

MINISTRY OF INDUSTRY AND TRADE  
HANOI UNIVERSITY OF INDUSTRY

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**RESEARCH ON THE INFLUENCE OF THE WEIGHT OF 5-  
SEATER CARS ON FUEL CONSUMPTION**

Major: Mechanical Engineering

Code: 9520116

SUMMARY OF DOCTORAL THESIS IN ENGINEERING

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This desertation has been completed at:

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The desertation can be found at:

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## INTRODUCTION

### 1. The urgency of the topic

Vietnam's economy is experiencing strong growth, with annual GDP growth approaching double digits. People's living standards are improving, leading to a growing desire to own and use small cars for transportation. The 5-seater car segment is experiencing particularly strong growth. This increase in the number of vehicles necessitates a significant increase in fuel supply for the transportation sector. Therefore, the issue of fuel consumption and efficient fuel use has become critical, not only for vehicle users but also for car manufacturers and assemblers, as well as for scientists researching automotive engineering and the relevant government policies.

Fuel prices worldwide and in Vietnam are constantly changing due to the influence of many factors: economic, geopolitical, and global environmental. Therefore, researching and understanding the factors affecting fuel consumption in automobiles, with the aim of improving the design, use, and operation of vehicles, is a very urgent requirement with significant economic and social implications.

Among the many factors affecting a vehicle's fuel consumption, such as engine characteristics, powertrain, vehicle shape, operating conditions, and driving habits, the car's weight is a fundamental factor that is often overlooked in practical research in Vietnam. According to Newton's second law, the force required to move an object is directly proportional to its mass. This means that the greater the car's mass, the more power the engine must generate to overcome the car's inertia, the rolling resistance between the tires and the road surface, and the resistance when climbing hills or accelerating. Consequently, the car's fuel consumption also increases.

Scientifically and in-depthly studying the relationship between the weight of a 5-seater car and fuel consumption will have significant practical implications. For car manufacturers and assemblers, the research results could provide a scientific basis for improving the design of the chassis structure, selecting lightweight materials, and improving the layout of systems to reduce vehicle weight while maintaining durability and safety. For consumers, the research results help them better understand the impact of vehicle weight on operating costs, enabling them to choose a more suitable vehicle when purchasing or to use their vehicle more efficiently. Furthermore, from an environmental perspective, reducing vehicle weight and fuel consumption will reduce CO<sub>2</sub> emissions, aligning with the green development trend and Vietnam's emission reduction commitments in the green energy transition process.

Based on the issues mentioned above, it is affirmed that the topic "*Research on the influence of the weight of 5-seater cars on fuel consumption*" is necessary and has practical significance, contributing an important factor to the problem of fuel saving, improving energy efficiency, and supporting the direction of design, production, assembly, and use of automobiles in Vietnam in the future.

### 2. Novelty of the thesis

Studies quantitatively assessing the specific impact of vehicle weight on fuel consumption, particularly for 5-seater passenger cars under Vietnamese traffic conditions, are still relatively limited.

Based on this reality, the thesis proposes a new approach that integrates dynamic modeling, simulation, and experimentation to truly clarify the relationship between the overall weight of a car and fuel consumption in real-world operation. On this basis, the thesis has the following novel points:

- This thesis analyzes and establishes a quantitative relationship between the mass of a 5-seater car and fuel consumption based on a longitudinal motion dynamics model of the car.

Unlike many previous studies that often consider mass as a secondary parameter in overall optimization problems, this thesis focuses on in-depth research into the individual influence of mass on motion resistance forces and fuel consumption during specific operation;

- This thesis develops an algorithm and simulation model for FC(stat) on the Matlab/Simulink platform, allowing for the determination of fuel consumption of a car when the mass changes during operation in different modes. The model is organized with a clear structure, showing the relationship between input and output quantities, and directly comparing theoretical simulation results with experimental measurement results, thereby improving the reliability of the simulation method;

- This thesis proposes and implements a method for measuring fuel consumption in automobiles in real time, through the design, fabrication, and validation of a measuring device for research purposes. The device allows for the simultaneous collection of important operating parameters of the automobile such as vehicle speed, brake pedal force, throttle opening, and fuel consumption in real time, producing experimental data for analysis and evaluation;

- By combining theoretical models, simulations, and experimental results, the thesis has established an empirical function representing the relationship between vehicle weight and fuel consumption with high accuracy. Comparative evaluation results show that the difference between simulation and experiment is within an acceptable range;

- Based on the research results, the thesis proposes a direction for reducing fuel consumption through solutions that reduce vehicle weight, emphasizing the selection and application of lightweight materials in car bodywork.

Thus, the novelty of the thesis lies not only in its research content but also in its approach, which combines theoretical modeling, numerical simulation, and experimentation, suitable for the conditions of automobile operation in Vietnam.

### **3. Research objectives, research subjects, and scope of the thesis.**

#### a) Objectives of the dissertation topic:

This thesis aims to identify, analyze, and quantitatively evaluate the impact of the weight of a 5-seater car on fuel consumption during actual operation. The thesis has the following objectives:

- Clarify the scientific basis of the influence of overall mass on dynamic characteristics and fuel consumption; develop a dynamic model of automobile motion as a foundation for establishing a quantitative relationship between mass and fuel consumption.

- Develop a simulation model to show the relationship between vehicle weight and fuel consumption under different operating conditions, ensuring consistency with real-world operating conditions.

- Propose a method for measuring fuel consumption suitable for automobile operating conditions; design and manufacture a measuring device that ensures accuracy and stability.

- Conduct experimental research on a 5-seater car (Toyota Vios 2009) to measure fuel consumption with different vehicle weights; compare experimental results with simulation results and theoretical calculations to verify the reliability of the model and measurement method.

- To assess the applicability of research results in scientific research, automotive engineering training, and supporting practical fuel consumption analysis.

- Propose recommendations to reduce fuel consumption, focusing on the application of lightweight composite materials in vehicle bodywork.

#### b) Research subjects:

It is the relationship between the overall weight of a 5-seater car and its fuel consumption, mediated by factors including drag force, engine power, and powertrain characteristics.

The specific subject of study was the 5-seater Toyota Vios, chosen because its technical characteristics are common in the passenger car segment in Vietnam, making it suitable for simulation and experimentation.

c) Scope of research: This study investigates, simulates, and experimentally examines the influence of the overall weight of a 5-seater passenger car (Toyota Vios 2009) on fuel consumption under real-world operating conditions in Vietnam. The research is conducted using a motion dynamics model and a fuel consumption simulation model, combined with experimental fuel consumption measurements to verify the model results.

#### **4. Scientific and practical significance.**

- Scientific significance: The thesis has established the necessary scientific foundation for the calculation and simulation process, reflecting the nature of the relationship between vehicle mass, motion resistance forces, and fuel consumption in automobiles. Based on this, it simulates replacing the actual vehicle body mass with a body made of lightweight materials. The theoretical and experimental research results in the thesis have contributed to the improvement of the scientific database for calculating, simulating, and experimentally determining fuel consumption for equivalent vehicle models, thereby contributing to supplementing the scientific basis as a prerequisite for research on energy efficiency and emission control in transportation.

- Practical significance: It supports manufacturers in the design, calculation, and refinement phases of vehicle structures to optimize weight, contributing to the goal of developing sustainable transportation and reducing adverse environmental impacts .

This dissertation topic meets the requirements and development direction of the automotive industry in the current period, as car manufacturers are continuously improving and applying lightweight materials in vehicles, and adopting new technologies to reduce vehicle weight while still ensuring safety, durability, and operational efficiency.

Beyond its technical significance, the research findings also contribute to improving users' understanding of the importance of reducing unnecessary load to save fuel.

#### **5. Research content and structure of the thesis:**

The thesis has four chapters:

- Chapter 1: Overview of Research
- Chapter 2: Scientific Basis of Research
- Chapter 3: Analyzing the influence of weight on fuel consumption materials in the car
- Chapter 4: Experimental Research

## **CHAPTER 1: OVERVIEW OF RESEARCH**

### **Chapter 1 focuses on research related to:**

The relationship between fuel consumption and vehicle weight, indicators for evaluating the fuel economy of automobiles, solutions for reducing automobile fuel consumption, etc.

Research findings both domestically and internationally on the impact of vehicle weight on fuel consumption, solutions to reduce automotive fuel consumption, and methods for measuring automotive fuel consumption.

### **From this, we can draw the following conclusion:**

Chapter 1 summarizes typical domestic and international studies related to automobile fuel consumption, influencing factors, and research methods used. Analysis shows that,

although vehicle weight is discussed in many studies, it is mainly considered as a secondary parameter in overall optimization problems. There are not many specific studies that quantitatively assess the individual impact of overall weight on fuel consumption under specific operating conditions.

Analysis of methods for measuring fuel consumption in vehicles reveals several approaches, such as weighing the fuel tank before and after driving, measuring on an AVL test bench, and measuring during the driving cycle. Each method has its own advantages and disadvantages, which serve as the basis for designing a measuring device for the experiments in this thesis.

Based on the analysis of the current research situation, Chapter 1 clarified the necessity of studying the relationship between vehicle weight and fuel consumption, and identified the approach, objectives, and content of the thesis. This overview provides a scientific basis for conducting theoretical, simulation, and experimental studies in the following chapters.

## CHAPTER 2: SCIENTIFIC BASIS OF RESEARCH

Some of the topics studied and presented in Chapter 2 include:

### 2.1. DYNAMIC MODEL OF AUTOMOBILE MOTION

The power required to move the vehicle is simply to overcome resistance.

$$P = \frac{(P_f + P_w + P_j + P_i) \times v}{\eta} \tag{2.1}$$

As the vehicle moves, rolling resistance constantly changes between 10% and 70%.

Rolling resistance is affected by tire pressure. For truck tires, rolling resistance increases by approximately 5 to 8% when pressure decreases by 20%, resulting in a 2 to 3% reduction in fuel efficiency.

Rolling resistance dissipates 10-33% of the energy at the interaction surface between the tire and the road, depending on the tire structure and axle load.

### 2.2. FUEL CONSUMPTION AND FUEL SAVINGS

Fuel consumption (FC) indicates the amount of fuel consumed per unit distance traveled by the vehicle (liters/km, kg/km, etc.).

Fuel economy (FE) indicates the distance the vehicle has traveled per unit of fuel (km/liter, km/kg, etc.).

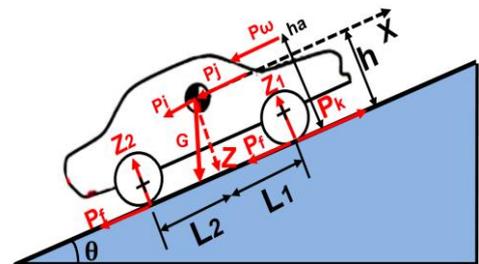
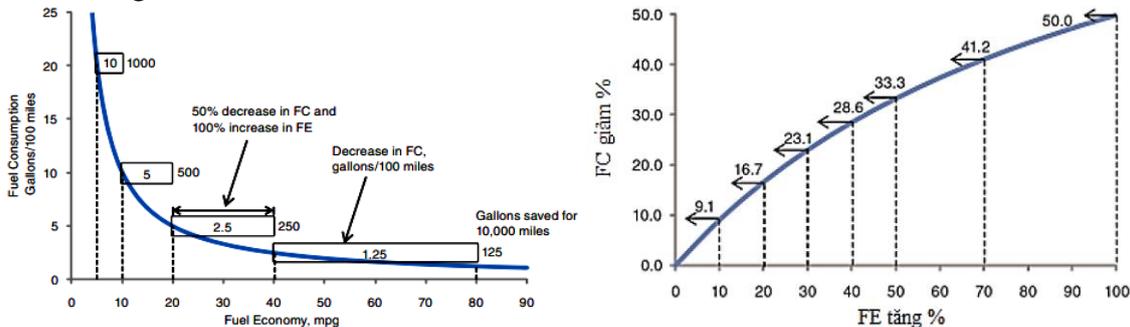


Figure 2.1 Schematic diagram of the longitudinal dynamics model of a car.



a. The proportional relationship between FC and FE b. The percentage relationship between FC and FE

Figure 2.2 : Relationship between FC and FE SEQ Hình \\* ARABIC \s 1

## 2.3. MODELS FOR DETERMINING FUEL CONSUMPTION IN AUTOMOBILES

### 2.3.1. Average vehicle operating point model

a. Modeling:

When a vehicle is operating on the road, there are many points of engine and vehicle operation (collectively referred to as vehicle operating points). The model combines all vehicle operating points into a single representative point to calculate the fuel consumption  $FC_{(Av)}$ .

