully finish the project.

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Lastly, I would like to thank my family, for their continuous support and caring especially when I was down. Their support has been my energy bar to boost me up to go through hard time, until I accomplished the project.

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LIST OF ABBREVIATIONS

Variables	Description	Unit
A	Overtaking Vehicle	-
B	Leading Vehicle	-
C	Oncoming vehicle in opposite lane	-
D_A	Longitudinal safe distance when vehicle B is ahead vehicle A	m
D_B	Longitudinal safe distance when vehicle A is ahead vehicle B	m
D_C	Longitudinal safe distance when vehicle A and C after overtaking	m
u_A	Vehicle A’s speed	m/s
u_B	Vehicle B’s speed	m/s
u_C	Vehicle C’s speed	m/s
d	Travel distance of vehicle A before overtaking	m
s	Relative speed between vehicle A and B	m/s
s'	Travel distance of vehicle C during overtaking time	m
T	Overtaking time	s
t	Time starts to overtake	s
D	Overtaking distance	m
D'	Safe distance between vehicle A and C to perform overtake safely	m

ABSTRACT

Overtaking is one of the most serious causes of accidents on two-lane two-way roads. Collisions with oncoming vehicles are account for 42% of the largest group. Collisions with oncoming vehicles can also be known as head-on collisions where the front ends of two vehicles hit each other in opposite directions. Safety is the most important issue while driving. Most traffic accidents occur because of an insufficient safe distance. In this paper, an overtaking safety system which can dynamically adjust the safe following distance between vehicles depending on the speed has been proposed. This system can be used to determine and maintain safe following distances both in front and rear of a car. The passenger car and the flying overtaking strategy will be used to simulate the overtaking scenario. With this proposed system, the safe longitudinal distance between the overtaking and oncoming vehicles can be calculated to make sure that the overtaking manoeuvre can be performed successfully to avoid head-on collision.

ABSTRAK

Melampaui batas adalah salah satu penyebab kemalangan yang paling serius di jalan dua lorong dan dua hala. Perlanggaran dengan kenderaan yang akan datang menyumbang 42 % kumpulan terbesar. Perlanggaran dengan kenderaan yang akan datang juga dapat dikenal sebagai perlanggaran langsung, di mana hujung depan dua kenderaan saling memukul ke arah yang bertentangan. Keselamatan adalah masalah yang paling penting semasa memandu. Sebilangan besar kemalangan jalan raya berlaku kerana jarak selamat yang tidak mencukupi. Dalam makalah ini, sistem keselamatan yang dapat secara dinamis menyesuaikan jarak selamat antara kenderaan bergantung pada kecepatan telah diusulkan. Sistem ini dapat digunakan untuk menentukan dan menjaga jarak yang selamat baik di depan dan di belakang kereta. Kereta penumpang dan strategi manuver terbang akan digunakan untuk mensimulasikan senario penyerangan. Dengan sistem yang dicadangkan ini, jarak membujur yang selamat antara kenderaan yang menyalip dan yang akan datang akan dikira untuk memastikan bahawa manuver penyerangan dapat dilakukan dengan jayanya untuk mengelakkan perlanggaran secara langsung.

CHAPTER 1

INTRODUCTION

1.1 Project Background

Driving a car is one of the most important tasks that humans perform every day, and with the advancement of modern technology, an increasing number of cars are produced each year. As the number of cars on the road increases, so does the probability of traffic jams and accidents. Even though passive safety technologies such as airbags, energy absorbing car body and safe belts have reduced the severity of accidents, the fundamental cause of car accidents remains unsolved. Approximately 1.25 million people die every year in road accidents. Between 20 to 50 million people suffer non-fatal injuries, many of whom are disabled as a result of the injuries.(World Health Organization, 2022)

The National Highway Traffic Safety Administration (NHTSA) forecasts that 8,730 people died in car accidents in the first three months of 2021, which is 10.5% higher than the 7,900 predicted by the NHTSA for the first quarter of 2020.(NHTSA, 2022) Drowsiness, nervousness, lack of experience, and human reaction time account for approximately 94% of serious accidents, especially when the driver decides to overtake another vehicle or perform lane changing, which are the most likely causes of accidents.

Overtaking is one of the most serious causes of accidents on two-lane two-way roads. By its very nature, there is a risk of collision with oncoming vehicles, which directly affects safety. An overtaking manoeuvre is not a single action to be performed.

Generally, it is one of the most difficult and challenging driving tasks as it requires complicated decisions, which include a series of continuous actions (lane changes, potential acceleration, or deceleration actions, estimating the relative speed of overtaking and overtaken vehicles, and so on) and can fail in a variety of ways. Thus, it proves that overtaking manoeuvres can result in a variety of types of accidents. According to Figure 1-1, collisions with oncoming vehicles account for 42% of all collisions. The other four collision types are distributed fairly evenly.(Thomas Richter, 2017)

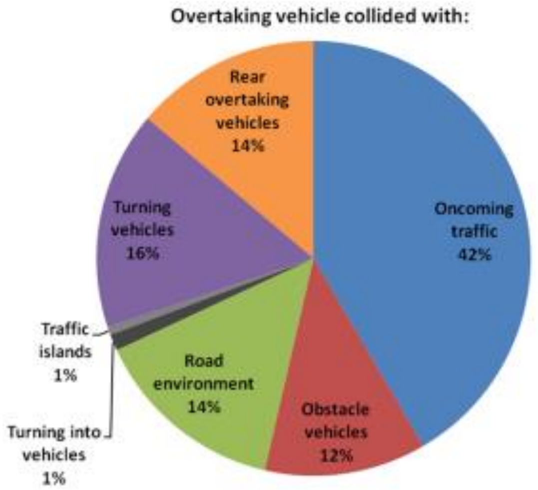


Figure 1-1: Collision Types of Overtaking Vehicles

Collisions with oncoming vehicles can also be known as head-on collisions, where the front ends of two vehicles hit each other in opposite directions. Sometimes, we approximate car crashes as perfectly inelastic collisions where total momentum is conserved but total kinetic energy is not conserved. Some of the kinetic energy is converted into sound energy and internal energy which allows the car bodies to deform as a result of the collision. Also, the force of the impact is equal to their combined inertia. Take an example, two cars are traveling at 60 km/h at opposite direction. When they crash head-on, the impact on each vehicle will be the same as if it collided with a solid wall at 120 km/h.

