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MEP55B15 - Low Carbon Transport Technology

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of the requirements for the degree of
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Declaration

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Contents

List of Figures

List of Tables

Abstract

This study develops an automotive drive cycle model to evaluate and optimize the carbon emissions of a MY14 Mazda 3 2.0L with Skyactiv Gasoline Engine and Skyactiv-Drive 6-speed automatic transmission, a C-Class sedan, using the Modified Indian Driving Cycle (MIDC) in Microsoft Excel. The baseline model, calculated from first principles, yielded 5.60 L/100 km and 134.80 gCO_2/km, validated against manufacturer data. Optimization strategies—10% weight reduction, 5% drag coefficient reduction, gear shifting logic, gear ratio adjustments, and a 15% ethanol blend (reflecting India's nationwide standard as of April 2025)—reduced emissions by up to 9.6%. This work demonstrates practical emission reductions within real-world constraints, supporting India's low-carbon transport goals.

1 Introduction

Transportation accounts for a significant portion of global carbon emissions, necessitating innovative low-carbon technologies. This study was conducted by developing a drive cycle simulation to assess and optimize the environmental performance of a baseline vehicle. For this assessment, a C-segment sedan, MY 2014 Mazda 3 Skyactiv Gasoline Engine with Skyactiv-Drive 6-speed automatic transmission, was selected, which was studied in the Indian environment. The rapid expansion of the population and economy has improved India's growth, but at the same time, the constant development increases GHG emissions [1].

Figure 1.1: MY 2014 Mazda 3 Skyactiv Gasoline Engine with Skyactiv-Drive 6-speed automatic transmission [2]

Total Passenger Vehicle Sales were 4.2 million in FY 2023-24, out of which Passenger cars were 1.5 million [3]. But in the current Indian market, sedans are losing popularity as they don't have much road presence as SUVs have. In Q4-2024, around 127,000 C-class sedans were sold, whereas from FY 2021, over 1.2 million are on the road [4]. This can be clearly seen in the fig.1.2

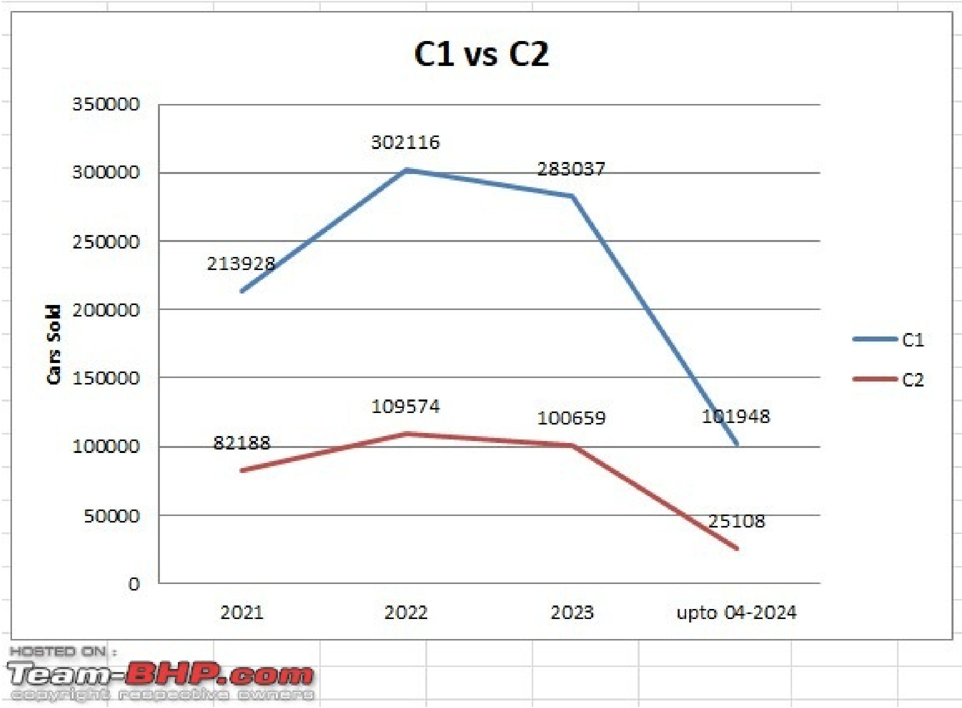

Figure 1.2: Total Sales of C-class Sedans over FY 2021-24 [4]

The MY24 Mazda 3 was chosen because BSFC maps for other popular brands in India were not found in a limited period of time, though as Mazda 3 is also a sedan, the emission will be assumed to be closer. As per a survey conducted by Times of India, Indian commuters travel around 35 km/day which is around 12,775 km annually. And if we consider a fleet of 1.2 million, then it is almost 15.33 billion km annually.

2 Methodology

2.1 Model Parameter Identification

The model was developed in Microsoft Excel from first principles, ensuring transparency and avoiding any other proprietary tools. The majority of the data was taken from the Automobile Catalogue website [5], which is a reliable website for almost all the details regarding most of the vehicles. Following is the data used from the website

MY14 Mazda 3 SkyActiv (C-segment)		
Parameters	**Values**	**Units**
Vehicle Mass	1235	kg
Driver Mass	70	kg
Total Mass	1305	kg
Frontal Area	2.258	m^2
Coefficient of Drag	0.26	$-$
Tire Width	205	mm
Tire Aspect Ratio	60	%
Rim Diameter	16	$inch$

(a) Vehicle Data

MY14 SkyActiv 6-speed Transmission	
Parameters	**Values**
Gear 1	3.552
Gear 2	2.022
Gear 3	1.452
Gear 4	1
Gear 5	0.708
Gear 6	0.599
Final Drive Ratio	4.325

(b) Transmission Data (Gear Ratios)

Table 2.1: Vehicle data from Automobile Catalogue [5]

The tyres were assumed to be Bridgestone Turanza Quiettrack, which is a touring tyre [6]. This was assumed because this tyre was light in weight and which will reduce the wheel inertia as well as it will be more economical. The rolling coefficient was taken from the appendix section of *Compilation and analysis of data related to the rolling resistance of passenger car tires* [7] document which had data for almost all the tires. The compiled dataset is a combination of experiments conducted by independent laboratories sponsored by the California Energy Commission (CEC) and additional data was provided by the Rubber Manufacturers Association (RMA) members, making it a very reliable source [7]. For the selected tyre, 205/60R16, the **rolling coefficient is taken as 0.0079**. The wheel inertia was estimated using an online calculator from the tire weight, and it was assumed the rim mass percentage of total wheel mass is 65%, which provides **wheel inertia of 0.28689 (kgm^3)** [8].

Engine inertia was taken from the CarSim application version 2017.1 [9]. This tool has common parameters for vehicles of different segments. As the Mazda 3 falls under the C-segment, the data for a similar segment was taken, which gave the **engine inertia of 0.16**

(kgm^3). All these parameters were taken from a reliable source and should be considered valid.

As for the gasoline, Indian standard says the density should be 720-775 kg/m^3 for 15°C [10], and the data for 20°C was not available, so following well-known values for gasoline were selected,

Parameters	Values	Units
LHV	43.2	MJ/kg
Density	780	kg/m^3
	0.78	kg/lit

Table 2.2: Gasoline Parameters

2.1.1 Brake Specific Fuel Consumption Data

For the selected vehicle, engine map was referred to the U.S. EPA for the SkyActiv engine [11]. The map is necessary to predict Brake Specific Fuel Consumption (BSFC) which will in turn let us identify the fuel consumption. The Engine Map can be seen in the fig.2.1

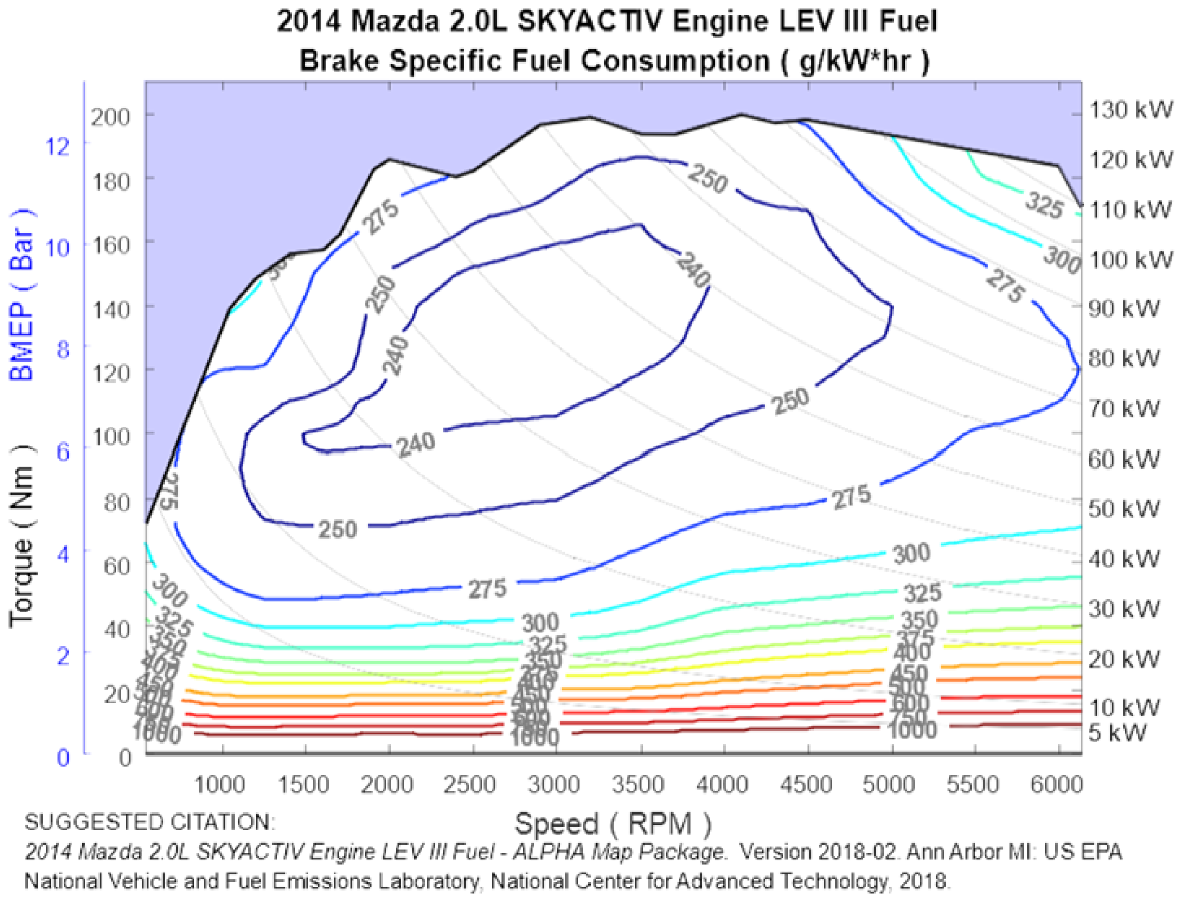

Figure 2.1: Engine Map for SkyActiv Engine [11]