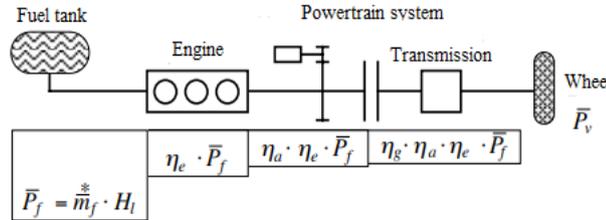


Figure 2.3 2Modeling and calculation of fuel consumption in an internal combustion engine.

Power balance equation:

$$\bar{P}_v = \eta_g \cdot \eta_a \cdot \eta_e \cdot \bar{P}_f \tag{2.6}$$

b. Simulation

+ Assumptions

Determine the calorific value of the fuel.

+ Determine the input parameters

+ Run the simulation program

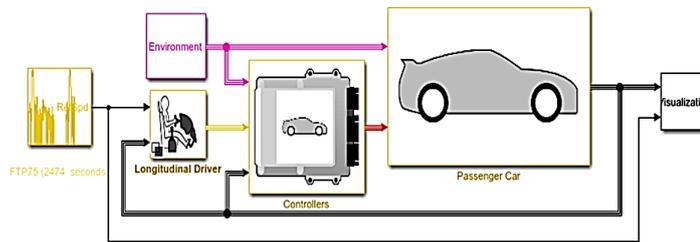


Figure 2.4 3Simulink diagram for determining fuel consumption in a car using the vehicle's average operating point model.

+ **Determine the applicability**

Published literature shows that the average operating point method can provide a reasonable estimate of fuel consumption for vehicles with simple powertrains, but it is not suitable for issues requiring structural optimization on the vehicle, and therefore does not offer options for energy management strategies.

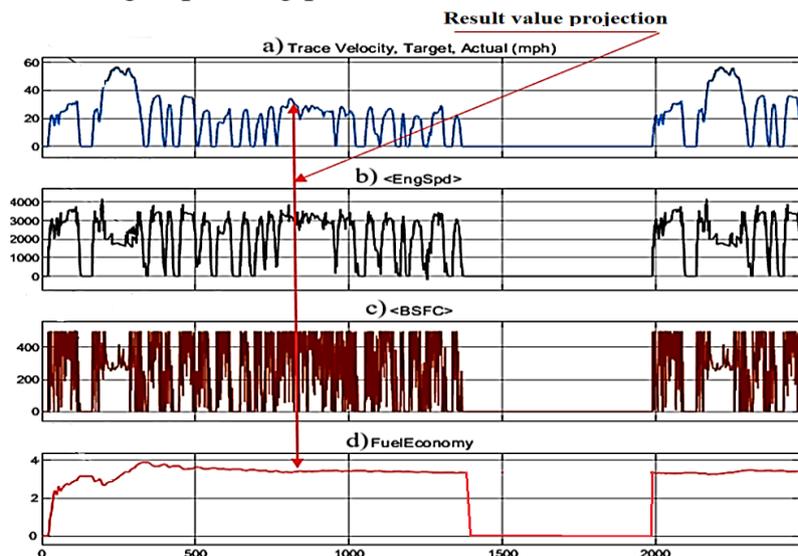


Figure 2.5 4Simulation results graph determining fuel consumption on a car based on the vehicle's average operating point model.

### 2.3.2 Dynamic Model dyn(FC)

Construct the dyn(FC) equation in the form of the following equation:

$$M_1 \frac{dv}{dt} = \left( \frac{\eta \times i_t}{r_{bx}} T_e \right) - (M_1 g \times \cos \alpha \times (r_o + \eta)) - \left( \frac{1}{2} \rho A_f C_d \times v^2 \right) - (M_1 g \times \sin(\alpha)) - P_p \quad (2.7)$$

Expand it into an equation.

$$M_1 \left( \frac{dv}{dt} + g \cos \alpha (r_o + \eta) + g \sin(\alpha) \right) = \left( \frac{\eta \times i_t}{r_{bx}} T_e \right) - \left( \frac{1}{2} \rho A_f C_d \times v^2 \right) - P_p \quad (2.8)$$

Equation (2.8) can be written in the form (2.9)

$$\frac{dv}{dt} = \frac{1}{C_1(\gamma)} \left( C_2(\gamma) T_e - C_3 v - C_4(\alpha) - P_p \right) \quad (2.9)$$

With:  $C_1(\gamma) = \frac{1}{M_1}$ ;  $C_2(i_t) = \frac{\eta \times i_t}{r_{bx}}$ ;  $C_3 = \frac{1}{2} \rho A_f C_d$ ;  $C_4(\alpha) = M_1 g (\cos(\alpha) \times (r_o) + \sin(\alpha))$

At a given moment, the vehicle's fuel consumption FC<sup>(dyn\_point)</sup>, related to load, engine torque, and vehicle speed, is calculated using the equation:

$$FC^{(dyn\_point)} = C_5 T_e(t) v(t) - C_6 v(t)^2 + C_7 v(t) + C_8 \quad (2.10)$$

With:  $C_5 = \frac{i_t}{\eta_e \times H_L \times r_{bx}}$ ;  $C_6 = \frac{P_{loss} \times V_{dc}}{\eta_e \times H_L \times 4\pi} \left( \frac{i_t}{r_{bx}} \right)^2$ ;  $C_7 = \frac{P_{loss} \times V_{dc}}{\eta_e \times H_L \times 4\pi} \left( \frac{i_t}{r_{bx}} \right)$ ;  $C_8 = C_{kt}(S)$

In real time from point p=1 to p = p-1, the total fuel consumption FC<sup>(dyn\_total)</sup> of the vehicle is the sum of the vehicle's FC<sup>(dyn\_points)</sup>, an equation relating the engine's output torque and the vehicle's average speed.

$$FC^{(dyn\_total)} = \sum_{i=0}^{p-1} C_5(g) T_i v_i + C_6(g) v_i^2 + C_7 f(g) v_i + C_8 \quad (2.11)$$

With  $T_i = \frac{1}{C_2(g)} \left( C_1(g) \frac{v_{i+1} - v_i}{\tau} + C_3 f(g) v_i + C_4 f(g, \delta) \right)$

The application of the dyn(FE) dynamic model is used for a comprehensive survey of the vehicle convoy to address two main objectives:

Monitor the emissions levels of the vehicle fleet over extended periods and with high mileage.

Evaluate the fuel economy of vehicle fleets in use and provide feedback to manufacturers so they can modify vehicle technical features or add design elements to achieve reasonable fuel consumption figures.

### 2.3.3. Static Model stat(FC)

The static model calculates fuel consumption based on the vehicle's speed, using a model that analyzes the traction forces overcoming resistance forces to move the vehicle on the road.

The fuel consumption of a car (FC<sup>(stat)</sup>) is determined by the general equation:

$$FC^{(stat)} = \frac{\int g_e P dt}{\int v dt} = \frac{\int g_e \left( \frac{P_{k.v}}{\eta} \right) dt}{\int v dt} \quad (2.13)$$

Expanding the equation based on thermal energy and engine power, we obtain the fuel consumption equation F<sup>(stat)</sup>.

$$FC^{(stat)} = \frac{1}{Q_{nhiet}} \times \frac{P.t}{\eta_{dong co}} \quad (2.14)$$

Resistance to motion affects the vehicle's power output. Vehicle power output (VSP) is the engine power per unit mass of the vehicle:

$$VSP = (P_f + P_w + P_i + P_p) \frac{v}{M} \quad (2.16)$$

The engine's power and the car's own power are related through influencing parameters including vehicle weight, vehicle speed, powertrain efficiency, and the state of resistance forces.

**Advantage:**

- Simple, easy to understand, and easy to implement under experimental conditions.
- Easy to collect input data: speed, mass, drag force, etc.
- Suitable for evaluating the impact of engineering improvements (weight reduction, aerodynamic optimization, etc.)
- Highly suitable for designing and testing real-world fuel consumption measurement devices.

**Disadvantages:**

- Limited to simulating rapidly varying operating situations (braking, rapid acceleration)
- Not good at real-time assessment or simulating complex convoys.
- Accuracy is not high if environmental factors and operating conditions change significantly.
- It does not fully reflect the lag or nonlinear characteristics of the motor.

## 2.4. DEVELOPING A METHOD FOR SOLVING MODELS TO DETERMINE FC AND FE

### 2.4.1. Determining fuel consumption using the carbon balance method

Assuming that the engine produces the same amount of carbon as the fuel consumed, the amount of fuel used can be determined by the amount of carbon captured in the engine's exhaust gases.

### 2.4.2. Calculating FE fuel savings using the approximation method

The FE fuel efficiency level is calculated by the equation:  $FE_{RL} = \frac{N}{\sum_i \frac{N_i}{T_i}}$  (2.17)

$FE_{RL}$  is the required fuel economy level,  $N$  is the total designed passenger capacity of the vehicle;  $N_i$  is the actual number of passengers in the vehicle;  $T_i$  is the target fuel economy level based on the actual number of passengers in the vehicle.

There are many software programs that use approximation methods, including CAFE software, which has been developed into a standard.

### 2.4.3. Online calculation method

When need to calculate fuel consumption with a specific goal, for example, comparing it to the vehicle's metering device, there are several online calculation tools available on websites, and the results can be used for reference, such as "Calculate Consumption".

### 2.4.4. Algebraic Calculation Methods

When direct calculation is necessary, algebraic calculations will be used; fuel consumption will be calculated in the general case:  $q_d = \frac{0,36 \times g_e (P_f \pm P_i + P_w \pm P_j)}{\rho_n \times \eta_t}; \frac{l}{100km}$ .

$$q_d = \frac{g_e \times N_e}{\rho_n}; \frac{l}{h}$$

$$q_d = \frac{0,36 \times g_e}{\rho_n \times \eta_t} (f \cdot G \cdot \cos \alpha \pm G \cdot \sin \alpha + W \cdot v^2 \pm \frac{G}{g} \cdot \delta_i \cdot j) \quad (2.19)$$

### 2.4.5. Numerical Simulation Methods

There are several commonly used numerical simulation software programs for simulating car fuel consumption, such as:

- AVL Cruise software is specifically designed for simulating automotive fuel consumption and is commonly used in laboratories.
- GT-SUITE software simulates the vehicle's dynamic system.

- The programming language is Python, using two libraries: NumPy for arithmetic calculations and Matplotlib for plotting graphs.

- MATLAB/Simulink software is used in many fields, including education, research and development, and practical applications. Building algorithms on the MATLAB/Simulink platform offers many advantages.

## 2.5. SELECTING A SIMULATION MODEL

The static model  $stat(FC)$  is built on fundamental mechanical equations, describing the relationship between velocity, drag, and powertrain efficiency. The model has the advantages of being simple, easy to build and implement, with input parameters such as vehicle mass, velocity, and drag coefficient easily measured directly without the need for complex simulation software. The model is highly flexible, applicable to many types of vehicles and operating conditions, supporting the evaluation of the effectiveness of technical solutions such as weight reduction, aerodynamic optimization, and improved engine and transmission efficiency. Furthermore, the model is intuitive, highly explanatory, low-cost, and suitable for implementation in research and training institutions. Combining it with the project "Design and fabrication of a fuel consumption measurement device for automobiles" has contributed to increasing the reliability and applicability of the model in practice.