The primary goal of a safe overtaking manoeuvre is to pass a slow-moving lead vehicle on a two-lane two-way road and safely return to the original lane or maintain a safe headway from the lead vehicle when the overtaking manoeuvre cannot be performed. In fact, safe overtaking manoeuvres can be done in various ways, primarily depending on the speed of the vehicle to be overtaken and the oncoming vehicle in the opposite direction.

The overtaking manoeuvre can be classified into 4 categories. First, normal also known as accelerative overtaking, means that a fast-moving vehicle approaches a slow leading vehicle will decelerate and follow the leading vehicle and waits for a sufficient gap in opposite lane, then accelerates and overtake it. Second is flying overtaking, the overtaking vehicle's speed is not adjusted to the leading vehicle, whereas maintain its current speed throughout the overtaking manoeuvre. Third is "piggy backing" overtaking, the overtaking vehicle follows another overtaker to performs overtake. Finally, is multiple overtake where the overtaker performs the overtaking manoeuvre to pass more than one vehicle.

Vehicles can also be classified into 5 categories, which are two-wheelers, passenger vehicles, light commercial vehicles, heavy vehicles, and buses. Different vehicle categories will have different overtaking characteristics. Mostly, heavy vehicles and buses account for a lower proportion of overtaking vehicles and a higher proportion of overtaken vehicles.(Asaithambi & Shravani, 2017) This could be due to their larger size, and as a result, the following vehicle will always try to overtake them.

The increased number of accidents has resulted in a greater demand for collision avoidance techniques. Collision avoidance also known as a pre-crash system that alerts drivers using the collision avoidance techniques that are available. The goal of collision avoidance is to reduce collisions and severity among pedestrians and vehicle drivers.(Jamlos et al., 2021) Some systems use artificial intelligence machine vision technology to detect impending collisions, while others use dash cams to capture images and GPS to acquire location information. When a collision is detected, these systems can warn the driver with sounds or lights in order to avoid a collision.

There are many different collision avoidance systems (CAS) have been invented in today market to improve safety such as FCW, AEB, V2V etc. Forward Collision Warning (FCW) systems warn the driver of an imminent collision with a vehicle or object in its forward path by using visual, audible, or tactile cues. Automatic Emergency Braking (AEB) is a technology that activates the vehicle's braking system automatically when it detects an oncoming object. Vehicle-to-vehicle (V2V) communication capabilities, which wirelessly exchange information about the speed, location, and direction of nearby vehicles help to avoid collisions. However, the greatest benefit can be obtained only if all vehicles can communicate with each other.

1.2 Problem Statement

According to the Insurance Information Institute (III), head-on collisions account for about 10% of all fatal accidents each year. A head-on collision occurs when the front ends of two vehicles that are travelling towards each other collide. The risk of head-on collisions increases when a driver initiates an overtake on a two-lane highway.

Overtaking is a dynamic and complicated driving task involving steering and speed controls, which requires high driver attention. As overtaking manoeuvres cannot be avoided, head-on car collision avoidance systems should be improved to prevent accidents. In today's market, there have some head-on collision avoidance systems have been invented. However, the algorithms can only be used in certain situations.

Most head-on car collisions occur because of an insufficient safe distance. Therefore, this project will develop a system for head-on collision avoidance between two cars that are moving in opposite directions with different speeds. There are some control parameters that need to be identified, such as the vehicle's speed, safe distance between vehicles and overtaking distance.

1.3 Objectives

The aims of this project are:

1. To study the control parameters that will be involved in head-on collision avoidance system.
2. Perform a simulation based on the safe following distance between vehicles and the vehicle's speed to find the safe overtaking distance to perform the overtaking manoeuvre.
3. Build the prototype by using Lego EV3 to validate with the simulation result.

1.4 Scope of Project

The scope of this study includes designing, simulating, and modelling a system for head-on collision avoidance that will be able to help the vehicle perform overtaking manoeuvre safely. In this project, flying overtaking manoeuvre decision algorithms will be presented. Also, the simulation of the head-on collision avoidance system will be simulated using MATLAB (Simulink) software. The experiment will be carried out by using the Lego EV3 to validate the simulation result. With this proposed system, the safe longitudinal distance between the overtaking and oncoming vehicles will be calculated to make sure that the overtaking manoeuvre can be performed successfully to avoid a head-on collision.

CHAPTER 2

LITERATURE REVIEW

2.1 Classification of Overtaking Phases and Strategies

The general overtaking pattern have been studied. Overtaking is a common occurrence while driving a vehicle. Inappropriate overtaking timing or operational errors can result in car accidents. Based on the proposed structure, overtake threshold is assumed to be equal to 10% of the speed difference. If the speed difference between ego car and lead car is more than 10%, ego car decides to overtake when there is no oncoming vehicle at the opposite lane. (Rezagholipour et al., 2016) Otherwise, before reaches lead car, it reduces its speed in order not to collide with lead car.

Overtaking manoeuvre is divided into 4 phases. The total distance travelled in overtaking is the sum of the distances travelled in each of these 4 phases. The initial period includes the overtaking driver's observation and reaction time. In this stage, the distance travelled is equal to the speed of ego vehicle multiplied by the reaction time, t behind lead vehicle. The driver's reaction time is 2.5 seconds, based on the ASHTO road design standard.

For the second phase, when the overtaking driver notices an overtake area, he accelerates the car and heads towards the road's axis. This phase continues until the vehicle has completely moved to the opposite lane. As a result, the front bumper of the ego vehicle parallels to the rear bumper of lead vehicle. This distance can be estimated as: $S = 0.19V_{ego} + 6.1$.