Once the data was obtained for the engine, BSFC was estimated by the RPM and torque generated by the engine for the simulation. Thus, we can say BSFC will be a function of

RPM and torque i.e., $BSFC = f(N, T)$. The function was created using a 6-deg polynomial for RPM and Torque by using the Linest function in Microsoft Excel; the correlation obtained using the CORREL function was 0.98, which is very close to 1. Following is the polynomial equation and the coefficients that were used to evaluate BSFC,

$$f(N,T) = a_1T^6 + b_1T^5 + c_1T^4 + d_1T^3 + e_1T^2 + f_1T \\ + a_2N^6 + b2N^5 + c_2N^4 + d_2N^3 + e_2N^2 + f_2N + Const \quad (2.1)$$

	a	b	c	d	e	f
Torque Coeff	7.77E-10	-5.3E-07	0.000146	-0.02017	1.488298	-56.4827
RPM Coeff	-1.1E-20	3.72E-16	-4.5E-12	2.49E-08	-6.2E-05	0.059718
Const			1131.914055			

Table 2.3: Polynomial Coefficients for BSFC function

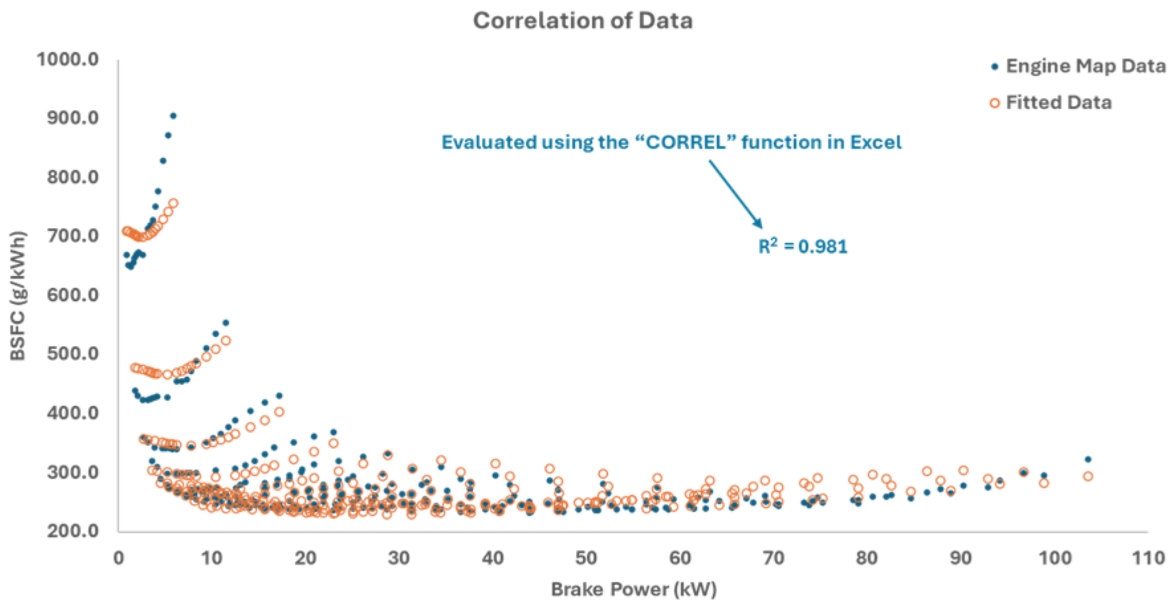

Figure 2.2: Correlation between Engine Map data and the funtion of BSFC developed

Though this is only possible when we delete the rows for which torque was very low, around 1.13 Nm for each particular RPM. As for those torque values, BSFC was higher than 4000 g/kWh, which throws off the correlation; it was decided to remove that data as that torque is very close to getting stalled.

2.1.2 Drive Cycle Selection

As the country of choice is India, the drive cycle is needed to follow Indian Standards. After careful consideration, the Modified Indian Driving Cycle (MIDC) was selected for this study. This cycle is mandated in India for vehicle certification under Bharat Stage VI (BS VI) emission norms [12]. MIDC is a modified version of the New European Driving Cycle (NEDC), and just like NEDC, MIDC has 2 distinct parts, one with 4 urban cycles and another with extra-urban cycles. The only difference between NEDC and MIDC is that the maximum speed achieved is 90 (*kmph*) and the average speed across the cycle is 33 (*kmph*) with the theoretical total distance covered being 10.646 (*km*) [13]. The drive cycle can be seen in fig.2.3. The direct values for MIDC were not available but **The Automotive Research Association of India** published **Automotive Industry Standard** [13] which has the information of different acceleration, deceleration, and idling phases of the driving cycle, which made it easy to replicate the driving cycle. The information used can be seen in fig.A1.1 and fig.A1.2 respectively.

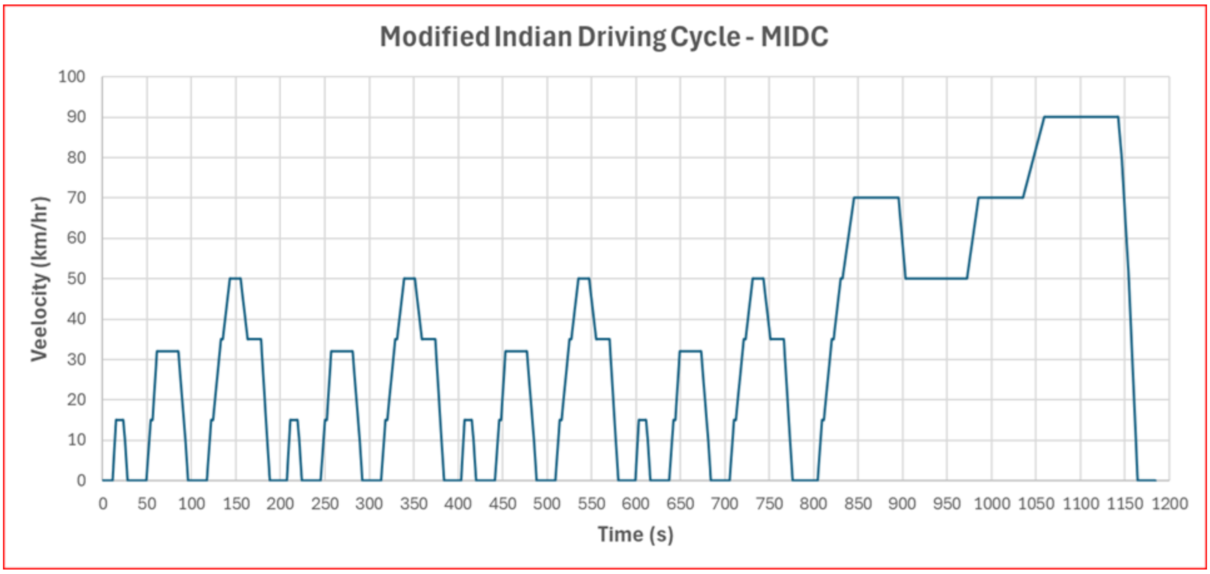

Figure 2.3: Modified Indian Driving Cycle (MIDC)

2.2 Model Setup

Model was set up in Microsoft Excel as guided in the ***MEP55B15 Week 16 Lecture 25022025*** by Prof. Charles Stuart [14]. But a simple modification was performed in the formula for the calculation of torque because the model developed by Prof. Charles Stuart was for US Driving Cycle (FTP - 72) and the current model uses MIDC. US Driving Cycles are more dynamic and look natural, whereas MIDC and NEDC have constant velocity and acceleration test cases. The following formula was used by Prof. Charles Stuart,

$$T = IF\left(a < 0, 0, \frac{a\frac{N^2 J_{eng} + 4 \cdot J_{wheel}}{r_{tyre}} + mr_{tyre}}{N} + \frac{r_{tyre}}{N}\left(\frac{\rho C_d A_{front} V^2}{2} + mgsin\theta + fmgcos\theta\right)\right) \quad [Nm] \tag{2.2}$$

Whereas the following formula was used in the current model,

$$T = IF\left(OR(v=0, a<0), 0, \frac{a\frac{N^2 J_{eng} + 4\cdot J_{wheel}}{r_{tyre}} + mr_{tyre}}{N} + \frac{r_{tyre}}{N}\left(\frac{\rho C_d A_{front} V^2}{2} + mgsin\theta + fmgcos\theta\right)\right) \tag{2.3}$$

This formula first checks if velocity is equal to 0 or acceleration is less than 0; if any condition becomes true, then the formula outputs the required torque to propel the vehicle forward as 0; else it will calculate the torque in Nm from the standard first principle equation. The reason to do this will be mentioned in Model Assumptions in Section 2.3. Rest equations will be mentioned and explained in the Appendix A1.

2.3 Model Assumptions

- Vehicle will have constant rolling resistance f.
- Total mass of the vehicle will remain same and weight change due to fuel consumption will be ignored.
- Air Density is assumed to be 1.223 kg/m^3 and Acceleration due to gravity as 9.81 m/s^2.
- First principle equations will be used to develop the model thus the only resistance to the motion is assumed to be Drag, Gradient and Rolling Resistance which the vehicles need to overcome and other losses, such as pumping loss, transmission loss, etc will not be considered
- The combustion will be stoichiometric to avoid air path involvement.
- As combustion will be stoichiometric, there will be only CO_2 emission, which is easy to calculate from the amount of fuel consumed.
- Amount of fuel consumed will be estimated from the relationship between brake power and BSFC where BSFC will be function of RPM and Torque required to propel vehicle forward.
- Auxiliary loads such as like AC, Alternator etc. will not be acting on engine.
- Gears will only shift based on current RPM i.e., if RPM crosses upper threshold, of 4000 (Max torque produced by engine) and/or RPM crosses lower threshold, of 1500 (the point where torque has steep drop. These points can be seen in fig2.4 which was obtained form the data provided by U.S. EPA [11]. This is to simplify model as actual gear shift depends not only on RPM but on various other factors such as speed, acceleration, throttle position etc.

Actual maximum RPM was observed 4 times in the dataset, which was taken from the U.S. EPA site and was extracted with the help of a pivot table after sorting for maximum torque for unique sets of RPM. These mentioned 4 points can be seen in the fig.2.4 where the flat line is observed between these 4 points. Thus, the middle value was chosen, which was closer to the eye of the BSFC so that if RPM crosses the eye, gear shift will bring it back to get maximum efficiency, as this vehicle would have been designed by the manufacturer, and this should help to get closer results to the manufacturer's specifications in terms of fuel economy and emission factors.