## 2.6 . DEVELOPING THE STAT(FC) ALGORITHM AND SIMULINK SIMULATION METHOD

### 2.6.1. Algorithm flowchart

The  $stat(FC)$  algorithm flowchart, based on a static model and programmed in Matlab/Simulink, for determining fuel consumption in a car is shown in the figure.

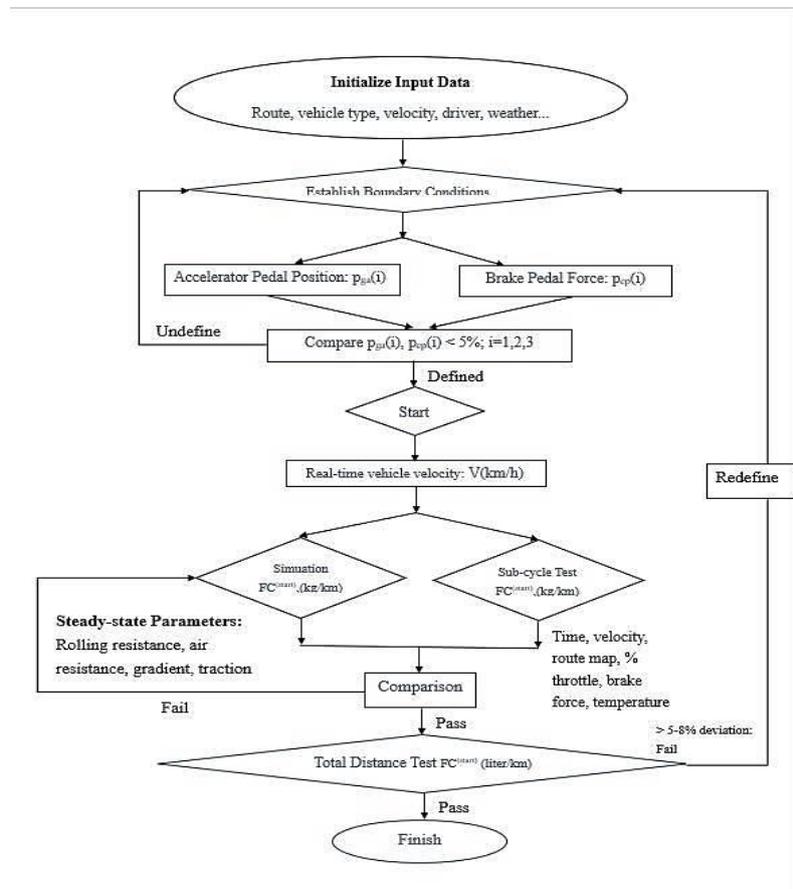


Figure 5: Schematic diagram of the  $stat(FC)$  algorithm based on the static model.

Content and execution sequence of the algorithm:

- Step 1: Create initial data.
- Step 2: Set up and prepare the data.
- Step 3: Perform the simulation and obtain the results.

### 2.6.2 . Simulation to determine parameters

The state and control variables of the algorithm are represented in the Matlab/Simulink environment, Figure 2.7 .

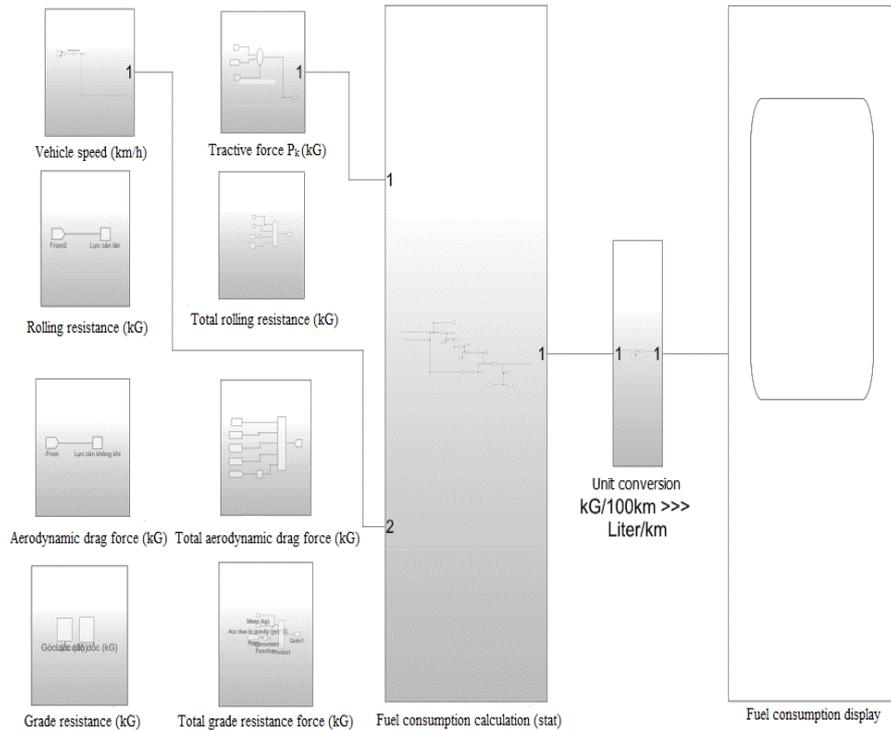


Figure 2.7 Real-space parameter variables R represented in Matlab Simulink

## CONCLUSION OF CHAPTER 2

Chapter 2 established the theoretical basis and dynamic models of automobiles for studying fuel consumption. Based on the analysis of forces acting on the automobile during operation, the chapter clarified the role of mass in relation to resistance forces and vehicle power.

From the dynamic model, mathematical relationships between mass, power, and fuel consumption have been established, accurately describing the core physical characteristics of the motion process. These results provide a direct scientific basis for developing the algorithm for calculating fuel consumption and the simulation model in Matlab/Simulink in the following chapters.

The distinguishing feature of Chapter 2 is that theoretical relationships are organized in a way that directly serves algorithm design and simulation, providing a foundation for experimental research evaluating the impact of vehicle weight on fuel consumption.

## CHAPTER 3: ANALYZING THE INFLUENCE OF WEIGHT ON FUEL CONSUMPTION MATERIALS IN THE CAR

### 3.1 . KEY ASSUMPTIONS

- The survey vehicle is a 5-seater passenger car;
- The engine on the surveyed vehicle is a gasoline engine (forced ignition - SI);
- Fuel type: gasoline;
- Fuel energy is used to completely overcome resistance.

### 3.2. DETERMINING DATA IN N-DIMENSIONAL SPACE

#### 3.2.1. Real-time data collection

Use real-world measurement programming to calibrate the initial data acquisition process in the algorithm and record the data in an Excel spreadsheet (xlsx).

24/01/2026 20:43:01 Monitoring and Report		Data table				
COM Select communication port:		Time	Velocity (km/h)	Force (kg)	Mass (kg)	Throttle valve (%)
Connection		2024-04-07 05:37:25.016	5.9	0	11.668	16
Disconnection		2024-04-07 05:37:25.887	5.9	0	11.668	16
Velocity	Mass	2024-04-07 05:37:25.940	8.2	0	11.505	12
000.0 km/h	00.000 kg	2024-04-07 05:37:26.803	8.2	0	11.505	12
Force	00.000 kg	2024-04-07 05:37:26.866	10	0	11.319	16
Throttle valve	000 %	2024-04-07 05:37:27.720	10	0	11.319	16

Figure 1: Table format of real-time data file results

### 3.2.2. Vehicle speed in real time

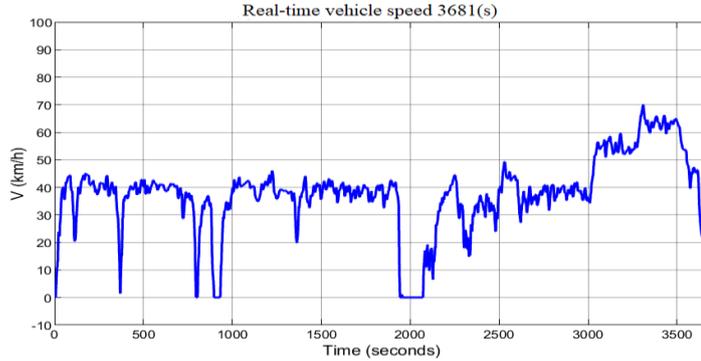


Figure 3.2: Graph of vehicle speed over time.

### 3.2.3. Controlling data stability conditions

- The number of times the brakes are applied and the percentage of pressure applied to the accelerator pedal will be selected as metrics for evaluating a driver's skill .

## 3.3. DETERMINING DATA IN M- DIMENSIONAL SPACE

### 3.3.1. Rolling resistance data on the road

Rolling resistance is determined by the equation:  $P_r = C_{rr} \cdot m_i \cdot g$  (3.3)

Use the blocks in Simulink to determine the rolling resistance, Figure 3.3.

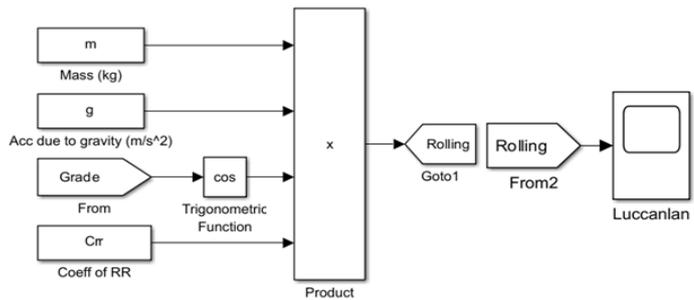


Figure 3.3: Simulink block diagram for determining rolling resistance.

### 3.3.2. Slope resistance data

The slope resistance is determined by the equation:  $P_i = m_i \times g \times \sin(\alpha)$  (3.4)

Use the blocks in Simulink to determine the slope resistance, Figure 3.4.

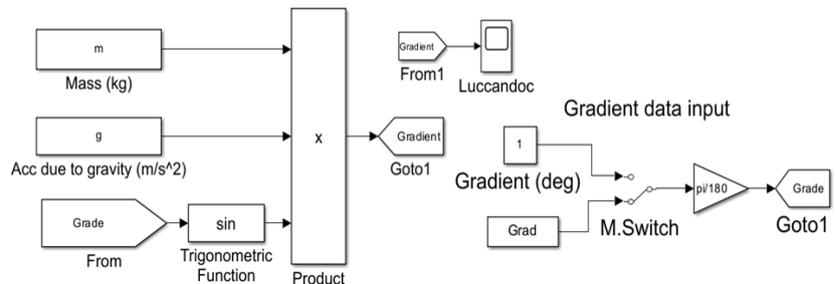


Figure 3.4: Simulink block diagram for determining slope resistance.

### 3.3.3. Aerodynamic drag data

Aerodynamic drag is determined by the equation:

$$P_w = \frac{1}{2} \rho A_f C_d \times v^2 \tag{3.6}$$

CFD analysis in Ansys Workbench software obtained the aerodynamic drag coefficient parameter for the 2009 Toyota Vios vehicle under investigation.

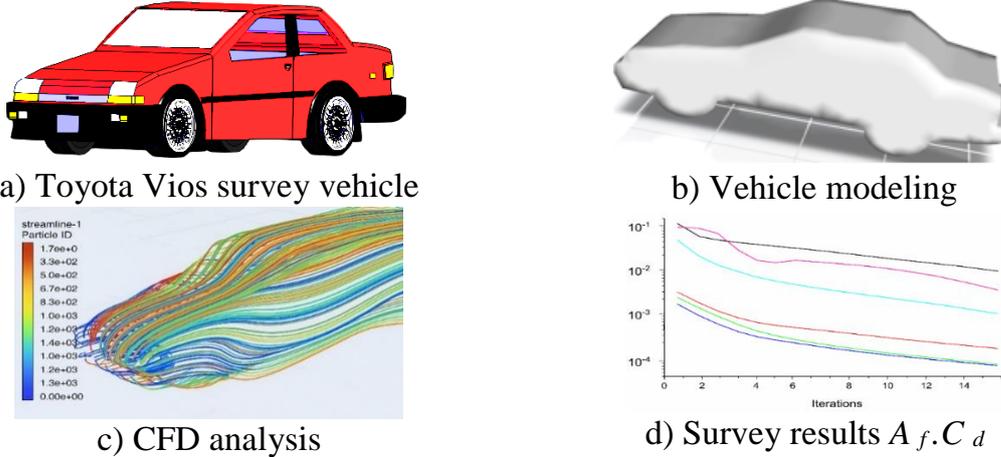


Figure 3.5: CFD analysis on a 2009 Toyota Vios to determine the aerodynamic drag coefficient.