For the third phase, ego vehicle should travel with higher speed than lead vehicle in opposite lane so that rear bumper of ego vehicle parallels to the front bumper of the lead vehicle. In this phase, the overtaking driver accelerates ego vehicle to ends this phase as quickly as possible before collides with an oncoming vehicle. Therefore, the length travelled during this phase is equal to the lengths of ego and lead vehicle, and its duration is calculated as: $t = \frac{L_{lead}+L_{ego}}{(at_i+V_{ego)}-V_{lead}}$, while t_i is average acceleration time of the ego vehicle. The travelled distance in the fourth phase is equal to the distance in the second phase.

2.2 Lane Changing

Lane changing begins when the ego vehicle starts to move laterally relative to the lead vehicle. The average speed of the ego vehicle must be at least 10km/h higher than that of the lead vehicle to ensure that the lane change (LC) is performed for overtaking. Iranian drivers terminate overtaking manoeuvre at the lateral distance of 3.3m related to the lead vehicle. This means that the overtaking driver can overtake without entering opposite lane, instead the driver only needs a 3.3m lateral distance.(Ramezani-Khansari et al., 2021)

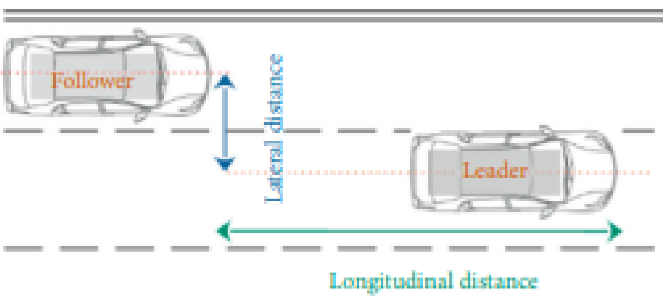


Figure 2-1: Lateral and Longitudinal Distance

For lateral speed modelling, there are 3 variables which are initial lateral distance, longitudinal speed, and time to collision (TTC). The lateral speed decreased by increased the TTC. The lateral speed increased as the initial lateral distance increased. When the initial lateral distance has been larger, the required lateral distance for completing the lane change manoeuvre has been shorter simultaneously, drivers have applied higher lateral speed because they have spent less time in lane change manoeuvre.

2.3 Overtaking Characteristics

The acceleration characteristics, overtaking vehicle speeds, overtaking distances and times, and safe opposing gap required for overtaking have all been studied. The speed of the vehicles overtaking and being overtaken determines the total distance covered by the overtaking vehicle. It also depends on how long it takes the overtaking vehicle to pass the lead vehicle. The vehicle's distance travel increases as the overtaking time increases. The shorter overtaking time indicates that the vehicle is travelling at a higher speed, resulting in a shorter overtaking distance.

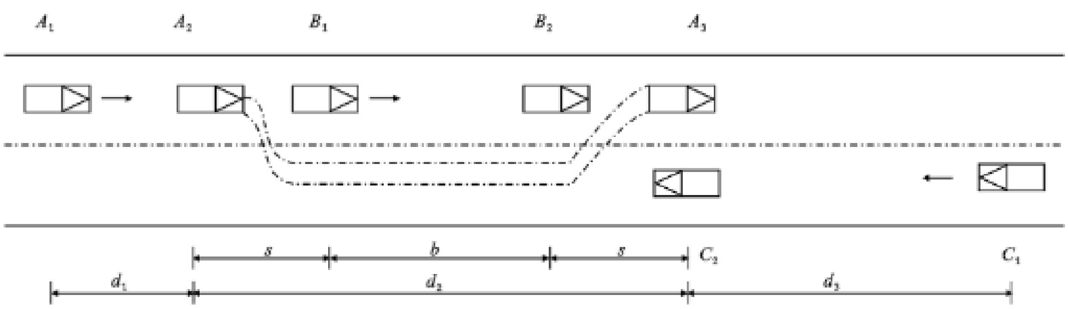


Figure 2-2: Overtaking Manoeuvre

In order to calculate the overtaking distances, several assumptions have been made.(Asaithambi & Shravani, 2017) When the overtaking vehicle (A) is at position A_1, it will reduce the speed to maintain the safety distance with the lead vehicle (B). At position A_2, vehicle A starts accelerating and shifts to the opposite lane to overtake the vehicle B and return to the original lane ahead of vehicle B in position A_3 in time T.

Minimum spacing, s is the minimum distance between 2 vehicles at position A_2 and B_1 while moving with the speed, v_b. s = 0.7 v_b+ 6. Distance covered by vehicle B, b during overtaking time is calculated as: b = $v_b T$.

T is depending on the speed of vehicle B and the acceleration of vehicle A. T can be calculated by equating d_2 to the general formula: $d_2 =$ b + 2s = $v_b T + \frac{aT^2}{2}$, T=$\sqrt{\frac{4s}{a}}$, $d_2 = v_b T$ + 2s If the spacing, s is known, the acceleration can be calculated as: a=$\frac{4s}{T^2}$. The speed of vehicle can be calculated as: $v_a = \frac{d_2}{T}$.

Also, the safe opposing gap for overtaking can be defined in terms of the time, and distance travelled by vehicle C moving at a design speed can be calculated as $d_3 = v_c T$.

2.4 Estimated Time Spent and Safety Distance for Overtaking

The overtaking vehicle should keep a certain distance which also known as safety distance from leading vehicle during overtaking manoeuvre to avoid a rear-end collision during lane change. Also, the safety distance should be maintained even after the overtaking is completed.

When the distance between the overtaking and leading vehicles is within the longitudinal safety distance, overtaking vehicle can perform overtake manoeuvre, and back to the original lane when the longitudinal distance is at least greater than the safety distance.

The 15th item in the Chinese government's "Measures for the Administration of Expressway Traffic," published in March 1995, states that, “When driving on a highway, it is necessary to keep a sufficient distance from the vehicle in front of the same lane. Under normal situations, when driving at 80 km/h, the distance headway should be at least 80m or more.