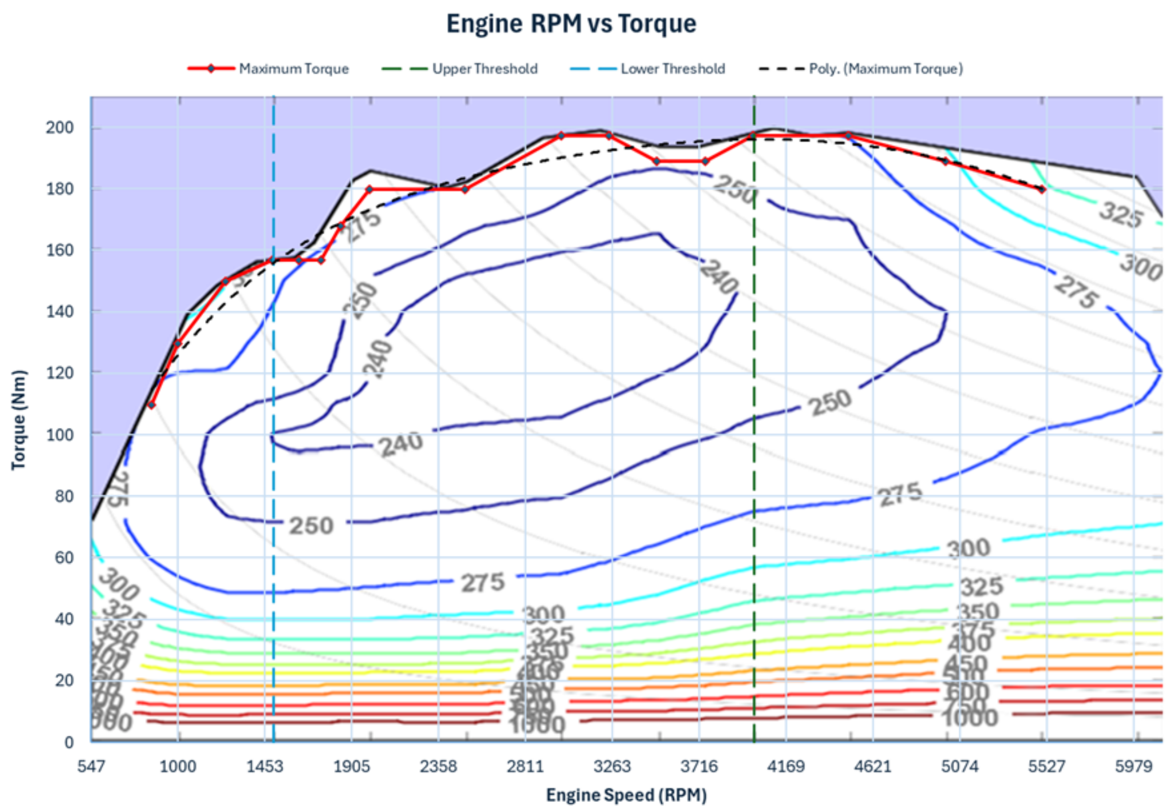

Figure 2.4: Image showing Maximum Torque along with Upper and Lower threshold for gear shift

These assumptions are valid for developing a simple and easy-to-setup model. The model behaviour was characterised from the following manufacturers' information,

- Vehicle is equipped with eSS (Engine Start Stop) function also known as i-stop function[5]. So fuel will be cut-off when vehicle will be standstill i.e., velocity and acceleration is 0.
- Vehicle has smart fuel management system which shuts off fuel during coasting to save fuel. Though this is not a mandate but many modern vehicles have this function [15] and it is assumed this vehicle will also have this function. Thus, fuel will be cut-off when vehicle is coasting i.e., velocity > 0 but acceleration < 0.

With these assumptions, the Equation 2.3 was modified as mentioned in Section 2.2. As there are constant acceleration and deceleration in MIDC, it was a necessary adjustment.

2.4 Carbon Emission Estimation

As the study was conducted to identify and minimize carbon emissions not only generally but the overall life cycle of the fuel used, the overall performance metrics not only for tank-to-wheel but also well-to-tank CO_2 emissions will be estimated.

Total CO_2 emissions based on the combustion of gasoline will be estimated as follows,

$$Total\ CO_2\ emission = Total\ fuel\ consumption\ in\ kg * 3.088 \qquad [kg_{CO_2}] \qquad (2.4)$$

And

$$Overall\ Carbon\ Intensity = \frac{Total\ fuel\ consumption\ in\ g * 3.088}{Total\ Distance\ Travelled\ in\ Driving\ Cycle\ in\ km} \qquad [gCO_2/km] \tag{2.5}$$

And CO_2 equivalent emission i.e., overall emission during the lifecycle of gasoline was estimated as follows,

$$Total\ CO_2\ emission = \frac{Total\ fuel\ consumption\ (kg) * LHV\left(\frac{MJ}{kg}\right) * Carbon\ Intensity\left(\frac{gCO_2e}{kg}\right)}{1000} \qquad [kg_{CO_2}] \tag{2.6}$$

But the carbon intensity used will be different for different countries as the emissions to get from well-to-tank will significantly change. For India, as per a study conducted by Soam *et.al*, well-to-wheel is approximately **84.69** gCO_2e/MJ [1]. Though ethanol is said to be a carbon-neutral fuel, as it absorbs CO_2 during its growth [16], in this study, CO_2 absorption was excluded to avoid overstating the emission reduction potential of the ethanol blend.

3 Baseline Results & Discussion

Once the setup and run were performed with the MIDC for 1180 sec, the expected results and obtained results can be seen in table 3.1 & 3.2 respectively.

Parameters	Values	Units
Theoretical Distance to be Covered [13]	10.646	km
Overall Carbon Intensity [17]	129	gCO_2/km
Mileage [17]	5.60	l/100 km

Table 3.1: Expected Results

Parameters	Values	Units
Total Distance Covered	10682.36	m
	10.68	km
Total Fuel Consumed	466.11	g
	0.47	kg
	0.60	litrs
Total CO_2 Emission	1.44	kg_{CO_2}
Overall Carbon Intensity	134.74	gCO_2/km
Mileage	17.88	KMPL
	5.59	l/100 km
Total CO_2e Emission	1.71	kg_{CO_2}

Table 3.2: Obtained resulted which will be considered as Baseline

The results were very close to the anticipated outputs, which shows that even if the simulation was performed with the first principle method with lots of assumptions, the expected result is not much far from the real-world scenario. The only outlier seems to be the CO_2 emission seen from the Car Emissions website [17], which might be due to additional emissions such as Carbon Monoxide, HC emissions and NO_x emissions that are observed in the real-world scenario. As the assumption stated in section 2.3, the combustion is stoichiometric; thus, no other emissions will be observed. Rest Engine RPM, Torque, BSFC, and Gear Shift pattern can be observed in fig.3.1, 3.2, 3.3, and 3.4 respectively. It was verified that none of the outputs don't cross the maximum threshold seen in the dataset obtained from U.S. EPA.