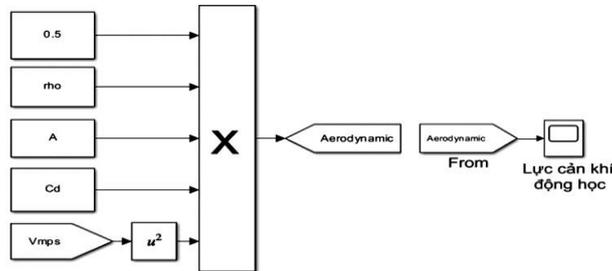


Figure 3.6: Simulink block diagram for determining aerodynamic drag.

**3.3.4. Total traction data**

From the traction force balance equation on a car, assuming the vehicle is running steadily without acceleration, the total traction force is equal to the sum of the resistance forces: rolling resistance, slope resistance, and air resistance. Using the blocks in Simulink to determine the traction force  $P_k$ , Figure 3.7.

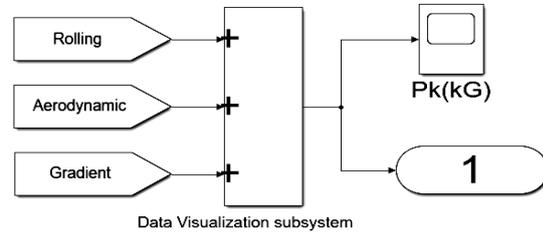


Figure 3.7: Simulink block diagram for determining total traction force

**3.3.5. Useful fuel consumption rate data**

The specific fuel consumption rate  $g_e$  is calculated at 85% of the engine's maximum power ( $N_e = 85\% N_{e_{max}}$ ) by the equation:

$$g_e = \frac{m_f}{P_e} \left( \frac{kg}{kWh} \right) \quad (3.7)$$

Using Matlab/Simulink on the engine parameters of a 2009 Toyota Vios to run the malab.m program, we obtained the useful specific fuel consumption rate graph  $g_e$  (kg/kWh) as shown in Figure 3.8.

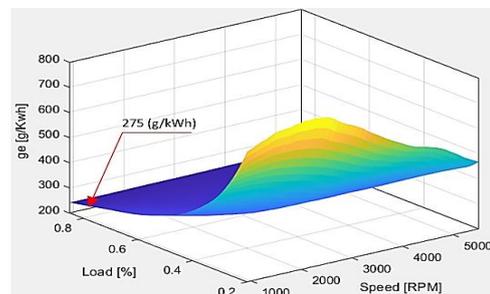


Figure 3.8: Matlab simulation results of useful specific fuel consumption rate  $g_e$

**3.3.6. Powertrain System Performance Data**

In vehicles with mechanical powertrains, the average efficiency is typically 0,7-0,8. In simulations, the average efficiency can be taken as 0,75.

### 3.4. MATLAB SIMULINK DIAGRAM SIMULATING FUEL CONSUMPTION CALCULATIONS

The fuel consumption during one driving cycle in the simulation, taken in real time, is 3681 (s). as shown in diagram 3.9.

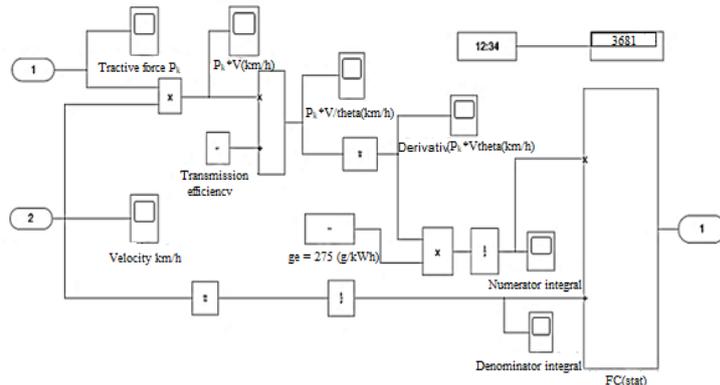


Figure 3.9: Simulink block diagram for calculating fuel consumption of a vehicle route.

### 3.5. ANALYSIS OF SIMULATION RESULTS

#### 3.5.1. Driving Cycle

During the driving process:

- The simulation time is exactly equal to the actual time the car travels, which is 3681 (s).
- A skilled driver ensures that deceleration and acceleration are performed at the correct times during the cycle.
- The vehicle speed in the simulation is taken from the vehicle speed in real time, so the simulation results are shown in Figure 3.12 .

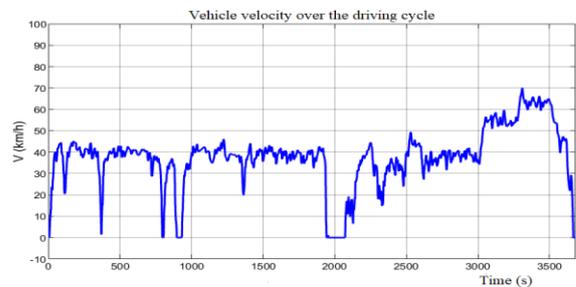


Figure 3.12: Driving cycle graph from 3590 seconds to 3641 seconds

#### 3.5.2. Engine power consumption

The vehicle's weight is determined by the following components: Unladen weight 940 kg; Fuel tank capacity 45 liters x 1/3 = 15 liters x 0,7 = 11 kg; 2 fire extinguishers = 18 kg; Driver = 75 kg; Technician = 74 kg; Vehicle accessories = 22 kg; Scale + weighing platform + fuel in the tank = 30 kg. Total weight of the fully loaded vehicle is 1170 kg.

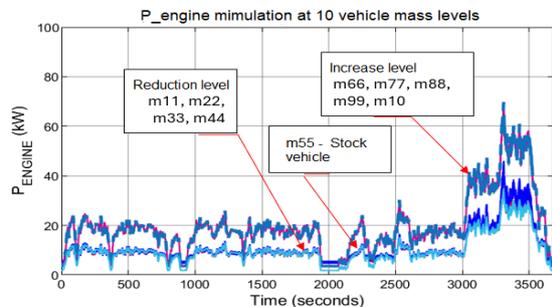


Figure 3.13: Graph of engine power consumption at different vehicle weights

#### 3.5.3. Rolling resistance

Surveys of rolling resistance during vehicle operation also yielded results showing changes in value over time, Figure 3.14.

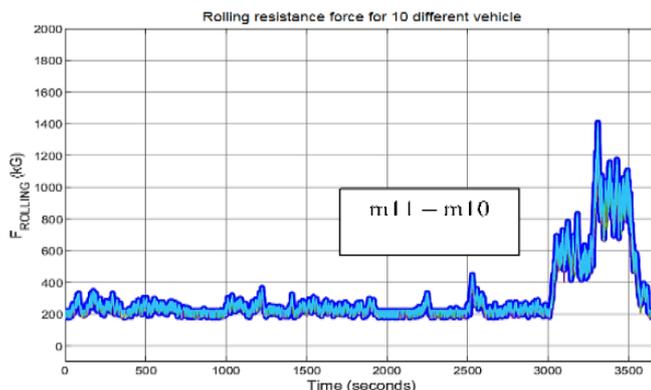


Figure 3.14: Rolling resistance force graph

#### 3.5.4. Aerodynamic drag

Since the vehicle's shape remains unchanged under all mass changes, there is no real-time amplitude change (Figure 3.15).

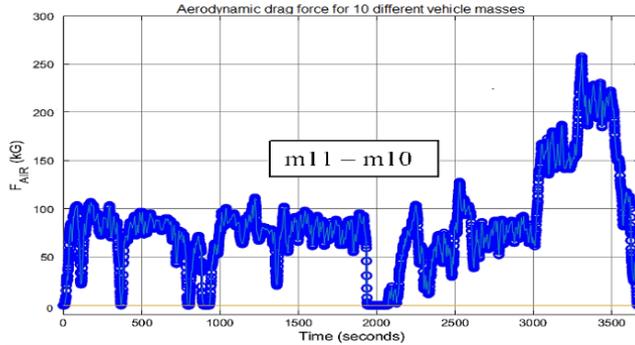


Figure 3.15: Aerodynamic drag force graph

**3.5.5. Slope resistance**

Since the experimental track has a small gradient and few slopes, slope resistance can be ignored and used as a hypothetical factor in the simulation.

**3.5.6. Total traction force**

The survey of total traction force clearly shows the dependence on various drag forces as well as different vehicle masses, Figure 3.16.

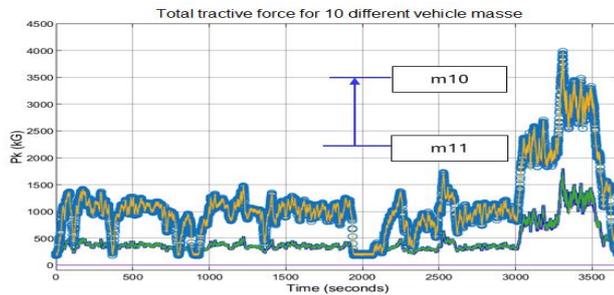


Figure 3.16: Graph of total traction force

**3.5.7. Fuel consumption**

Examining the changes in the total traction force values and corresponding fuel consumption will clearly show the dependence on different vehicle weights, Figure 3.17.

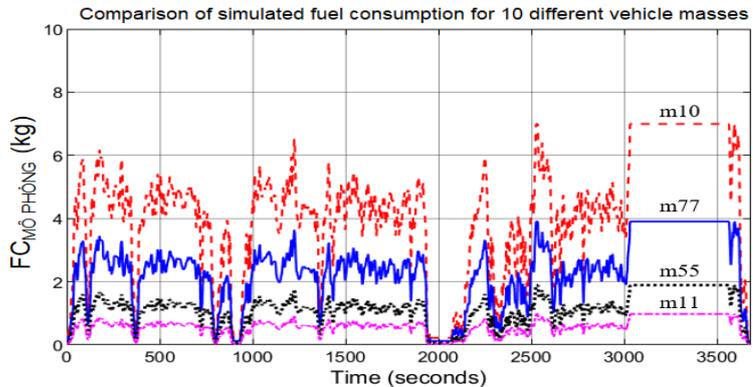


Figure 3.17: Fuel consumption graph

**3.5.8. Comments**

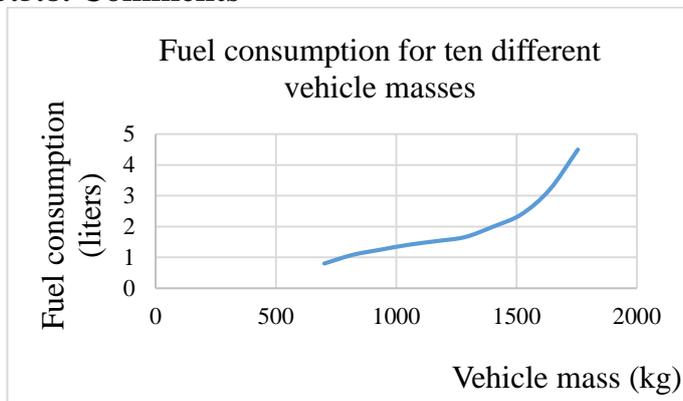


Figure 3.18: Fuel consumption variation as a function of ten different vehicle masses

Based on the graph in Figure 3.19, using the least squares quadratic polynomial regression method to determine the empirical function representing the relationship between vehicle weight and fuel consumption, we obtained the equation describing fuel consumption as a function of weight:  $FC = 3,8 \times 10^{-6}m^2 - 0,00644m + 3,7336$  (lít), with a coefficient of determination  $R^2 \approx 0,954$ .