The estimated time spent on overtaking can be calculated as: $t = \frac{D_a + D_b}{u_1 - u_0}$, where $u_1$and u_0 are the speed of overtaking and leading vehicles, $D_a$is the longitudinal safety distance of two vehicles, D_b is the minimum distance for overtaking. The estimated driving distance of overtaking vehicle can be calculated as:$S_1 = u_1 t.$ (Zhao et al., 2018)

2.5 Safety Following Distance

There are numerous factors that can influence safe distance. Driving safety distance factors include: vehicle speed, vehicle size, road surface, driver attentiveness and weather conditions. There is a suggestion for keeping safe driving distance is “2 second rule”. A driver should ideally stay at least 2 seconds behind any vehicle directly in front of his or her vehicle. But counting time may be distracting the driver. Another guideline for safe following distance in metres is ½ the velocity (km/h) for passenger vehicles and velocity -20 for SUV and 4X4 vehicles. (Kuo-Hsien Hsia, Jia-Hong Cai, Shu-Li Pai, 2019)

The safe following distance is $d = \frac{v}{2}(1 + r + g + s)$ where v is the velocity of vehicle, r is the rain’s status, g is the fog’s status, and s is the slope of hill. When there is no rain, the parameter r=0, and when there is heavy rain, r=1. Similarly, the parameters g and s are defined. For instance, if a passenger vehicle is travelling at 100 km/h on the highway in nice weather with flat roads, the safety following distance should be 50 m. The safety following distance should be larger than 50 m for the same velocity but in the downhill section. The faster the velocity of vehicle or the bad weather, the longer the safe following distance.

CHAPTER 3

METHODOLOGY

3.1 Proposed Model

There are 3 vehicles in this proposed model which are the overtaking vehicle (A), leading vehicle (B), and oncoming vehicle (C). The type of these vehicles is passenger cars. The overtaking strategy taken here is flying overtake. In flying overtaking, the overtaking vehicle's speed is not adjusted to the leading vehicle, whereas maintain its current speed throughout the overtaking manoeuvre.

The proposed flying overtaking manoeuvre decision illustration is shown in figure 3-1. The variables that are observed in this overtaking manoeuvre are:

- What is the distance prior to and after the overtaking manoeuvre between vehicle A and vehicle B?
- What is the duration of the total overtaking manoeuvre?
- Does the overtaking duration dependent on the speed of vehicle B?
- How long the distance to complete the overtaking manoeuvre?
- What is the safe longitudinal distance between vehicle A and vehicle C so that the vehicle A can perform overtaking manoeuvre?

3.2 Flying Overtaking Maneuver Decision Illustration

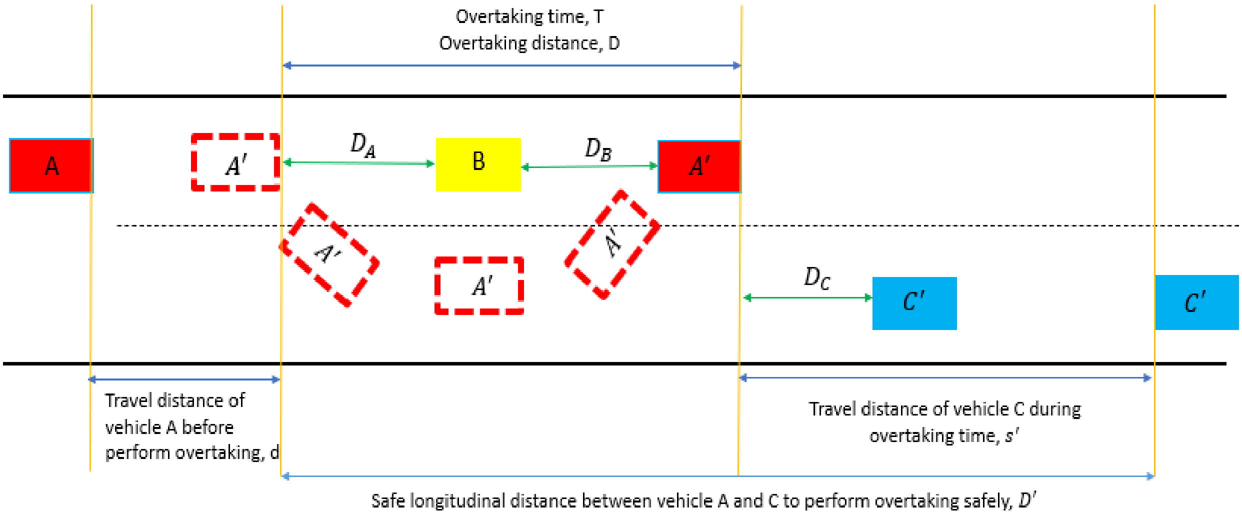


Figure 3-1: Overtaking Manoeuvre Illustration

In this paper, the overtaking procedure is divided into 3 stages: lane changing, overtaking and merging. Vehicle overtaking model based on two kinds of safe distances between the overtaking and overtaken vehicles will be discussed.

The simulated scenarios of a vehicle overtaking are simplified as follows:

- The roads are assumed to be flat and straight within the city.
- Vehicles A and B are in the same lane, while vehicle C is in the adjacent lane. Vehicle B is in front of vehicle A.
- Vehicle B and C drives straight ahead with a constant speed, while vehicle A overtakes vehicle B with a constant speed.

The vehicle A should keep a safe following distance from the vehicle B to avoid a rear-end collision. Also, the safe following distance should be maintained after the overtaking is completed. Vehicle A can only return to the original lane ahead of vehicle B when the longitudinal distance between them is at least greater than safe following distance.