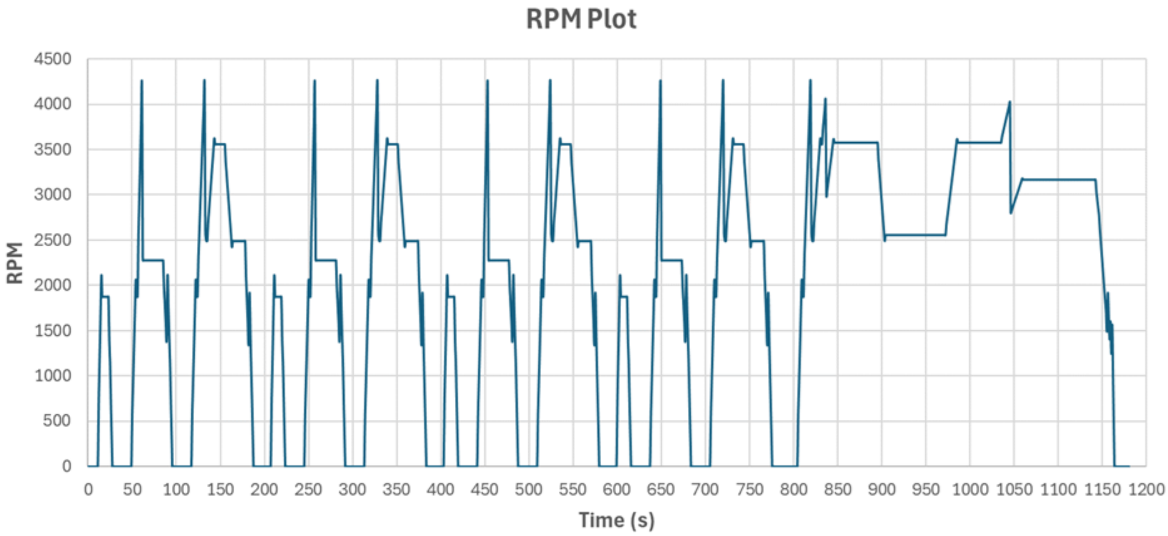

Figure 3.1: Baseline RPM

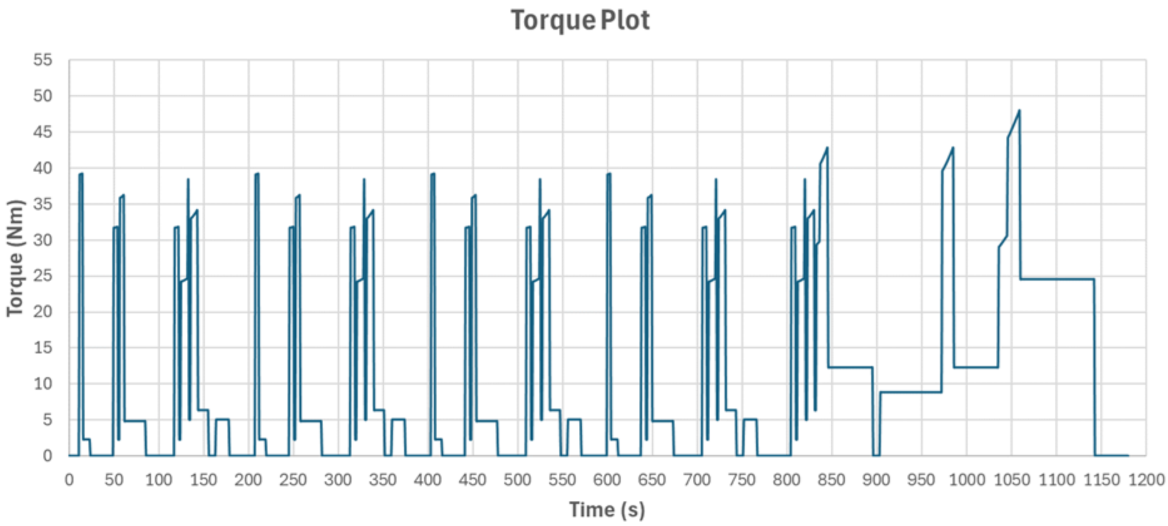

Figure 3.2: Baseline Torque

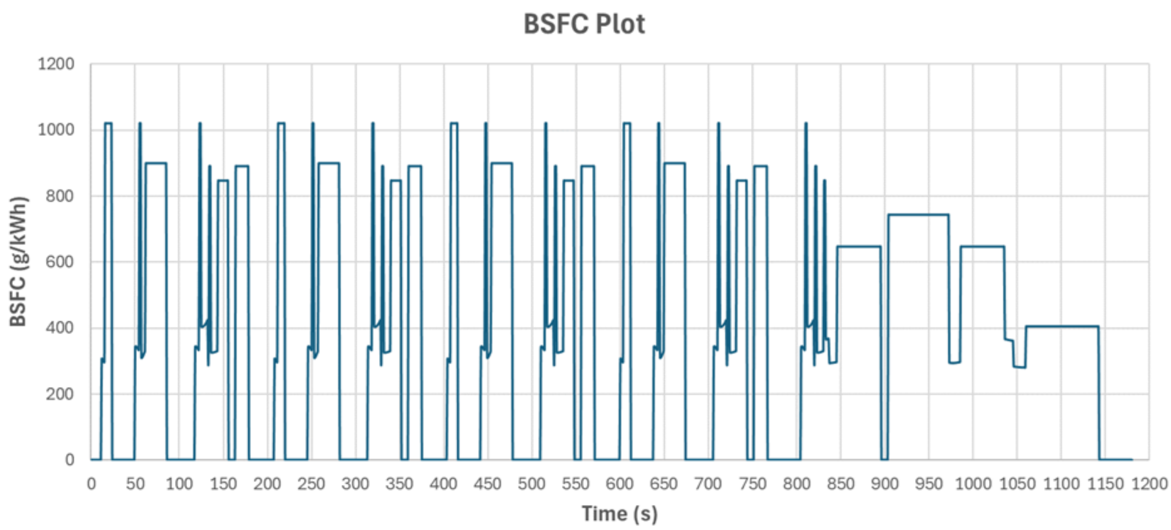

Figure 3.3: Baseline BSFC

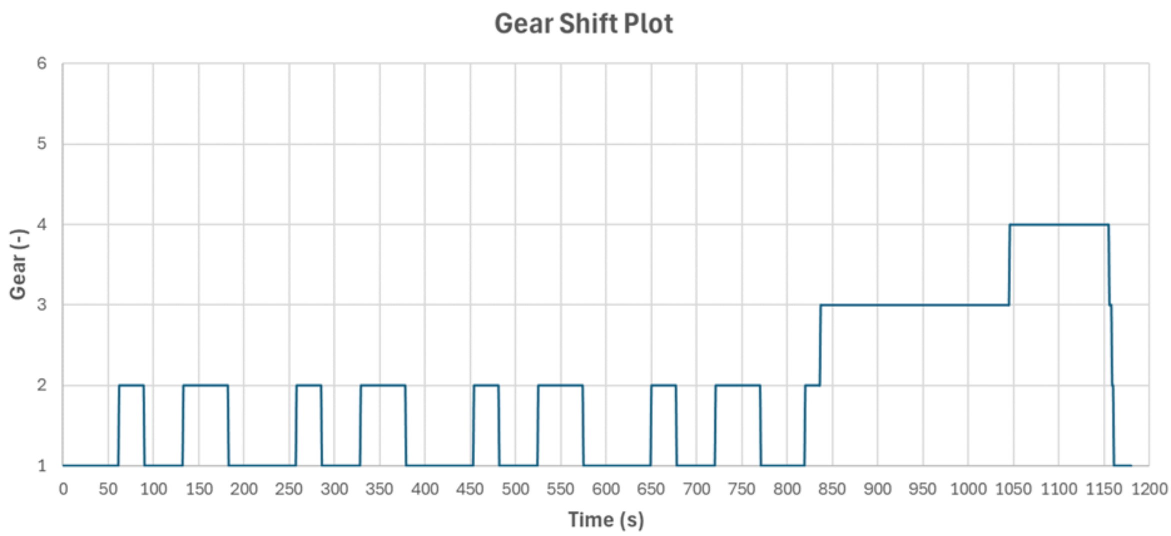

Figure 3.4: Baseline Gear Shift Pattern

When considered the entire fleet of the vehicles, the following were the results,

Parameters	Values	Units
Total Fuel Consumed	857562732	lit
Total CO2 Emmision	1727206.01	kgCO2
Overall Carbon Intensity	2065559.9	mil tonn CO2
Total CO2e Emmision	2046363.25	kgCO2

Table 3.3: Fleet-wise Estimation

4 Optimisation Strategy

After studying and completing various assignments in the subject MEP55B15: Low Carbon Transport Technology, there were lots of methods available to reduce overall carbon emissions significantly, out of which 5 Optimization Strategies implemented in the analysis, which are mentioned as follows :

- Vehicle Mass Reduction by 10%
- Improving Drag coefficient by 5%
- Optimizing gear shifting strategy
- Optimizing gear ratios
- Using Ethanol blended gasoline as fuel.

4.1 Mass Reduction

In Assignment 1 for MEP55B15, the analysis was performed on how the various parameters will affect the torque required to propel the vehicle forward by first principle method. It was observed that reducing the mass of the vehicle by 20% significantly reduces the torque required to propel the vehicle. Thus, here it was seen if, by cost cutting and using various light materials to reduce the weight of the vehicle by 10% of the original value, the change in the fuel consumption is seen or not, which will reduce the overall emission.

4.2 Drag Reduction

In the same assignment 1, the effect of the aerodynamics was also seen where a similar reduction in the torque required to propel the vehicle was seen as the effect of drag coefficient reduction. The drag coefficient was reduced by 5% which will make the vehicle more aerodynamic but will be very difficult to design in real life, so a 5% reduction is a sufficient assumption. The effect will be seen only at high speed as $Drag\ force \propto V^2$, the effect will only be seen at high speed, so emissions and fuel consumption are not expected to improve by much.

4.3 Optimizing Gear Shifting Strategy

Above mentioned strategies were hardware-based, which are very difficult to modify and the changes are permanent. So a software strategy was involved where the up-shift RPM threshold was altered such that the CO_2 emission at that RPM would be low. This was done with the help of Microsoft Excel solver where the down-shift RPM was set as 1200, which is lower compared to baseline, and the obtained up-shift threshold was found to be 2129.29. The lower down-shift RPM was selected so that the gears don't constantly up and down-shift repeatedly, which doesn't happen in real life as it will damage the transmission and engine faster by constantly switching the load on the driveshaft and engine. The idea here is to keep the engine as center of the eye of the BSFC as possible.

4.4 Optimizing Gear Ratios

The fourth optimization was hardware-based, where the gear ratios for the first 3 gears. The idea is to reduce the gear ratios to reduce the size and mass of the gearbox, which will make the vehicle more compact and will help to reduce weight. Though in the current analysis, the weight was kept unchanged. Another anticipated outcome is that the torque will improve a bit and engine RPM will be brought down as the overall gear ratio will reduce, which is to be tested and verified in this analysis. The optimum gear ratios were identified using Microsoft Excel solver for the least possible CO_2 emission. Following were the obtained gear ratios which will be used,

Parameters	Original Ratio	Modified Ratio	% Change
Gear 1	3.552	3.459	2.68
Gear 2	2.022	1.942	4.06
Gear 3	1.452	1.289	12.61
Gear 4	1	1	0
Gear 5	0.708	0.708	0
Gear 6	0.599	0.599	0

Table 4.1: Comparison with Original and Modified Gear Ratio

4.5 Using Ethanol Blended Gasoline as Fuel

The final strategy is to use an alternate fuel which has low CO_2 emissions compared to gasoline,and for this study, the ethanol blended gasoline was chosen as the main fuel, making this automotive a flex fuel vehicle. India is the second largest producer of sugarcane and is also facing oil crises like Brazil in the 1970 [16]. Thus, just like Brazil mandated the ethanol blending to reduce the fuel prices with sugarcane ethanol, India decided to do the same from December 2013 and successfully reached the 5% ethanol blended target in 2018-19 [18]. In 2019, **Bureau of Indian Standards (BIS)** a body which defines the Indian standards, officially mandated a 5% blend in India in 2019 [19]. As of August 2024, India met its 15% blending target all over India and is planning to reach 20% by 2025 [20]. The reason why the ethanol blended gasoline was chosen is that India already has a good production and supply chain for ethanol; in fact, the Indian government is the largest buyer of the sugarcane from its domestic market [21]. India is so close to achieving its target, that Narendra Modi, Prime Minister of India, already launched 20% ethanol blended gasoline on February 2023 in Bengaluru in 11 major states [22] [23]. As the official status is not available for the current ethanol blended gasoline standards for 20% and what will come after the achievement of this goal, the study will see the effect of 15% ethanol blend.

As for the study, the standard properties of ethanol will be used as shown in table 4.2

Parameters	Values	Units
LHV	27	MJ/kg
Density	789	kg/m^3
	0.789	kg/lit
Carbon Emission Factor	1.913	–

Table 4.2: Ethanol Parameters

But as we are using the blend of ethanol and gasoline, the fuel properties such as LHV, density, CO_2 emission factors will also change based on the blend percentage. Prof. Charles Stuart showed a method in **MEP55B15 Week 16 Lecture 18022025** for such a scenario which is as follows,

$$Blend\ Parameter = (1 - Blend\%) * Gasoline\ values + (Blend\%) * Ethanol\ values \tag{4.1}$$

This equation will be used to estimate LHV, Density, and Total CO_2 emitted for tank-to-wheel and for well-to-tank. But as the density and LHV are updated, in the current case, the density of fuel will increase by a negligible amount for 15% ethanol, but the LHV will change by a significant amount. This will increase BSFC and in turn, fuel consumption and affect mileage. But as BSFC is estimated from the map provided by U.S. EPA, we don't have data for the same engine for different fuels. But study conducted by Siwale *et.al.* can help as the study showed a simple assumption and relation between brake thermal efficiency, BSFC and LHV [24].

$$\eta_{brake\ thermal} = \frac{1}{BSFC * LHV} \tag{4.2}$$

In the current study, we will assume that the brake thermal efficiency for the engine will remain constant; so,

$$BSFC_{blend} * LHV_{blend} = BSFC_{gasoline} * LHV_{gasoline} \tag{4.3}$$

$$\implies BSFC_{blend} = BSFC_{gasoline} * \left(\frac{BSFC_{gasoline}}{BSFC_{blend}}\right) \qquad [g/kWh] \tag{4.4}$$