### 3.6. PROPOSED SOLUTIONS TO REDUCE FUEL CONSUMPTION BY CHOOSING LIGHTWEIGHT MATERIALS FOR THE BODY.

#### 3.6.1. Material distribution diagram on the vehicle body frame

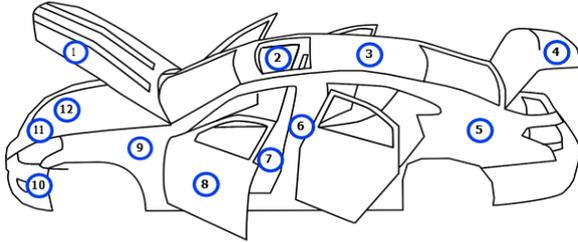


Figure 3.19: Material structure distribution diagram on the car body.

- 1) Hood: Aluminum;
- 2) Sunroof: Polycarbonate;
- 3) Roof: Low-carbon steel;
- 4) Trunk lid: Low-carbon steel;
- 5) Rear side panels: Low-carbon steel;

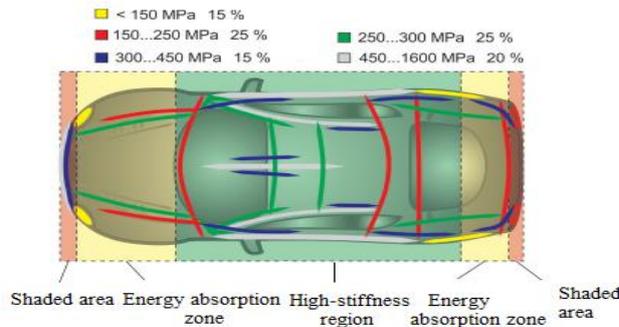


Figure 3.20: Material requirements distribution diagram according to hardness.

- 6) Pillar: Hot-stamped steel 1000-1500 MPa;
- 7) Vehicle floor: Low carbon steel;
- 8) Outer doors: Hardened steel, Inner doors: Low carbon steel;
- 9) Fenders: Medium carbon steel or hardened steel;
- 10) Front bumper: Plastic;
- 11) Front grille: Steel 980-1200 MPa or aluminum;
- 12) Engine compartment: High-strength alloy sheet steel;
- 13) Engine compartment walls: High-strength alloy sheet steel/high-strength steel.

- Analyzing the material distribution according to stiffness structure, steel is often used in areas requiring high stiffness, and newer vehicles use ultra-high-strength steel. The main materials in car body shells are steel, aluminum, magnesium, copper, titanium, plastic, and carbon fiber (Figure 3.20).

#### 3.6.2. The possibility of using lightweight materials in the vehicle body frame.

There are many types of lightweight materials used in vehicle frames and bodies, some of the main ones include:

- Composite materials are lightweight, have good rigidity, and are less susceptible to corrosion.
- Polycarbonate (PC) plastic is used to manufacture bumpers, ...
- Polyamide is used to manufacture parts located under the hood of the engine compartment.
- Acrylonitrile Butadiene Styrene (ABS) plastic is used to manufacture parts for the car body and dashboard.
- Thermoplastic alloy PC + acrylonitrile / butadiene / styrene + polyamide (ABS + PA) is used to manufacture interior and exterior decorative parts.
- Polyvinyl chloride (PVC) is used to manufacture protective underlayment for car floors, as an interior lining, and as a covering for electrical cables in vehicles.
- Polypropylene (PP) plastic is used to manufacture car bumpers, battery casings, fuel tanks, and floor mats.
- Polyurethane (PUR) plastic is used to manufacture flexible foam seat cushions, foam insulation panels, elastic tires, automotive suspension bushings, etc.
- Polystyrene (PS) glass fiber polymer is used to manufacture device housings and buttons.
- POM polymer plastic is used to manufacture interior and exterior components, ...

- PMMA (Acrylic) thermoplastic is used in the manufacture of windows and screens.
- Polybutylene terephthalate is used to manufacture fog light housings and bezels, ...
- Polyethylene terephthalate is used to manufacture wiper blades and gear shift housings, etc.

### 3.6.3. Mass distribution ratio on the vehicle

The vehicle body frame offers the easiest material changes for designers, manufacturers, and operators.

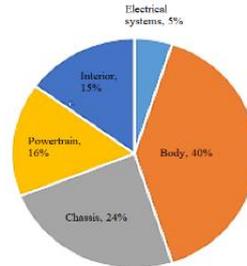


Figure 3.22: Mass distribution diagram on a passenger car.

### 3.6.4. Criteria for selecting lightweight materials and basis for mass change

Using composite materials with a density of 1600 kg/m<sup>3</sup> on the vehicle body frame shows a mass difference ratio compared to sheet steel of 7890/1600 = 4,93.

According to the diagram showing the weight distribution of the chassis, which is approximately 40% of the total vehicle weight, the simulated model will have the weight as shown in Table 3.9.

Table 3.9: Analysis of the simulated vehicle's mass

	Total vehicle weight (kg)	Frame weight ~40% (kg)	Weight of other components (kg)
Original steel body	1170	470	700
CFRP-Epoxy Composite Body	795	95	700

### 3.6.5. Resistance to motion in the use of composite materials on the shell frame

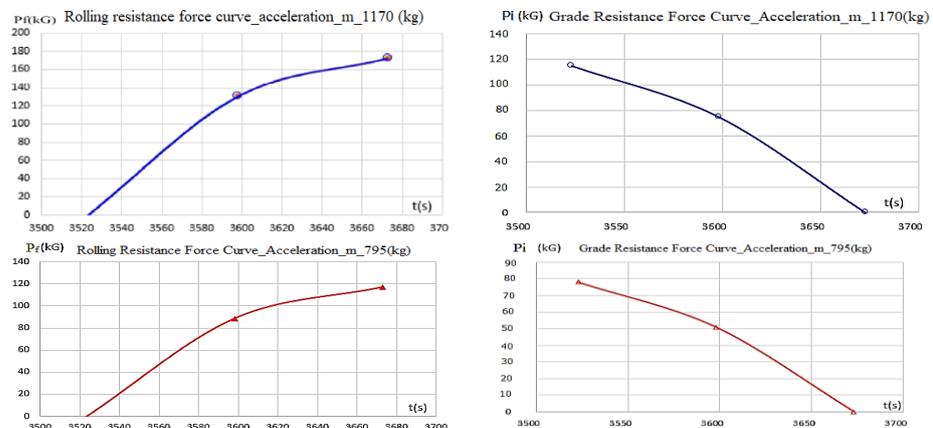
#### 3.6.5.1. Throughout the entire cycle time

CFRP-Epoxy composite chassis is reduced by 55,25 kg, a 32% reduction compared to the original vehicle with a steel chassis. Downhill resistance on vehicles with lightweight CFRP-Epoxy composite chassis is reduced by 39,1 kg, also a 32% reduction compared to the original vehicle with a steel chassis. Aerodynamic drag on both vehicles with lightweight CFRP-Epoxy composite chassis and the original car has the same steel frame and body because the car's aerodynamic structure remains unchanged.

#### 3.6.5.2. During acceleration

The vehicle has a steel frame and body .

The vehicle has a CFRP-Epoxy composite frame and body.



32,05% reduction compared to vehicles with steel frames.

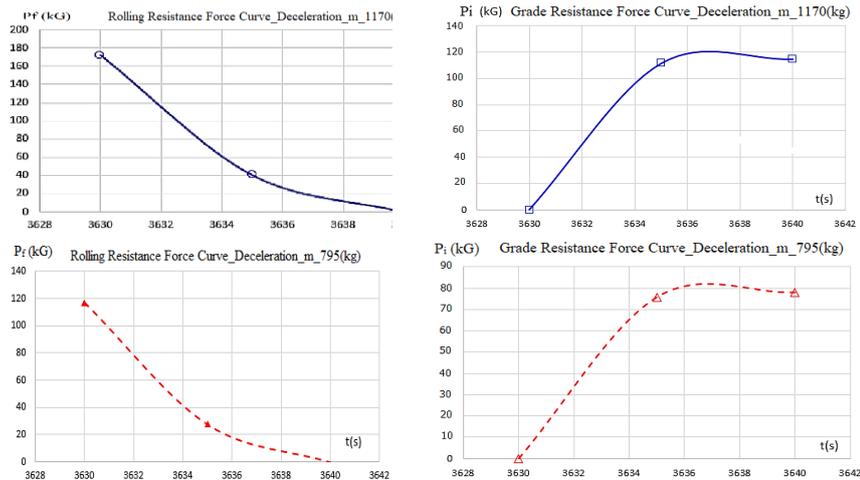
32,1% reduction compared to vehicles with steel frames.

Figure 3.24: Graph of rolling and slope resistance forces during acceleration.

**3.6.5.3. During deceleration**

The vehicle has a steel frame and body.

The vehicle has a CFRP-Epoxy composite frame and body.



32,05% reduction compared to vehicles with steel frames.

32,05% reduction compared to vehicles with steel frames.

Figure 3.25: Graph of rolling and slope resistance forces during deceleration.

**3.7. EVALUATING THE ECONOMIC ASPECTS OF VEHICLES USING LIGHTWEIGHT MATERIALS**

The fuel economy of a vehicle, based on YFS (Liters) fuel consumption, is determined by the following equation:

$$YFS = \frac{L \times (FC1 - FC2)}{100} \tag{3.8}$$

Let's assume the vehicle travels 100,000 km per year:

Table 3.10: Fuel economy assessment of the vehicle

a) In the direction of decreasing mass.					
Sign	chichi	m22	m33	m44	m55
Weight (kg)	702	819	936	1053	1170
FC (liters/100km)	2,31	3,11	3,60	4,06	4,41
YFS (L)	2105	1298	808	347	0
SM (Vietnamese Dong)	42.100.000	25.960.000	16.160.000	6.940.000	-
b) In the direction of increasing mass.					
Sign	m66	m77	m88	m99	m10
Weight (kg)	1287	1404	1521	1638	1755
FC (liters/100km)	4,78	5,76	6,92	9,22	12,97
YFS (L)	-374	-1354	-2506	-4812	-8558
SM (Vietnamese Dong)	-7.480.000	-27.080.000	-50.120.000	-96.240.000	-171.160.000

**CONCLUSION OF CHAPTER 3**

Chapter 3 implemented the automotive dynamics model developed in Chapter 2 into a simulation environment to analyze the effect of overall weight on fuel consumption. Based

on the selected operating conditions and input parameters, the chapter performed calculations and simulations to determine the variation of fuel consumption with vehicle weight.

The results of the simulation data processing allowed for the construction of an empirical equation representing the relationship between fuel consumption FC and the overall weight of the vehicle, in the form:  $FC = 3,8 \times 10^{-6}m^2 - 0,00644m + 3,734$  (liters), where m is the overall weight of the vehicle.

The above equation quantitatively reflects the variation in fuel consumption with vehicle weight within the study area, showing that as vehicle weight increases, fuel consumption increases in a non-linear fashion. This is an important result of Chapter 3, allowing for a direct assessment of the impact of weight on fuel consumption through a specific mathematical expression.

Based on the established relationship between vehicle weight and fuel consumption, Chapter 3 proposes reducing the vehicle's own weight using lightweight materials to contribute to lower fuel consumption. The proposal to use lightweight materials is considered a feasible technical solution, stemming directly from simulation results and the developed FC equation, providing a scientific basis for further research and application in the design and improvement of automotive structures towards fuel efficiency.

## CHAPTER 4: EXPERIMENTAL RESEARCH

### 4.1. EXPERIMENTAL METHODS FOR DETERMINING FUEL CONSUMPTION IN AUTOMOBILES.

#### 4.1.1. Measurement experiment on a test bench

- a) Engine test bench.
- b) Chassis test bench.

#### 4.1.2. Direct measurement on a moving vehicle on the road.

Using a disassembled fuel tank, weighed after each test run to determine fuel consumption (Figure 4.1).

The advantages of this method are that it complies with environmental regulations for vehicles, and the cost of the measurement process is more reasonable.



Figure 4.1 How to measure fuel consumption in a road-driving vehicle according to SAE J1321 standard.