3.3 Process Flow Chart

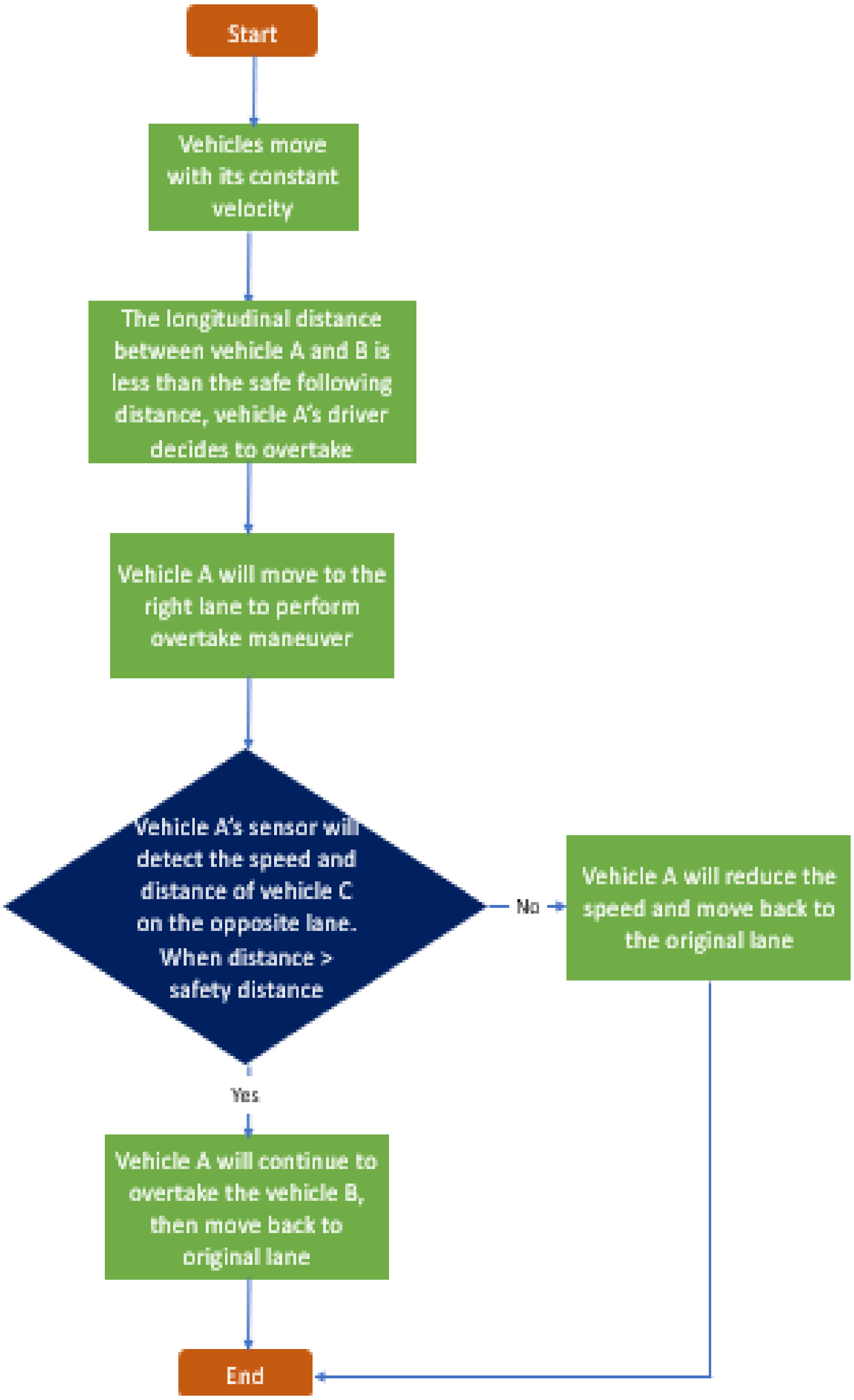


Figure 3-2: Process Flow Chart

3.4 Part I: Flying overtaking Algorithms

The parameters have been set as shown in table 3-1. The average speed for vehicle A (follower) must be at least 10km/h faster than vehicle B (Leader) to perform the overtaking manoeuvre based on the literature review.

Table 3-1: Parameters of vehicles

Vehicle	Overtaking (A)	Leading (B)	Oncoming (C)
Position (m)	0	120	Unknown
Speed (km/h)	90	70	80
Speed (m/s)	25	20	22

In view of safety driving, when the longitudinal distance between the vehicles A and B is less than the safe following distance, the vehicle A can start overtaking when there is no vehicle on the adjacent lane. Based on the literature review, if the driving speed of vehicle A is at 90 km/h, the safe following distance should be maintained at 90m or more. Thus, the formula of $safe\ following\ distance = 3.6u_A$ is formed.

$$safe\ following\ distance = 3.6 \times 25$$

$$safe\ following\ \ distance = 90m$$

When the longitudinal distance between vehicles A and B equal to the safe following distance = 90m, the vehicle A should start to perform overtaking. The time where the vehicle A starts to overtake:

$$t = \frac{P_B - D_A}{v_A - v_B}$$

$$t = \frac{30}{5}$$

$$t = 6.0s$$

Thus, the vehicle A's driver need decide to perform overtake at 6.0s to prevent rear end collision.

Travel distance of vehicle A before perform overtaking:

$$d = t \times u_A$$

$$d = 6.0s \times 25m/s$$

$$d = 150m$$

The duration of overtaking time is influenced by the speed of vehicles A and B and the safe following distance between vehicles A and B. The estimated time spent on overtaking is calculated as follows:

$$T = \frac{D_A + D_B}{u_A - u_B}$$

$$T = \frac{90 + 72}{25 - 20}$$

$$T = 32.4s$$

The estimated overtaking distance is calculated as follows:

$$D = t \times u_A$$

$$D = 32.4 \times 25$$

$$D = 810m$$

To perform the overtaking manoeuvre, the vehicle A must make sure that there is sufficient space in the opposite lane. Thus, it is important to know the position of the oncoming vehicle before performing an overtake. Vehicle C's position after 32.4s,

$$s' = T \times u_A$$

$$s' = 32.4 \times 22$$

$$s' = 712.8m$$

To avoid a head-on collision during overtaking, the safe longitudinal distance between the vehicle A and vehicle C, D' can be calculated as follows:

$D' = D + s'$

$D' = 810m + 712.8m$

$D' = 1522.8m$

The safe longitudinal distance between vehicles A and C must be at least greater than 1522.8m to perform an overtaking manoeuvre successfully.

3.5 Part II: Simulation

To verify the correctness of the collision avoidance algorithms, MATLAB Simulink is used to simulate the vehicle overtaking scenario. Simulink is a block diagram environment for designing multidomain models, simulating before moving to hardware, and deploying without writing code. Simulink provides a graphical editor, customizable block libraries, and solvers for modelling and simulating dynamic systems.