5 Revised Results

5.1 Mass Reduction

When the mass of the vehicle was reduced by 10%, as anticipated, torque needed to propel the vehicle forward was reduced significantly with an overall average value of 4%. This reduction in torque helps in the reduction of BSFC, which in turn reduces the overall fuel consumption. Fig.5.1 and in 5.2. The overall Co_2 emission was dropped and mileage was improved by 2.94% respectively, which can be seen in table 5.2

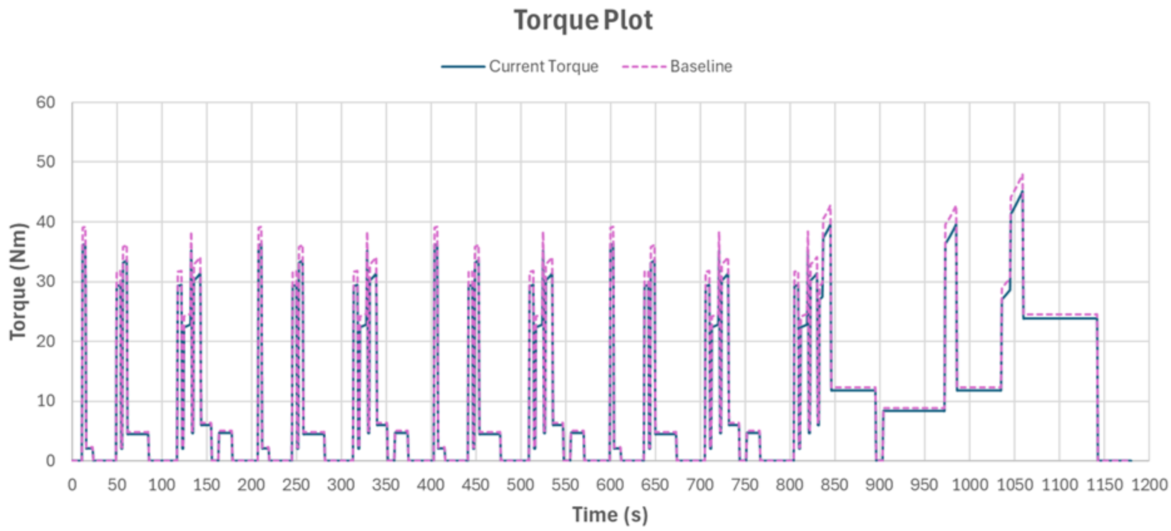

Figure 5.1: Torque Comparison with Baseline and Current Optimisation

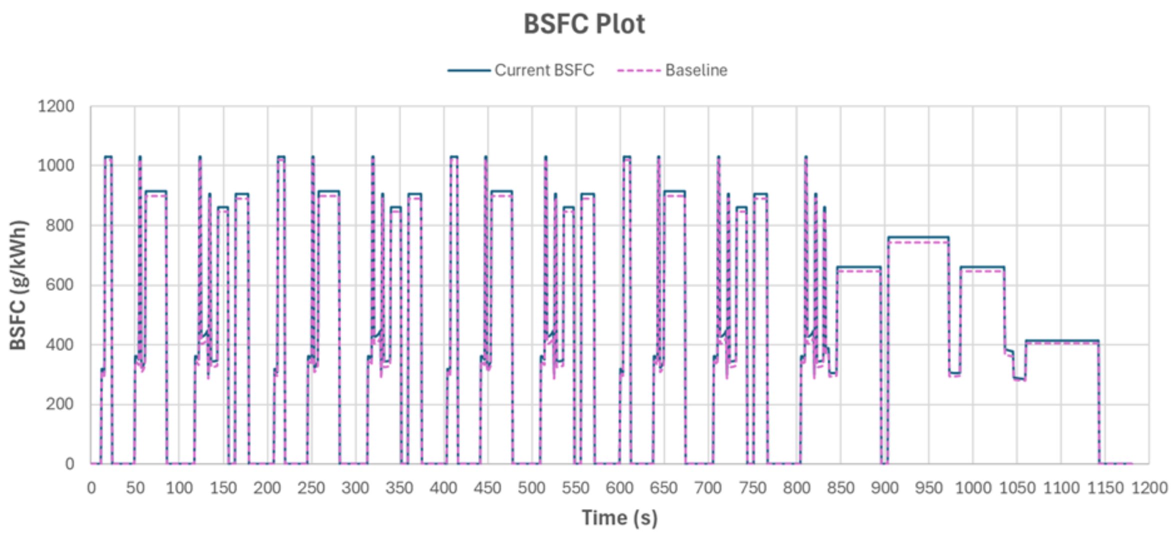

Figure 5.2: BSFC Comparison with Baseline and Current Optimisation

Parameters	Values	Units
Total Fuel Consumed	452.38	g
	0.45	kg
	0.58	litrs
Total CO_2 Emission	1.40	kg_{CO_2}
Overall Carbon Intensity	130.77	gCO_2/km
Mileage	18.42	KMPL
	5.43	l/100 km
Total CO_2e Emission	1.66	kg_{CO_2}

Table 5.1: Obtained resulted which Optimisation 1

Parameters	% decrease
Total CO_2 Emission	2.94
Overall Carbon Intensity	
Total CO_2e Emission	
Mileage	

Table 5.2: Percentage Change observed with Optimisation 1 compared to Baseline

Parameters	Values	Units
Total Fuel Consumed	832312137.5	lit
Total CO_2 Emmision	1676349.11	$kgCO_2$
Overall Carbon Intensity	2004740.31	mil tonn CO_2
Total CO_2e Emmision	1986108.89	$kgCO_2$

Table 5.3: Fleet-wise Estimation for Optimisation 1

Parameters	Values	Units
Total Fuel Consumed	25250594.18	lit
Total CO_2 Emmision	50856.89	$kgCO_2$
Overall Carbon Intensity	60819.59	mil tonn CO_2
Total CO_2e Emmision	60254.35	$kgCO_2$

Table 5.4: Fleet-wise Savingsfor Optimisation 1

5.2 Drag Reduction

When the drag coefficient was reduced by 5%, the effect was minimal but noticeable. The effect was seen at high-speed points, which was just like the first optimisation method; the torque was reduced but plot for BSFC (fig5.4) shows BSFC increased slightly but fuel consumption was reduced. The overall CO_2 emission was dropped and mileage was improved by only 0.75% respectively, which can be seen in table 5.6.

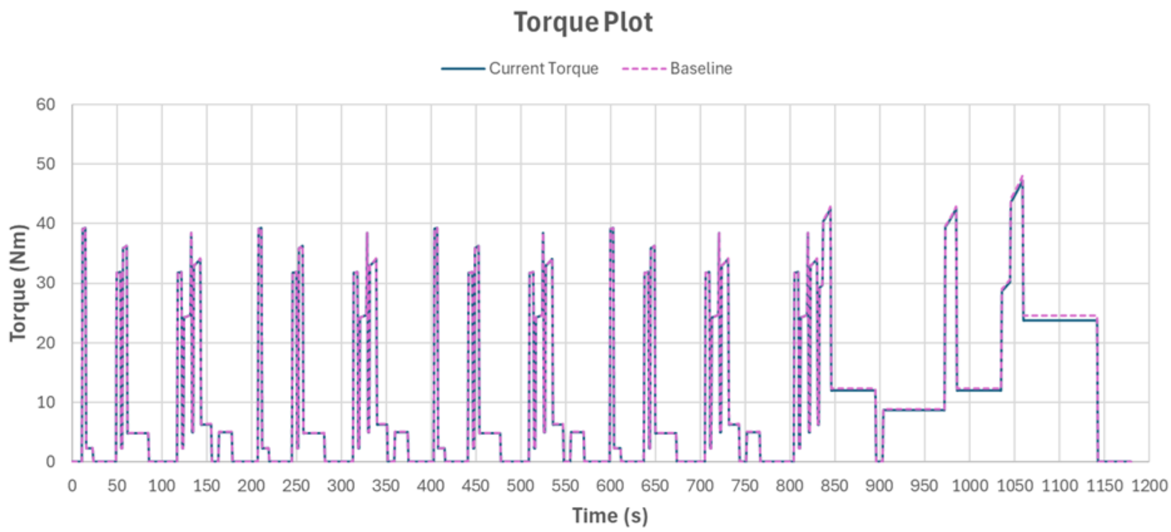

Figure 5.3: Torque Comparison with Baseline and Current Optimisation

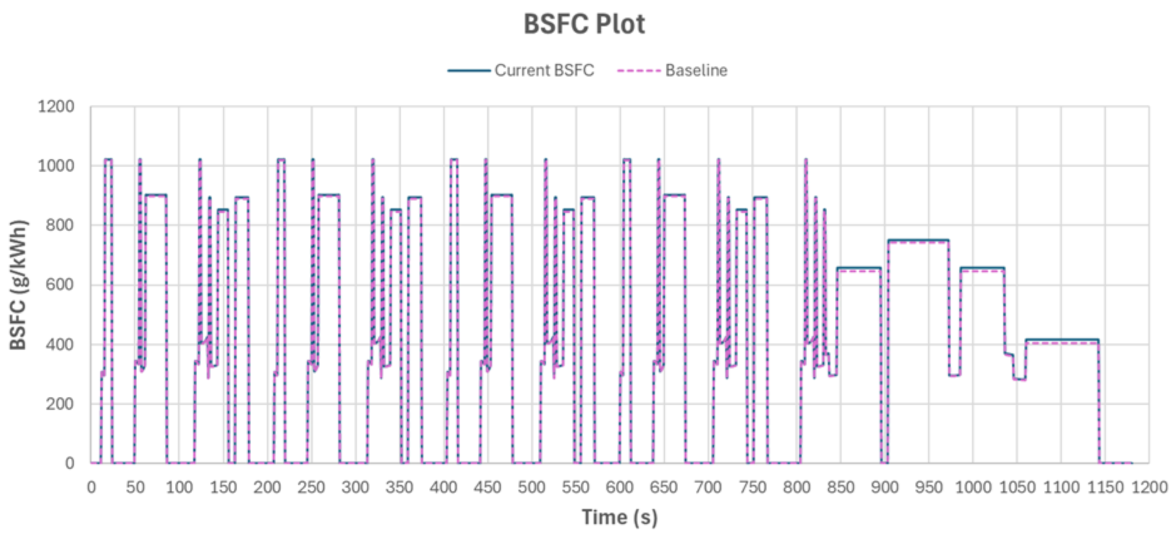

Figure 5.4: BSFC Comparison with Baseline and Current Optimisation

Parameters	Values	Units
Total Fuel Consumed	462.59	g
	0.46	kg
	0.59	litrs
Total CO_2 Emission	1.43	kg_{CO_2}
Overall Carbon Intensity	133.72	gCO_2/km
Mileage	18.01	KMPL
	5.55	l/100 km
Total CO_2e Emission	1.69	kg_{CO_2}

Table 5.5: Obtained resulted which Optimisation 2

Parameters	% decrease
Total CO_2 Emission Overall Carbon Intensity Total CO_2e Emission Mileage	0.75

Table 5.6: Percentage Change observed with Optimisation 2 compared to Baseline

Parameters	Values	Units
Total Fuel Consumed	851100003	lit
Total CO_2 Emmision	1714189.5	$kgCO_2$
Overall Carbon Intensity	2049993.51	mil tonn CO_2
Total CO_2e Emmision	2030941.53	$kgCO_2$

Table 5.7: Fleet-wise Estimation for Optimisation 2

Parameters	Values	Units
Total Fuel Consumed	6462728.76	lit
Total CO_2 Emmision	13016.49	$kgCO_2$
Overall Carbon Intensity	15566.38	mil tonn CO_2
Total CO_2e Emmision	15421.71	$kgCO_2$

Table 5.8: Fleet-wise Savings for Optimisation 2

5.3 Optimizing Gear Shifting Strategy

The gear shifting strategy reduced the shift timing and now the up-shift was quicker, shifting gears up quickly which reduced the engine speed, increased torque and as a result, BSFC was dropped, decreasing the fuel consumption.The overall CO_2 emission was dropped and mileage was improved by whopping 24.26% respectively, which can be seen in table 5.10.