### 4.2. OBJECTIVES, METHODS, AND SUBJECTS OF THE EXPERIMENT

#### 4.2.1. Experiment Objectives

The experiment aimed to achieve the following main objectives:

- Develop an empirical dataset for modeling and analysis.
- Measuring and evaluating the actual fuel consumption of a 2009 Toyota Vios.
- Compare experimental results with simulation models.

#### 4.2.2. Experimental methods

The experiment measured the fuel consumption of a car using a combination of direct measurement, surveying, and calculation methods to determine five parameters.

#### 4.2.3. Experimental subjects

Experiment conducted on a 2009 Toyota Vios.

### 4.3. EXPERIMENTAL EQUIPMENT

#### 4.3.1. Diagram of the connection of experimental equipment

The fuel consumption testing equipment features internationally standardized measurement modules integrated with additional custom-made modules and specialized software called Kisster, which has been quality-tested and evaluated by the Vietnam General Department of Standards, Metrology and Quality Control.

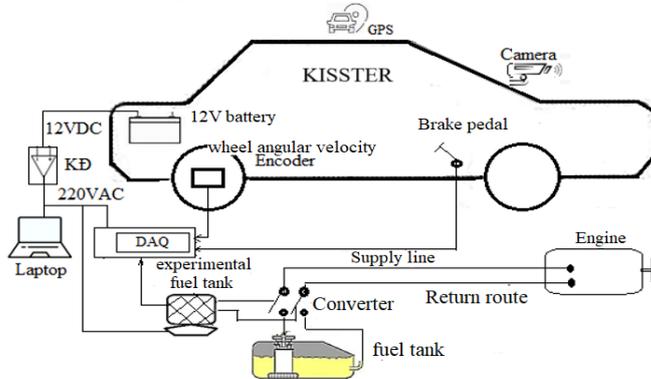


Figure 4.3: Diagram of the experimental equipment connection on the test vehicle.

#### 4.3.2. Laboratory equipment and instruments

- Experiment monitoring team (engine ECU, GPS unit).
- Measuring equipment (electronic scale, frame, connecting cables, data reading software, sensors).

### 4.4. EXPERIMENTAL PROCEDURE

#### 4.4.1. Developing a test vehicle route

The vehicle's cycle can be composed of several subcycles depending on traffic conditions and operating circumstances, and is implemented in three phases: acceleration phase I, steady-state driving phase, and deceleration phase, to match the simulation as shown in Figure 4.12, where  $qc\_1, qc\_2, \dots, qc\_n$  are subcycles, with  $n$  being the number of subcycles.

Estimated rest time along the way is  $6.8 - 4.39 = 2.41$  hours

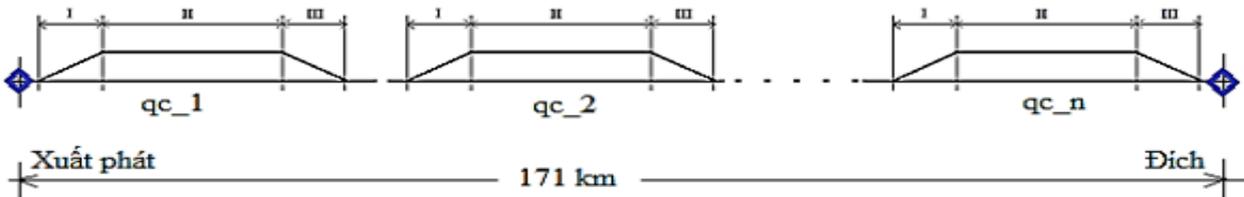


Figure 4.12: Vehicle cycle in the experiment

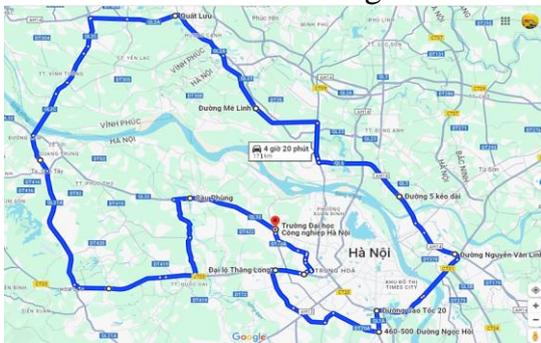


Figure 4.13: First test vehicle route

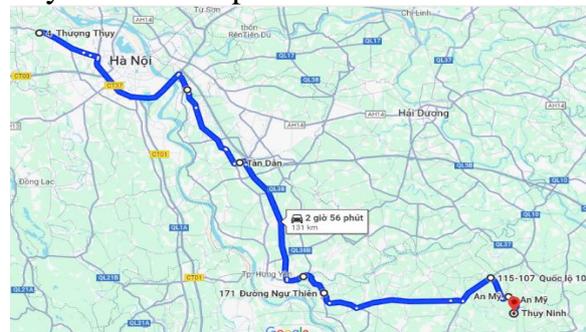


Figure 4.14: Second test vehicle route

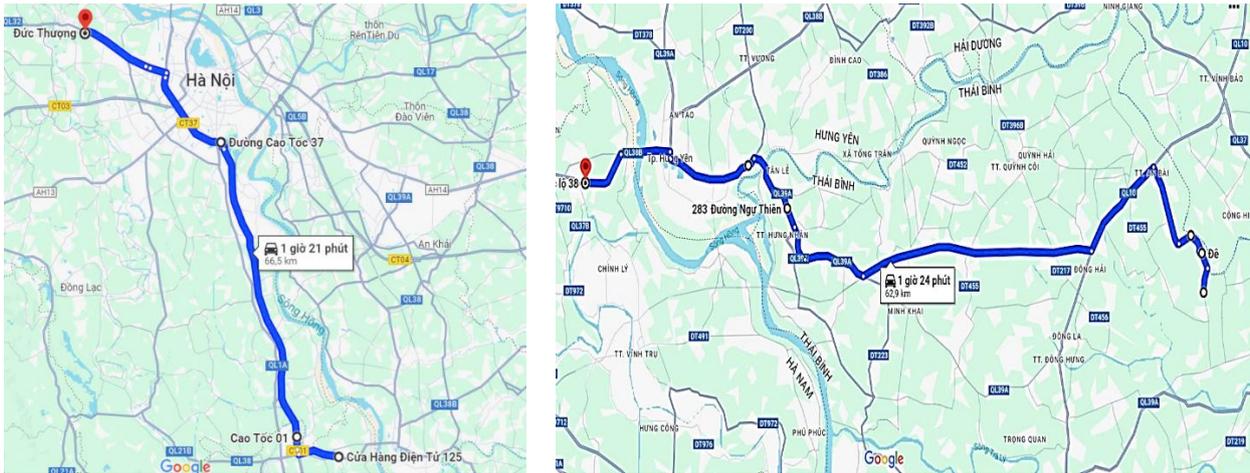


Figure 4.15: Third test vehicle route

#### 4.4.2. Establishing Data Stability Conditions

Using identical brake pedal force and throttle opening data from driving the same vehicle on three different test routes.

##### a) Brake pedal force

Figure 4.16 shows the magnitude of the force on the brake pedal, with the peaks representing the selected number of brake pedal strokes.

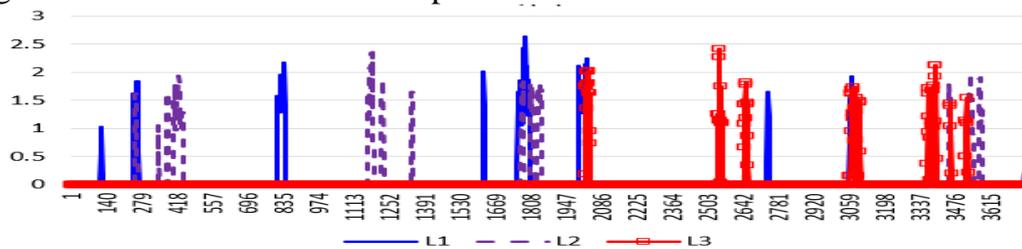


Figure 4.16: Graph of brake pedal force in 3 trajectories

##### b) Percentage of throttle opening

Figure 4.17 shows the percentage of throttle opening that can approximate the percentage of the driver's pedal use. In the three experimental routes, the percentage values of the driver's pedal use were L1 = 14,76628 (%) , L2 = 14,45064 (%) , and L3 = 14,57764 (%) .

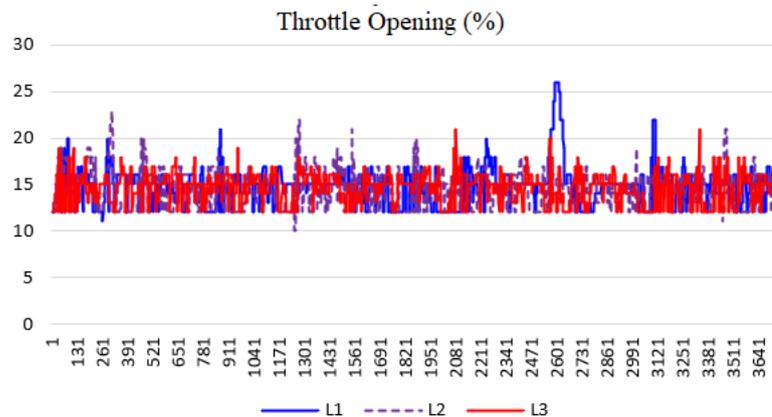


Figure 4.17: Graph of percentage throttle opening in 3 routes

### 4.5. COLLECTION AND PROCESSING OF EXPERIMENTAL RESULTS

#### 4.5.1. Preparing data files

Input parameters, output parameters, vehicle parameters, equipment parameters, etc., are updated in the software to create data files along with the test vehicle's speed.

The input parameters are set according to the structure of the data logging software .

### 4.5.2. Implementation Process

Each resulting file shows the starting and ending points, regardless of whether it's an urban road, highway, or rural road.

The initial fuel volume is set as the initial reference (kg), and the throttle level sensor and brake pedal count sensor are displayed on the corresponding software of the measuring device.

Each cycle will have its own results file; the collection of results from all cycles constitutes the vehicle's route.

### 4.5.3. Experimental Results

#### 4.5.3.1. Real-time data table

- Kisster software records data in Excel spreadsheet format (.xlsx).

1	Thời gian	Vận tốc (km/h)	Áp lực (kg)	Khối lượng (kg)	Bướm ga (%)
30	2024-04-07 05:37:25.016	5.9	0	11.668	16
31	2024-04-07 05:37:25.887	5.9	0	11.668	16
32	2024-04-07 05:37:25.940	8.2	0	11.505	12
33	2024-04-07 05:37:26.803	8.2	0	11.505	12
34	2024-04-07 05:37:26.866	10	0	11.319	16
35	2024-04-07 05:37:27.720	10	0	11.319	16
36	2024-04-07 05:37:27.785	10	0	11.446	18
37	2024-04-07 05:37:28.644	10	0	11.446	18
38	2024-04-07 05:37:28.704	10.3	0	11.416	18
39	2024-04-07 05:37:29.596	12.7	0	11.277	19
40	2024-04-07 05:37:29.634	12.7	0	11.277	19
41	2024-04-07 05:37:30.493	12.7	0	11.277	19

Figure 4.18: Table format of real-time data file results

#### 4.5.3.2. Vehicle speed in the experiment over time.

The vehicle's speed in the experiment is shown in real time (Figure 4.19).

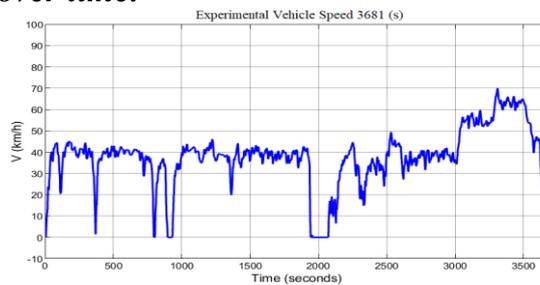


Figure 0the 2

#### 4.5.3.3. Real-time fuel consumption measurement values

- The fuel consumption measured on the test vehicle  $m_1 = 1170$  kg,  $FC^{(stat)}_{max} = 4,2$  (lit/100km), is shown in Figure 4.20.