The complete head-on collision avoidance system was built as shown in figure 3-3:

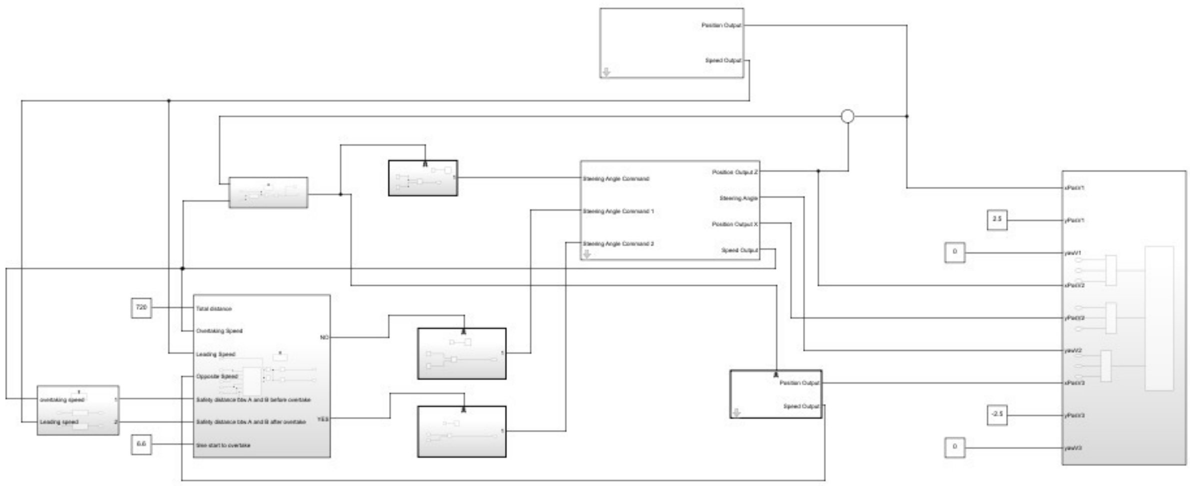


Figure 3-3: Head-on Collision Avoidance System in Simulink

There are 3 subsystems that have been developed for the vehicles A, B and C as shown in figure 3-4. The system mask is created for the subsystem and promotes the initial speed and initial position parameters to allow us to change them easily from outside to simulate different conditions.(MOBATSim, 2019)

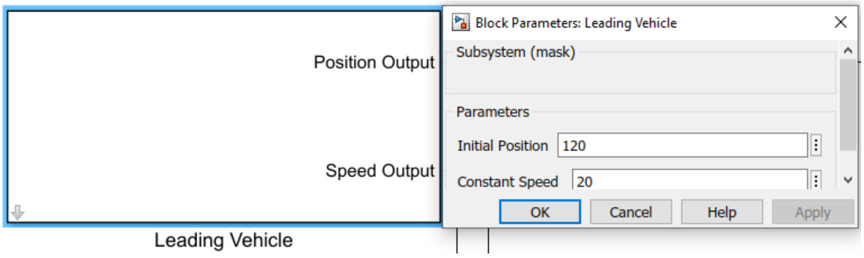


Figure 3-4: Vehicle B's Subsystem and Mask

The overtaking decision maker subsystem was built as shown in figure 3-5. The equation of $safe\ distance = 3.6u_A$ had been inserted into the subsystem.

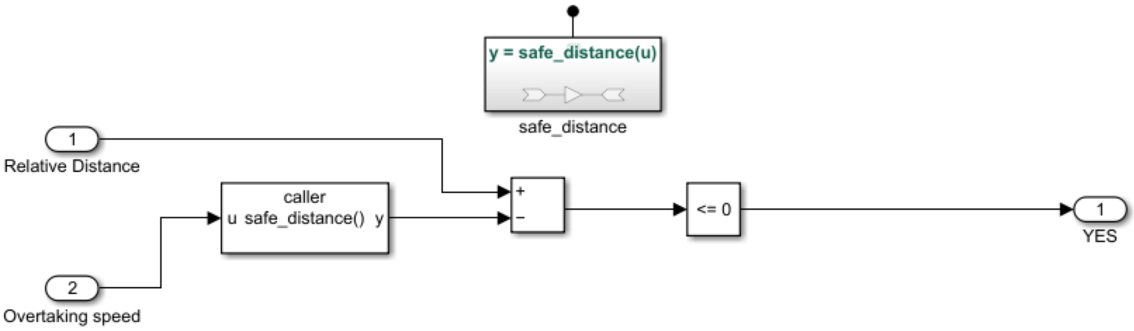


Figure 3-5: Safe Distance Equation in Simulink

When the longitudinal distance between vehicles A and B is less than the safe following distance, the overtaking decision maker will trigger the steering angle command to start performing the overtaking manoeuvre as shown in figure 3-6. Then, vehicle A will start to change to the adjacent lane.

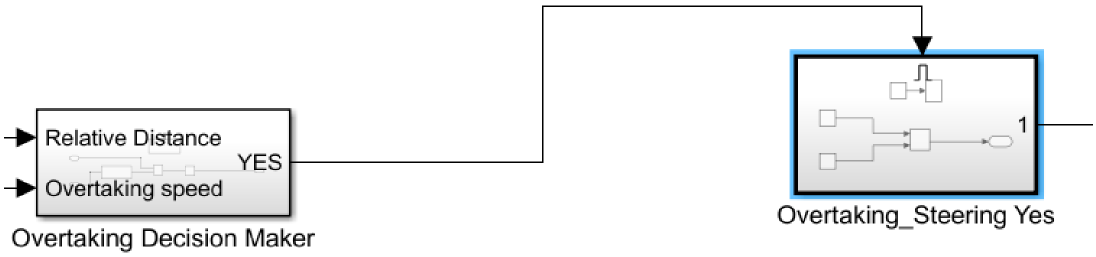


Figure 3-6: Connection between Overtaking Decision Maker with Steering Command

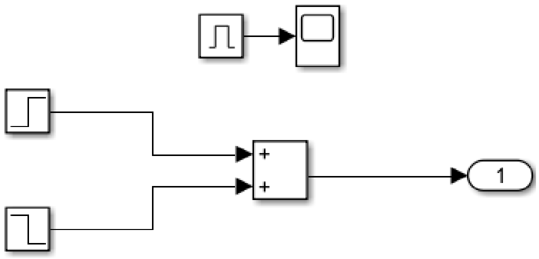


Figure 3-7: Steering Angle Command

When vehicle A moves to the adjacent lane, the vehicle A's sensor will start to detect the oncoming vehicle. The formula for safe longitudinal distance between vehicles A and C has been inserted into the subsystem as shown in figures 3-8 and 3-9.