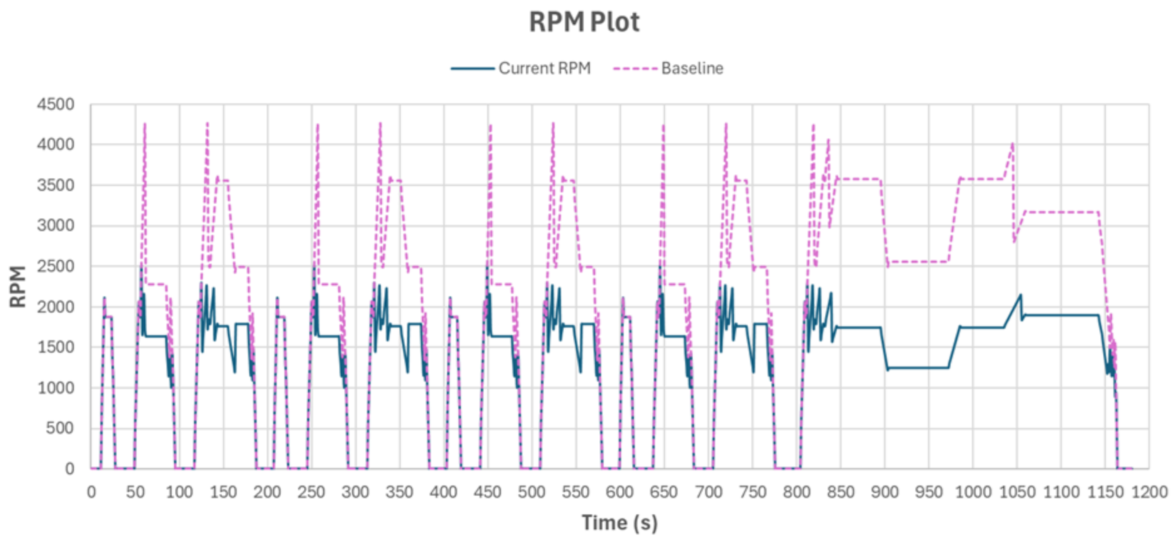

Figure 5.5: RPM Comparison with Baseline and Current Optimisation

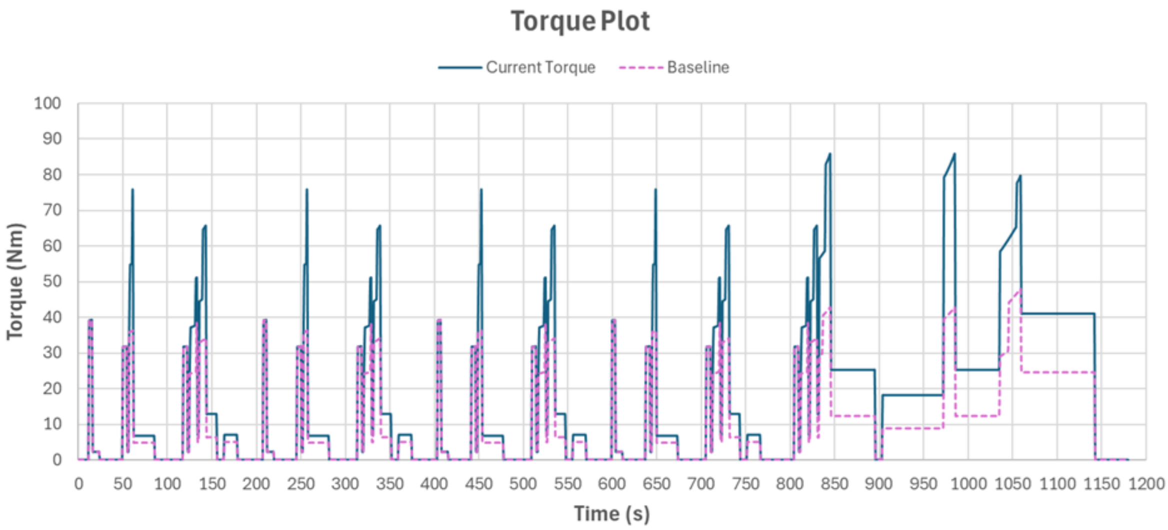

Figure 5.6: Torque Comparison with Baseline and Current Optimisation

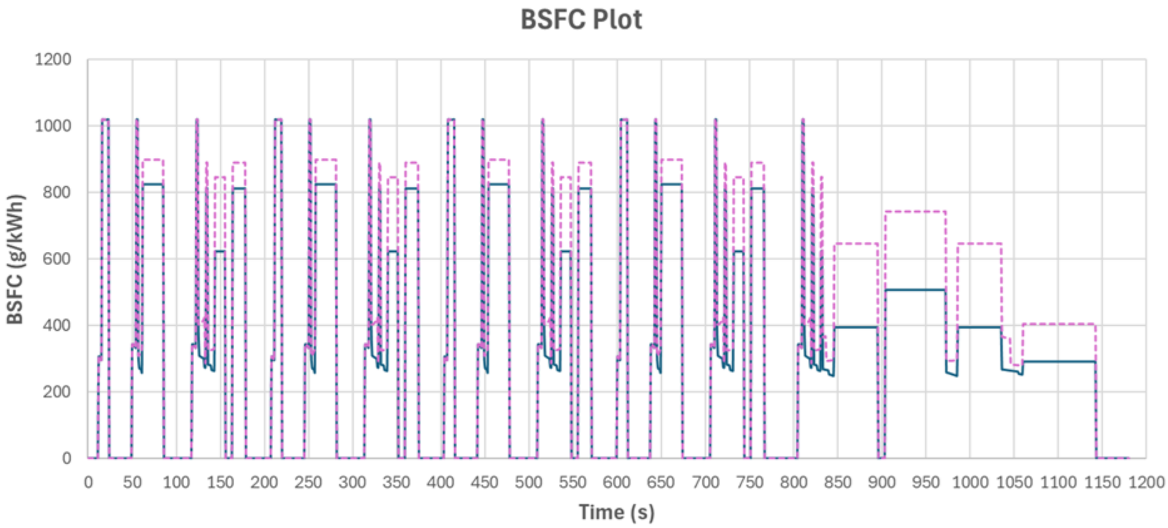

Figure 5.7: BSFC Comparison with Baseline and Current Optimisation

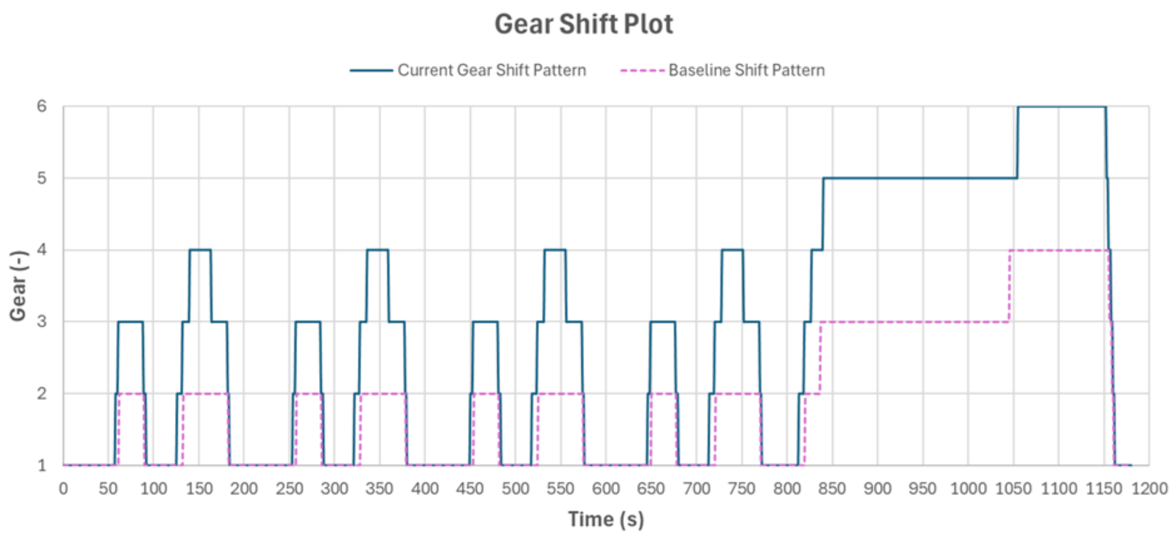

Figure 5.8: Gear Shift Comparison with Baseline and Current Optimisation

Parameters	Values	Units
Total Fuel Consumed	353.03	g
	0.35	kg
	0.45	litrs
Total CO_2 Emission	1.09	kg_{CO_2}
Overall Carbon Intensity	102.05	gCO_2/km
Mileage	23.60	KMPL
	4.29	l/100 km
Total CO_2e Emission	1.29	kg_{CO_2}

Table 5.9: Obtained resulted which Optimisation 3

Parameters	% decrease
Total CO_2 Emission Overall Carbon Intensity Total CO_2e Emission Mileage	24.26

Table 5.10: Percentage Change observed with Optimisation 3 compared to Baseline

Parameters	Values	Units
Total Fuel Consumed	649512905.3	lit
Total CO_2 Emmision	1308175.54	$kgCO_2$
Overall Carbon Intensity	1564442.764	mil tonn CO_2
Total CO_2e Emmision	1549903.33	$kgCO_2$

Table 5.11: Fleet-wise Estimation for Optimisation 3

Parameters	Values	Units
Total Fuel Consumed	208049826.4	lit
Total CO_2 Emmision	419030.46	$kgCO_2$
Overall Carbon Intensity	501117.13	mil tonn CO_2
Total CO_2e Emmision	496459.91	$kgCO_2$

Table 5.12: Fleet-wise Savings for Optimisation 3

5.4 Optimizing Gear Ratios

With the current optimisation mentioned in table 4.1, the effect was not much changed because Mazda 3 is a C-segment vehicle which is a compact passenger car, thus the gear ratios are already low enough to provide sufficient torque. Even so, the change in gear ratio improved torque and reduced RPM enough to reduce fuel consumption. The overall CO_2 emission was dropped and mileage was improved by 2.54% respectively, which can be seen in table 5.14.