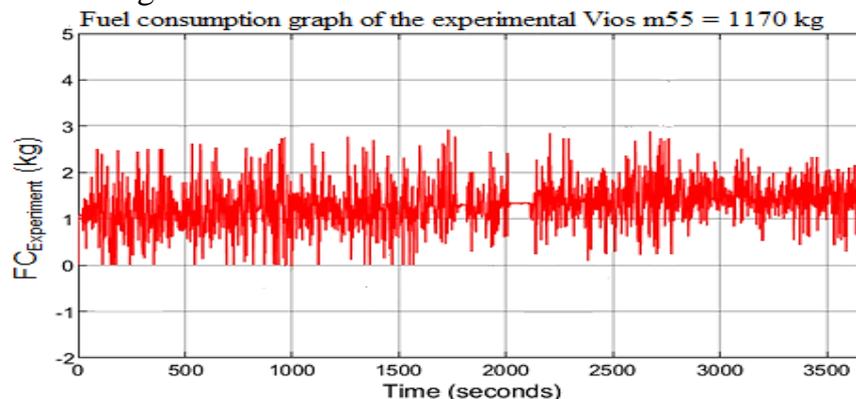


Figure 4.20: Fuel consumption measured on the test vehicle.

## 4.6. EVALUATION OF EXPERIMENTAL RESULTS

### 4.6.1. Constructing the regression equation

Actual regression equation

$$y = 5.26 + 67.2x_1 + 10090.3x_2 + 385.7x_3 \quad (4.2)$$

$x_1$  : Vehicle speed  $V$  (km/h) ;

$x_2$  : Rolling resistance, slope resistance related to vehicle mass  $m_i$  (kg);

$x_3$ : Aerodynamic drag related to vehicle shape and size  $P_w$  (kG).

### 4.6.2. Assessing the reliability of regression coefficients

Use the coefficient of determination  $R^2$  to assess the model's fit; the closer  $R^2$  is to 1, the better the model fits, and the more reliable the regression coefficients are.

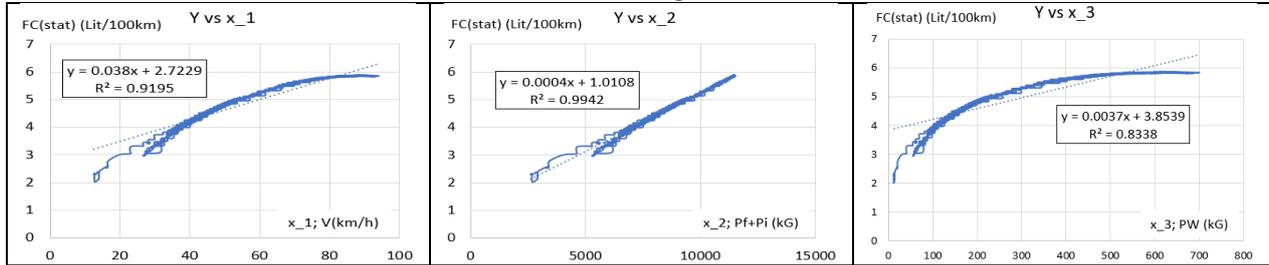


Figure 4.21: Graph showing the relationship determining  $R^2$  of FC(stat) with  $x_1$ ,  $x_2$ ,  $x_3$

### 4.6.3. Analyzing the influence of factors on FC (stat)

NCS used Minitab software to analyze the influence of various factors on the results of determining fuel consumption (FC) in automobiles.

- The effect of velocity  $x_1$  on FC (stat) Y

The correlation function between velocity factor  $x_1$  and factor Y is first-order, and the statistical significance is indicated by a p-value of  $0,993 > 0,05$ , suggesting that  $x_1$  will have a very large influence on Y.

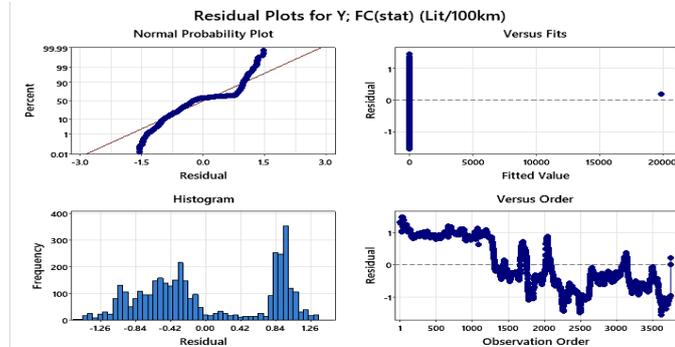


Figure 4.23: Effect of velocity  $x_1$  on Y

- The effect of mass  $x_2$  on FC (stat) Y

The correlation function of mass factor (in the components of rolling and slope resistance)  $x_2$  to factor Y is a first-order function, statistically significant with a p-value of  $0,996 > 0,05$ , so  $x_2$  will have a much larger influence on Y than  $x_1$ .

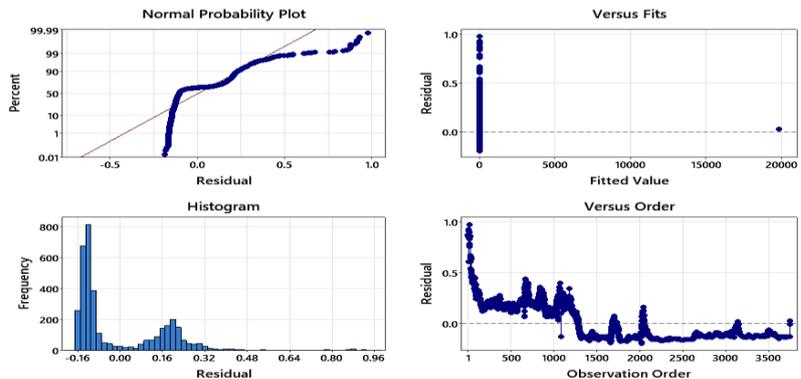


Figure 4.24: Effect of mass  $x_2$  on Y

- Effect of aerodynamics  $x_3$  on FC (stat)

The correlation function of the aerodynamic factor (vehicle design shape)  $x_3$  to factor Y is first-order, statistically significant with a p-value of  $0,988 > 0,05$ , so  $x_3$  will have an influence on Y, but it will be smaller than  $x_1$  and  $x_2$ .

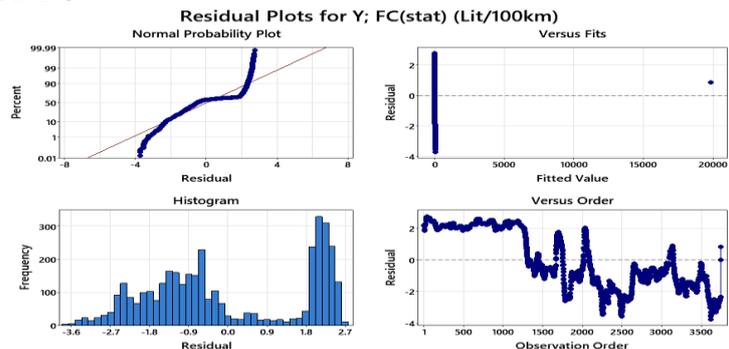


Figure 4.25: Effect of aerodynamic  $x_3$  on Y

- The main influencing factors are qualitatively identified on the Main Effects Plots (Figure 4.26).

Looking at the graph, we see that the slope of the mass curve is much steeper than the slope of the velocity curve. Therefore, we can conclude that both the vehicle's mass and speed affect fuel consumption FC(stat), but the vehicle's mass  $m_1$ (kg) is the main influencing factor, with an influence level of 5,6 times.

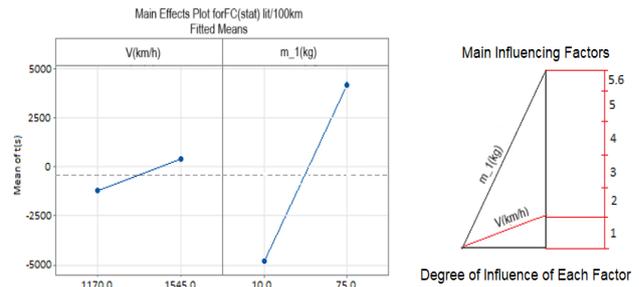


Figure 4.26: The degree of influence of vehicle mass and velocity parameters.

**4.6.4. Comparison of experimental and simulation results**

**4.6.4.1. Basis for comparison**

Graduate student selected the experimental route for April 7, 2024, as shown in Figure 4.13 above, with a total distance of 171 km, divided into 5 sub-cycles. The first cycle, covering a distance of 34,7 km, starts from the Hanoi University of Technology and ends at Dong Truc (Lang Hoa Lac Expressway).

Table 4.2: Summary of test vehicle routes on April 7, 2024

Fuel consumption test on cars, April 7, 2024										
	Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5	
Content	Data	Result	Data	Result	Data	Result	Data	Result	Data	Result
Departure time	4:12		5:37 AM		7:02 AM		8:27 AM		9:52 AM	
End time	5:12 AM	1 hour	6:37 AM	1h02'	8:02 AM	1 hour	9:27 AM	1 hour	10:55 AM	1h06'
First kilometers	0	34.7	34.7	34.7	69.4	34.7	104.1	34.7	138.8	31.7
Final kilometers	34.7		69.4		104.1		138.8		170.5	
Initial fuel quantity (g)	12,464		11,391		10,377		11,323		10,232	
Final fuel quantity (g)	11,407	1,057	10,382	1,009	9,352	1,025	10,241	1,082	9,067	1,165
Running route	University of Technology - Phung Bridge - Thây Pagoda - Dong Truc (Lang Hoa Lac Expressway)		Dong Truc (CT Lang Hoa Lac) - Son Tay - Vinh Thinh Bridge - Dong Van - Yen Lac		Dong Van (Yen Lac) - National Highway 2A - Me Linh Road - Vo Van Kiet Road		Vo Van Kiet Street - Dong Tru Bridge - Thanh Tri Bridge - Do Muoi Street (Hoang Mai District)		Do Muoi Street (Hoang Mai District) - Ngoc Hoi - Cau To Bridge - Van Khe - Le Trong Tan - Lang Hoa Lac - My Dinh - Trinh Van Bo - Hanoi University of Technology	
Road characteristics	City center, suburbs, highway		The suburbs have slopes.		Suburban		Suburbs, Urban areas		Densely populated urban areas	
Break time	End of first session: 25 minutes		Second attempt ends: 25 minutes		Third attempt: 25 minutes		End of round 4: 25 minutes			

Specifically, the experimental results from the first subcycle were used to comprehensively compare fuel consumption figures between the experiment and the simulation.

There are five basic mathematical methods for comparing experimental and simulation results data, including: (1) Descriptive statistical methods; (2) Measurement of errors using MAE (Mean Absolute Error) indices; (3) Statistical testing methods; (4) Correlation analysis methods using Pearson correlation; (5) Visual methods using one of the graphs.

The thesis selected the Line plot method from Matlab Simulink software (method 5) to obtain visual analysis results and combined them with the key evaluation indicators from the four methods above to compare and evaluate the experimental and simulation results (Figure 4.28).

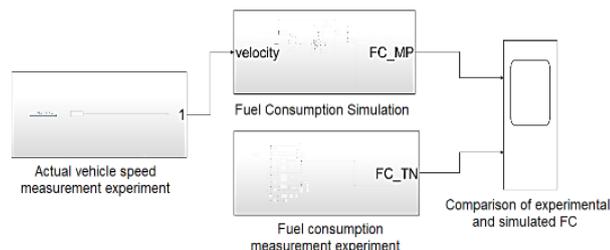


Figure 4.28: Simulink diagram comparing the overall results of experimental and simulation-based FC.

**4.6.4.2. Comparison Results**

a) Graph showing the comparison results.