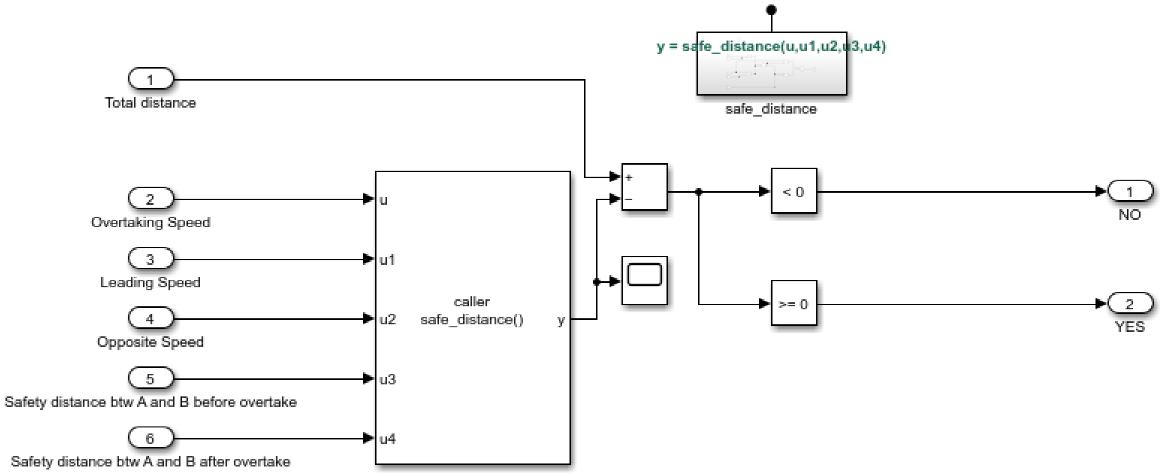


Figure 3-8: Safe Longitudinal Distance Between Vehicles A and C Equation

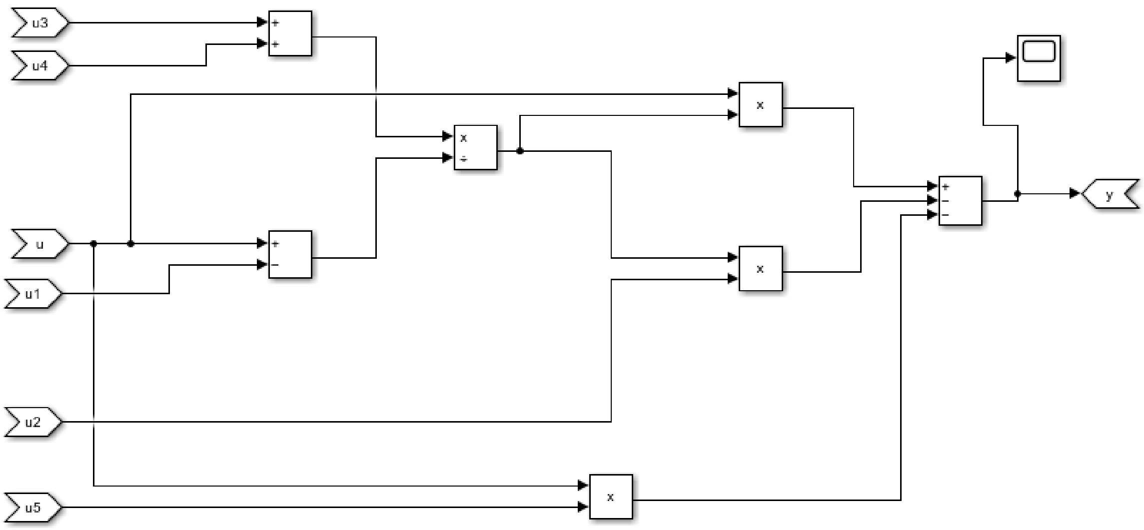


Figure 3-9: Safe Longitudinal Distance Between Vehicles A and C Equation

The decision that can be made is either “Yes” or “No” as shown in figure 3-10. As shown in Figure 3-11, the "No" decision is linked to the steering angle command 1, while the "Yes" decision is linked to the steering angle command 2.

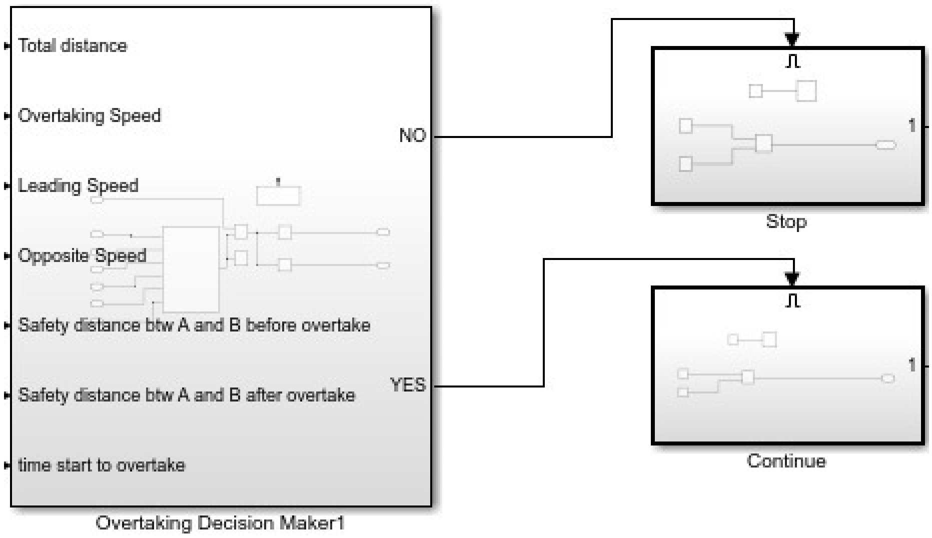


Figure 3-10: Connection Between Safe Longitudinal Distance Equation with the Steering Command