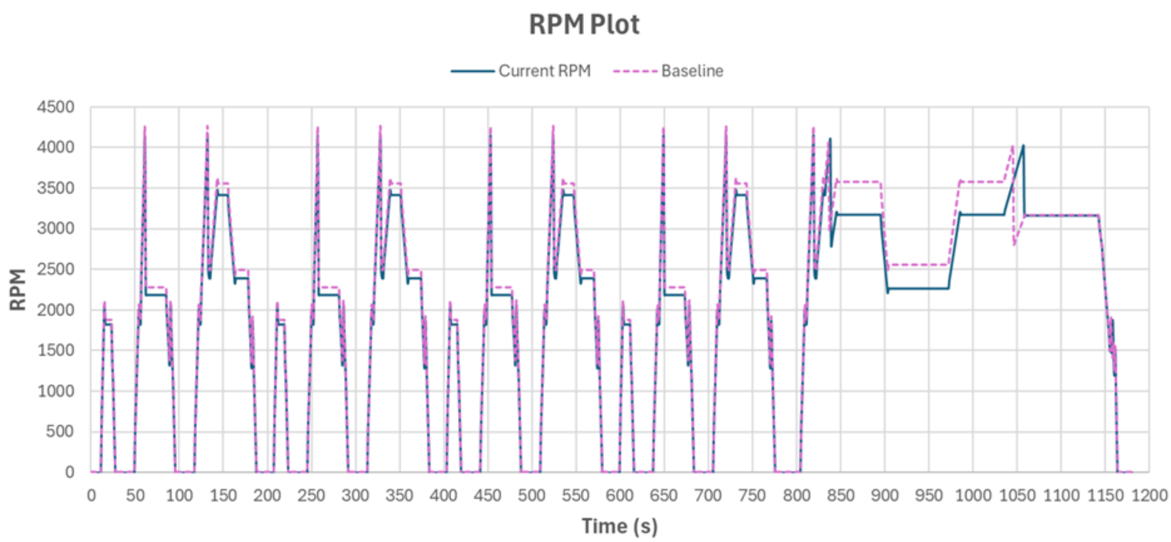

Figure 5.9: RPM Comparison with Baseline and Current Optimisation

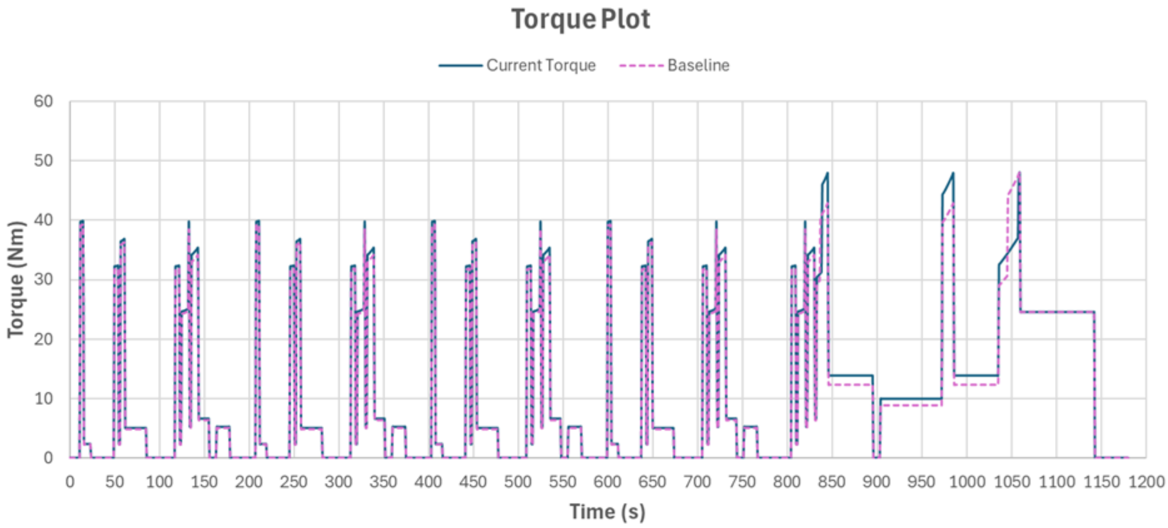

Figure 5.10: Torque Comparison with Baseline and Current Optimisation

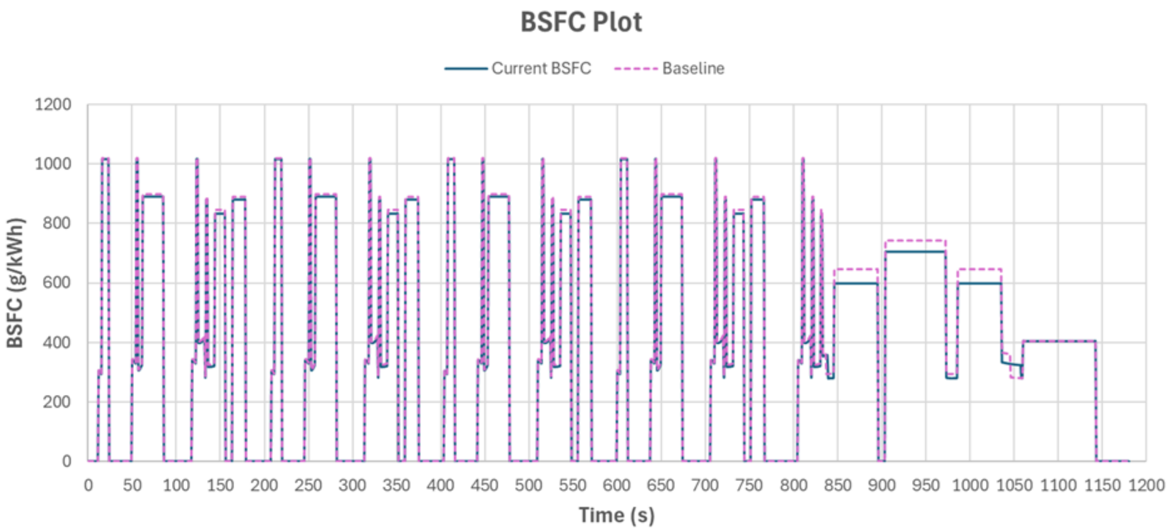

Figure 5.11: BSFC Comparison with Baseline and Current Optimisation

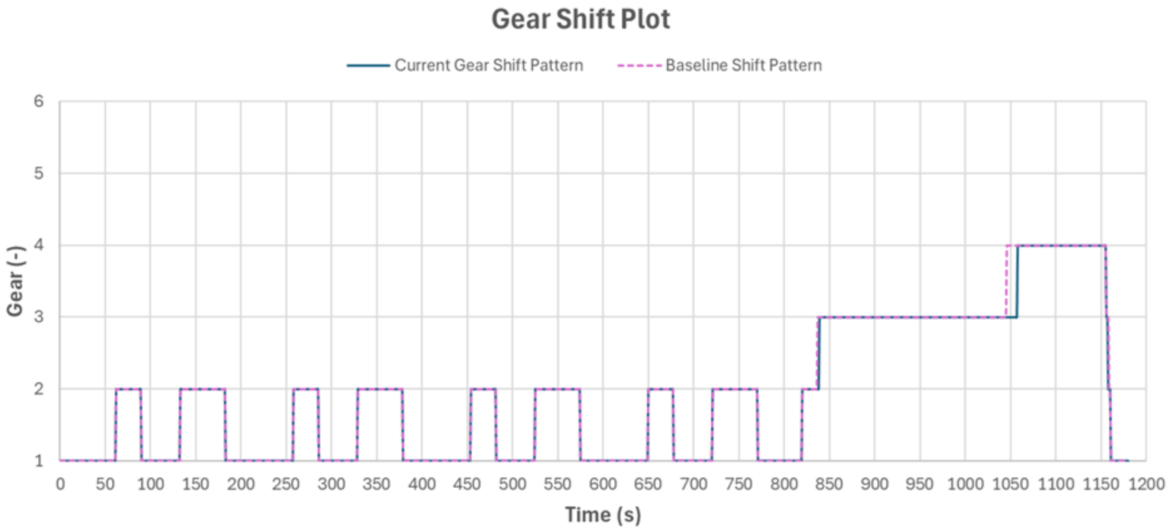

Figure 5.12: Gear Shift Comparison with Baseline and Current Optimisation

Parameters	Values	Units
Total Fuel Consumed	454.26	g
	0.45	kg
	0.58	litrs
Total CO_2 Emission	1.40	kg_{CO_2}
Overall Carbon Intensity	131.32	gCO_2/km
Mileage	18.34	KMPL
	5.45	l/100 km
Total CO_2e Emission	1.66	kg_{CO_2}

Table 5.13: Obtained resulted which Optimisation 4

Parameters	% decrease
Total CO_2 Emission	2.54
Overall Carbon Intensity	
Total CO_2e Emission	
Mileage	

Table 5.14: Percentage Change observed with Optimisation 4 compared to Baseline

Parameters	Values	Units
Total Fuel Consumed	835768666.7	lit
Total CO_2 Emmision	1683310.86	$kgCO_2$
Overall Carbon Intensity	2013065.84	mil tonn CO_2
Total CO_2e Emmision	1994357.05	$kgCO_2$

Table 5.15: Fleet-wise Estimation for Optimisation 4

Parameters	Values	Units
Total Fuel Consumed	21794065.06	lit
Total CO_2 Emmision	43895.14	$kgCO_2$
Overall Carbon Intensity	52494.05	mil tonn CO_2
Total CO_2e Emmision	52006.19	$kgCO_2$

Table 5.16: Fleet-wise Savings for Optimisation 4

5.5 Using Ethanol Blended Gasoline as Fuel

As anticipated, ethanol blend didn't affect the torque and RPM but increased the BSFC, which increased the fuel consumption by 5%. But CO_2 emission for tank-to-wheel was decreased by only 0.09% for 15% blend. But the well-to-wheel i.e., CO_2e emission was decreased by 9.6% which is quite significant achievement by just changing the fuel. The results can be seen below,