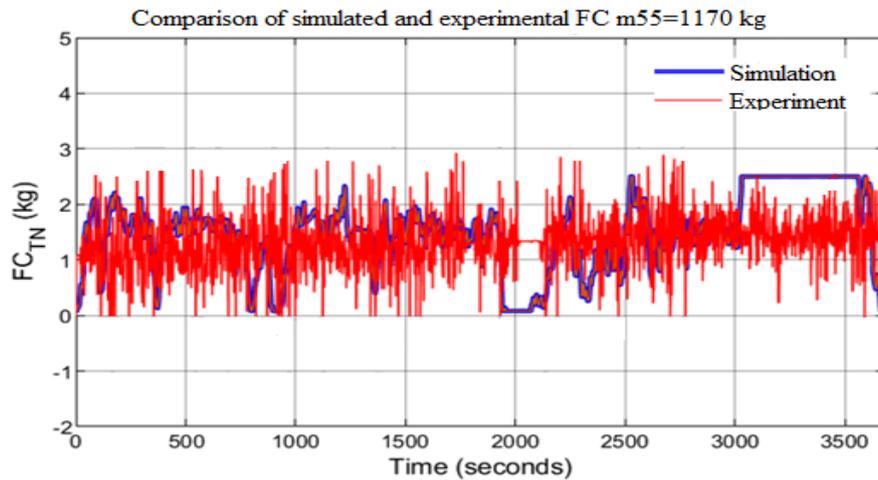


Figure 4.30 : Graph comparing experimental and simulation FC results.

b) Simulation results of FC\_MP fuel consumption.

The standard deviation in the ranges with a mean value of 0 – 2,48 kg and in the range of 0,80 – 4,95 kg with a mean value of 2,06 kg both have a standard deviation of 0,42 kg.

The data are stable with a low coefficient of variation  $CV = 20,03\%$ .

The distribution is slightly skewed to the right (skewness = 0,36), with no negative values.

The graph conforms to the pattern of high Kurtosis (4,04) with a sharp peak and few outliers at the tail.

**Comment:** The simulation data is of good quality and stable, and the predictions will match the actual physical measurement signals.

c) Results of the FC\_TN fuel consumption experiment

FC\_TN has a mean value of 0 – 2,62 kg with a standard deviation of 1,07 and in the range of 6,84 – 9,77 kg with a standard deviation of 1,69 kg. Thus, the total standard deviation is  $1,69 - 1,07 = 0,52$ , a difference of 0,1 compared to 0,42 of the simulation.

The data is unstable with a high coefficient of variation ( $CV = 66,03\%$ ) due to the presence of many variable parameters in the experiment, generating signal noise.

The distribution shows a large right-skew (skewness = -0,16), with many negative values (14,085/659,043 values), accounting for 5,68% of the total signal due to noise. However, this percentage is acceptable in mechanical measurements.

The graph shape is flatter than a normal distribution with low Kurtosis (0,14).

**Comment:** The experimental data contains noise; the negative values clearly indicate the influence of the measuring sensors or the fluctuations of the fuel in the tank. Based on this, recommendations are made regarding the selection of measuring sensors and signal normalization in the experiment.

d) Comparative comments between FC\_MP and FC\_TN

- Average value: Within the average value range of FC\_MP 2,48 kg and FC\_TN 2,62 kg, there is a difference of +0,14 kg, calculated as a percentage:  $(2,62 - 2,48) / 2,08 \times 100\% = 6,73\%$ . Thus, FC\_TN is 6,73% higher.

- Stability  $\sigma$ : FC\_MP has  $\sigma_{MP} = 0,42$  kg (stable) and FC\_TN:  $\sigma_{TN} = 1,07$  kg (unstable). Thus, FC\_MP has a stability level 2,5 times higher than FC\_TN.

- Measurement errors in the experiment: Mean absolute error MAE = 0,98 kg. Mean square error RMSE = 1,22 kg.

- Statistical test results: T-test: p-value < 0,001 indicates high statistical significance. Mann-Whitney U: p-value < 0,001 shows that all differences are statistically significant.

- Correlation analysis: Pearson  $r = 0,934$  indicates high correlation, ensuring reliability. Spearman index  $\rho = 0,95$  shows strong hierarchical correlation, and the very high homogeneity  $CCC = 0,720$  suggests that the two datasets are close together and strongly correlated.

#### 4.6.4.3. Comparison of results in reduced volume

Table 4.3: Summary of experimental results from July 14, 2024 with  $m = 936$  kg

Fuel consumption test on a car, April 14, 2024										
Content	Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5	
	Data	Result	Data	Result	Data	Result	Data	Result	Data	Result
Departure time	4:02 AM	1 hour	5:27 AM	1h02'	7:55 AM	1 hour	8:20 AM	1 hour	9:45 AM	1h06'
End time	5:02 AM		6:29 AM		7:55 AM		9:20		10:51	
First kilometers	0	34,7	34,7	34,7	69,4	34,7	104,1	34,7	138,8	31,7
Final kilometers	34,7		69,4		104,1		138,8			
Initial fuel quantity (g)	12,488	0,974	11,516	0,974	10,546	0,93	11,683	0,948	10,735	1,103
Final fuel quantity (g)	11,514		10,542		9,616		10,735			
Running route	University of Technology - Phung Bridge - Thây Pagoda - Đông Trú (Lang Hoa Lac Expressway)		Dong Truc (CT Lang Hoa Lac) - Son Tay - Vinh Thinh Bridge - Dong Van - Yen Lac		Dong Van (Yen Lac) - National Highway 2A - Me Linh Road - Vo Van Kiet Road		Vo Van Kiet Street - Dong Tru Bridge - Thanh Tri Bridge - Do Muoi Street (Hoang Mai District)		Do Muoi Street (Hoang Mai District) - Ngoc Hoi - Cau To Bridge - Van Khe - Le Trong Tan - Lang Hoa Lac - My Dinh - Trinh Van Bo - Hanoi University of Technology	
Road characteristics	City center, suburbs, highway		The suburbs have slopes.		Suburban		Suburbs, Urban areas		Densely populated urban areas	
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The results of the comparative test run in cycle 1 showed that the car traveled 34,7 km in 1 hour, with a fuel consumption of 0,974 kg (FC) = 1,35 liters. Compared to the original weight ( $m_{55}$ ), a 10% reduction in weight resulted in a 7,8% reduction in fuel consumption, and compared to the simulation, it was 7,2%. Thus, the difference of  $7,8 - 7,2 = 0,6\%$  is due to driving skill and external factors.

## CONCLUSION OF CHAPTER 4

Chapter 4 presented experimental research to verify the theoretical and simulation results of the thesis. Based on research objectives and real-world conditions, the chapter developed a suitable experimental vehicle cycle to evaluate the fuel consumption of a car when its mass changes. The experimental cycle was designed to reflect the operating characteristics of the car within the research area and to serve as a basis for organizing experimental measurements.

In this chapter, the thesis designed and fabricated a fuel consumption meter for experimental research. The fabricated meter was then validated, ensuring the accuracy and reliability of the measured data during the experiment.

Based on the experimental vehicle cycle and the constructed measuring system, fuel consumption measurements were conducted under defined conditions, and the vehicle's mass was varied to assess the effect of mass on fuel consumption. Experimental results showed that fuel consumption increased with increasing vehicle mass, consistent with the variation trend identified in the theoretical and simulation models in previous chapters.

A comparison between experimental results, simulation results, and results calculated using the FC equation developed in Chapter 3 shows an average difference of 6.73% between the two results, which is within an acceptable range. This demonstrates the reliability of the model, the FC equation, the experimental vehicle cycle, and the constructed measurement system.

The results obtained in Chapter 4 have reinforced the conclusions of the thesis, while also providing a scientific and practical basis for applying solutions to reduce vehicle weight, including the use of lightweight materials, in order to reduce fuel consumption in actual operation.

The correlation between experimental and simulation results suggests that the proposed research method is likely to accurately reflect the influence of vehicle weight on fuel consumption under real-world operating conditions.

## **GENERAL CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS OF THE THESIS**

The thesis "*Research on the influence of the weight of 5-seater cars on fuel consumption*" achieved the following results:

- The thesis has systematized the scientific basis and research methods on automobile fuel consumption, analyzed the influencing factors, and clarified the role of overall mass in the resistance to motion and fuel consumption of automobiles.

- Based on the dynamics of automobile motion, the thesis developed a simulation model of the relationship between mass and fuel consumption. Simulation results show that when the vehicle mass decreases, fuel consumption decreases, and conversely, when the mass increases, fuel consumption increases. Using least squares regression, an equation describing fuel consumption as a function of mass for a 5-seater car was obtained, in the form:  $FC = (3,8 \times 10^{-6}m^2 - 0,00644m + 3,734) \times 100/34,7$  (liters/100km), where  $m$  is the mass of the vehicle. This equation reflects the non-linear variation trend of fuel consumption as a function of vehicle mass within the study area, allowing for the evaluation and prediction of fuel consumption when vehicle mass changes.

- Proposals suggest reducing fuel consumption by decreasing the weight of automobiles, emphasizing the potential application of lightweight materials in design and structural improvements to vehicles.

- The thesis has developed an experimental vehicle cycle to verify theoretical and simulation results. Experimental results show that the change in fuel consumption with mass is consistent with the simulation results; the difference between simulation and experimental results is 6.73%, which is within acceptable limits, thereby confirming the reasonableness and reliability of the model, the FC equation, and the research methodology of the thesis .

- The research results demonstrate that the thesis has achieved its objectives: clarifying the influence of overall weight on the fuel consumption of automobiles using both simulation and experimental methods. The results obtained from the thesis provide a scientific basis for further research, as well as for application in design, structural optimization, and material selection to reduce automobile fuel consumption in practice.

- Besides the achievements, the research still has some areas that need further improvement. The research model and FC equation developed in the thesis are established within the scope of operating conditions and the surveyed load range; therefore, their applicability to other operating conditions or other types of vehicles needs further research, expansion, and verification.

- The experimental vehicle testing process did not fully cover the complex and diverse traffic conditions in reality. Furthermore, the influence of several other factors such as environmental conditions, the vehicle's technical condition, and driver behavior was not comprehensively considered within the scope of this thesis.

The limitations mentioned above serve as a basis for further research aimed at improving the model. The model will be further refined and applied to a wider range of applications, as well as improving the accuracy of assessing car fuel consumption.

### **Directions for further research:**

Due to time constraints and research limitations of the thesis, the measurement system could only be implemented on 5-seater passenger cars. Therefore, the doctoral candidate proposes the following directions for further research:

- Continue to expand and apply AI research to study the impact of various other factors with the same mass under real-world operating conditions on fuel consumption in passenger cars.

- AI applications are being used to study fuel consumption across various car models.
- The measurement system will be refined so that it can be widely used on various types of vehicles in research and towards practical applications.

## SCIENTIFIC PUBLICATION

- [1] *Ngo Quang Tao, Nguyen Thanh Quang*, Influence of kinematic parameters on fuel consumption in cars, 2024 4th International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME), Male, Maldives, 2024, pp. 1-6, *doi:10.1109/ICECCME62383.2024.10796898*.
- [2] *Ngo Quang Tao, Nguyen Thanh Quang*, Analysis relationship between mass and lightweight materials on the body to resistance forces of the car moving, (The 7th International Conference on Engineering Research and Applications – ICERA 2024).
- [3] *Ngo Quang Tao, Nguyen Thanh Quang, Le Van Anh, Pham Minh Hieu, Le Duc Hieu*, Analysis of effect of rolling resistance coefficient on automobile fuel consumption, *HaUI Journal of Science and Technology*, Vol. 60 - No. 5, pp. 216 -218, May 2024
- [4] *Ngo Quang Tao, Nguyen Thanh Quang, Le Van Anh*, Relationship Between Rolling Resistance and Deformation Energy of Car Tires, (Proceedings of the 4th Annual International Conference on Material, Machines, and Methods for Sustainable Development (MMMS2024)), Vol 1: Advanced Materials and Manufacturing Technologies - pp. 281 - 287, 03 August 2025, [https://doi.org/10.1007/978-3-031-93816-0\\_34](https://doi.org/10.1007/978-3-031-93816-0_34).