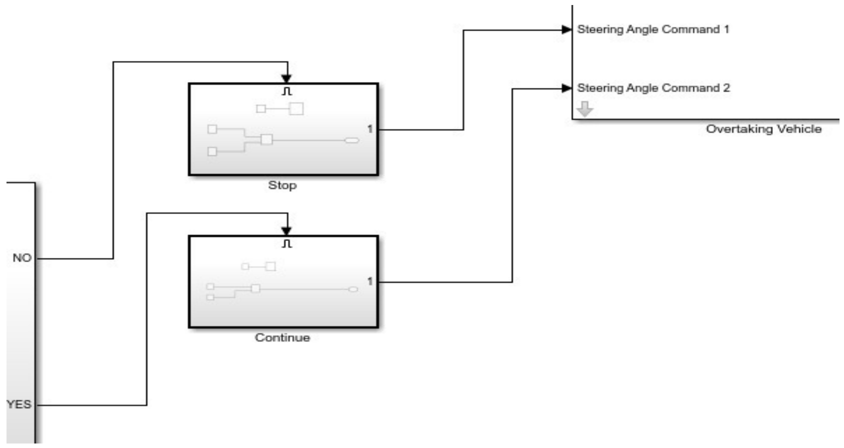


Figure 3-11: Steering Angle Commands for “Yes” and “No” Decision

When the longitudinal distance between vehicles A and C is larger than the safe longitudinal distance to perform overtaking, the “Yes” decision will be triggered. Vehicle A will complete the overtaking manoeuvre by overtake the vehicle B then move back to original lane.

The “No” decision will be triggered when the longitudinal distance between vehicles A and C is less than the safe longitudinal distance to perform overtaking. Vehicle A will return to an original lane and the speed will reduce then stop. The commands to stop the vehicle are shown in figure 3-12. From the video (https://youtu.be/VJeqsSFrWGI), the vehicle A will stop before it collides with the vehicle B.

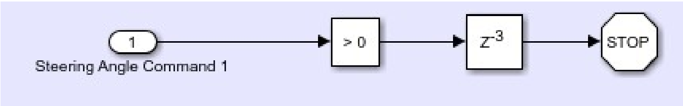


Figure 3-12: Commands to Stop the Vehicle A

The simulation is created through 2D traffic visualization to plot the vehicles and the road inside Simulink by using a MATLAB Function Block. Kindly refer to APPENDIX, for the details of 2D traffic visualization coding. In the 2D animation, the rectangle with a length of 4m and a width of 2m represents a vehicle. The road is set with a width of 5m. The initial position Y of vehicles A and B is at 2.5m while for the vehicle C is at -2.5m (opposite lane).

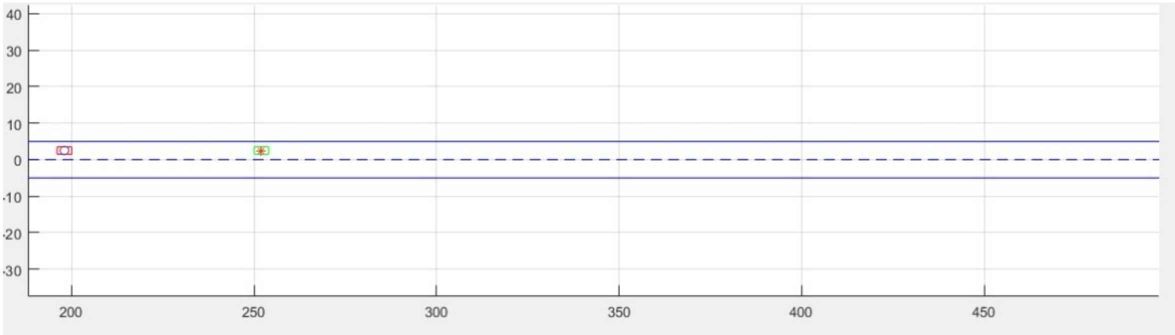


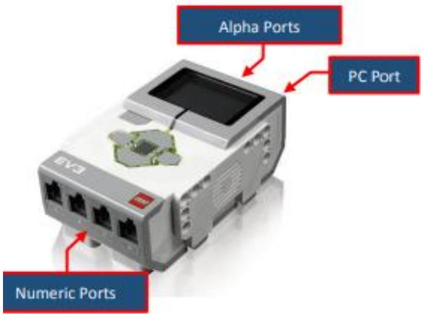
Figure 3-13: 2D Traffic Visualization

3.6 Part III: Experiment

To validate the simulation result, the experiment has been carried out using the Lego Mindstorms EV3. It can be used to build and programme the vehicle. The vehicles were built with Lego elements, motors and sensors as shown in figure 3-14. The function of each component is explained in table 3-2.

Figure 3-14: A Vehicle Built by Lego

Table 3-2: Components Used for Vehicle

Component	**Function**
Control center / "Brick" 	• Programs are executed from the Brick. • Sends programmed information to motors. • Receives information from sensor to initiate programmed parameters. • Must be connected to motors and sensors via cabling to function. • Motors must be connected to the front alpha ports. • Sensors must be connected to the rear numeric ports.

Large motor 	• Receives programmed instructions from the Brick. • Heavy duty with lower gearing for mobility requirements.
Ultrasonic sensor 	• Detects distance to an object and sends that data to the Brick for possible action according to programmed parameters. • Using the same principle as Bats and submarines, it uses echo location by emitting an ultrasonic wave that is received back after bouncing off an object. • The distance to that object is determined by the time it takes to be received back. • Can detect objects from approximately 5-255cm away.

The vehicles are programmed using the EV3 programming software. The commands of the vehicle are inserted into the programming window by dragging and dropping the desired blocks. Each color of block has a function, only green and orange colors will be used for our experiment. Green color block if for action while orange color block is for flow control.

The command for the leading vehicle (B) and the opposite vehicle (C) are shown in figure 3-15. It only includes the green color move steering block to control the two