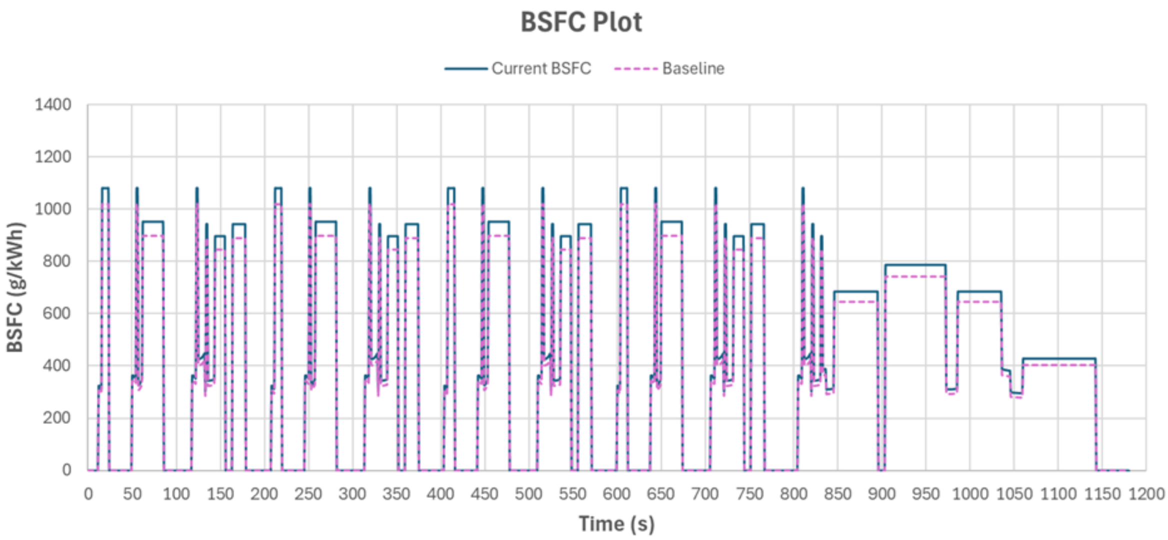

Figure 5.13: BSFC Comparison with Baseline and Current Optimisation

Parameters	Values	Units
Total Fuel Consumed	454.26	g
	0.45	kg
	0.58	litrs
Total CO_2 Emission	1.40	kg_{CO_2}
Overall Carbon Intensity	131.32	gCO_2/km
Mileage	18.34	KMPL
	5.45	l/100 km
Total CO_2e Emission	1.66	kg_{CO_2}

Table 5.17: Obtained resulted which Optimisation 5

Parameters	% decrease
Total CO_2 Emission Overall Carbon Intensity	0.09
Total CO_2e Emission	9.60
Mileage	-5.78

Table 5.18: Percentage Change observed with Optimisation 5 compared to Baseline

Parameters	Values	Units
Total Fuel Consumed	907105751.5	lit
Total CO_2 Emmision	1725694.71	$kgCO_2$
Overall Carbon Intensity	2063752.54	mil tonn CO_2
Total CO_2e Emmision	1849881.93	$kgCO_2$

Table 5.19: Fleet-wise Estimation for Optimisation 5

Parameters	Values	Units
Total Fuel Consumed	-49543019.78	lit
Total CO_2 Emmision	1511.29	$kgCO_2$
Overall Carbon Intensity	1807.35	mil tonn CO_2
Total CO_2e Emmision	196481.31	$kgCO_2$

Table 5.20: Fleet-wise Savings for Optimisation 5

6 Conclusion

It was seen that with all the optimisations, the CO_2 reduction was significant except there are few drawbacks,

- Reducing weight of the vehicle is quite tricky as there are accessories for comfort of humans sitting inside the car so unlike F1 cars they cannot be removed to reduce weight. Also if chasis is made lighter then in case of accident, driver and passengers life will be in danger, so weight reduction has to be done carefully.
- To reduce the drag coefficient, the shape needs to be altered which in compact cars is difficult as the car is designed to be small but the shape optimisation might force designers to make engine and transmission smaller which is very expensive and for 0.75% emission decrease is not worth looking at overall picture.
- The gear shifting strategy is really good but it only works when road is perfectly flat. If the inclination angle is increased, this optimisation fails miserably and same is valid for change in gear ratio.
- Another loss for changing gear ratio is that it will make manufacturing more expensive as more precise tools will be required which increases overall cost.
- As for flex fuel application, unless government don't put any efforts, the goal to reach zero emission will increase further. Unlike India and Brazil not many countries have options to generate surplus ethanol which removes it from being number 1 alternative of gasoline.

As seen in section 5, the optimisation strategy do work but with lots of assumptions but we can say we were able to apply maximum knowledge of what we learned.

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A1 Model Setup Equations

A1.1 Driving Cycle Generation

Driving Cycle was developed by referring to the following images,

	Operation	Phase	Acceleration (m/s^2)	Speed (km/h)	Duration of each: Operation (s)	Duration of each: Phase (s)	Cumulative time (s)	Gear to be used in the case of a manual gearbox
1	Idling	1	0	0	11	11	11	6 s PM + 5 s K_1 [1]
2	Acceleration	2	1.04	0-15	4	4	15	1
3	Steady speed	3	0	15	9	8	23	1
4	Deceleration	4	-0.69	15-10	2	5	25	1
5 5	Deceleration, clutch disengaged		-0.92	10-0	3		28	K_1 [1]
6	Idling	5	0	0	21	21	49	16 s PM + 5 s K_1 [1]
7	Acceleration	6	0.83	0-15	5	12	54	1
8	Gear change			15	2		56	
9	Acceleration		0.94	15-32	5		61	2
10	Steady speed	7	0	32	24	24	85	2
11	Deceleration	8	-0.75	32-10	8	11	93	2
12	Deceleration, clutch disengaged		-0.92	10-0	3		96	K_2 [1]
13	Idling	9	0	0	21		117	16 s PM + 5 s K_1 [1]
14	Acceleration	10	0.83	0-15	5	26	122	1
15	Gear change			15	2		124	
16	Acceleration		0.62	15-35	9		133	2
17	Gear change			35	2		135	
18	Acceleration		0.52	35-50	8		143	3
19	Steady speed	11	0	50	12	12	155	3
20	Deceleration	12	-0.52	50-35	8	8	163	3
21	Steady speed	13	0	35	13	13	176	3
22	Gear change	14		35	2	12	178	
23	Deceleration		-0.99	35-10	7		185	2
24	Deceleration clutch disengaged		-0.92	10-0	3		188	K_2 [1]
25	Idling	15	0	0	7	7	195	7 s PM [1]

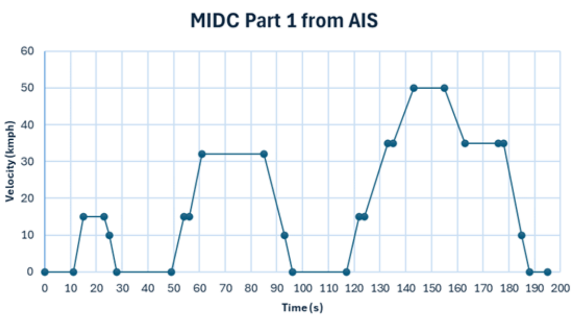
Figure A1.1: Modified Indian Driving Cycle - Part 1 [13]

No. of Operation	Operation	Phase	Acceleration (m/s²)	Speed (km/h)	Duration of each Operation(s)	Duration of each Phase(s)	Cumulative Time(s)	Gear to be used in the case of a manual gearbox
1	Idling	1	0	0	20	20	20	K_1[1]
2	Acceleration		0.83	0-15	5		25	1
3	Gear change			15	2		27	-
4	Acceleration		0.62	15-35	9		36	2
5	Gear change	2		35	2	41	38	-
6	Acceleration		0.52	35-50	8		46	3
7	Gear change			50	2		48	-
8	Acceleration		0.43	50-70	13		61	4
9	Steady speed	3	0	70	50	50	111	5
10	Deceleration	4	-0.69	70-50	8	8	119	4s 5+ 4s 4
11	Steady speed	5	0	50	69	69	188	4
12	Acceleration	6	0.43	50-70	13	13	201	4
13	Steady speed	7	0	70	50	50	251	5
14	Acceleration	8	0.24	70-90	24	24	275	5
15	Steady speed[2]	9	0	90	83	83	358	5[2]
16	Deceleration[2]		-0.69	90-80	4		362	5[2]
17	Deceleration[2]	10	-1.04	80-50	8	22	370	5[2]
18	Deceleration, clutch, disengaged		1.39	50-0	10		380	K_5[1]
19	Idle	11	0	0	20	20	400	PM[1]

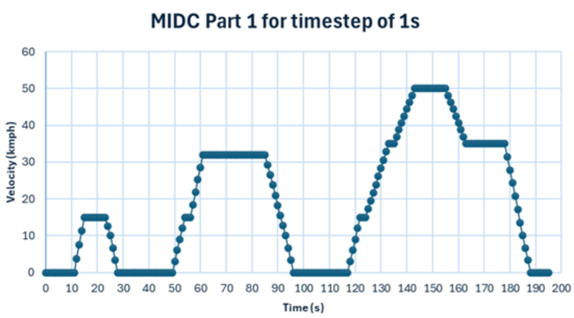
[1] PM = gear box in neutral, clutch engaged. K_1, K_5 = first or second gear engaged, clutch disengaged
[2] Additional gears can be used according to manufacturer recommendations if the vehicle is equipped with a transmission with more than five gears.

Figure A1.2: Modified Indian Driving Cycle - Part 2 [13]

Both fig.A1.1 and fig.A1.2 have the speed and operation time of that particular operation. Though it also shows gears to be used, which will be ignored in the current model simulation for simplification, as it is applicable for manual transmission, not for automatic transmission. Once the basic cycle was plotted, the time step was converted to 1 second to make the estimation and calculation simple and as accurate as possible.



(a) Drive Cycle developed from AIS



(b) Drive Cycle converted to time step of 1s

Figure A1.3: Drive Cycle generation example

As seen in fig.A1.3, using a cycle with a time step of 1 sec makes more sense as now it will be easier to monitor and understand what happens in the drive cycle.

A1.2 Equations for Analysis

Following equations were used for analysis:

$$a = \frac{v_{curr} - v_{prev}}{timestep} \qquad \left[\frac{m}{s^2}\right] \tag{A1.1}$$

$$s = v \cdot (timestep) + \frac{1}{2} a \cdot (timestep)^2 \qquad [m] \tag{A1.2}$$

$$\omega_{wheel} = \frac{s}{r_{tyre} \cdot (timestep)} \qquad \left[\frac{rad}{s}\right] \tag{A1.3}$$

$$Final\ Gear\ Ratio = Current\ Gear\ Ratio \times FDR \tag{A1.4}$$

$$\omega_{eng} = \omega_{wheel} \times \text{Overall Gear Ratio} \qquad \left[\frac{rad}{s}\right] \tag{A1.5}$$

$$N = \omega_{wheel} \cdot 9.549297 \qquad [RPM] \tag{A1.6}$$

$$T = \frac{a\frac{N^2 J_{eng} + 4 \cdot J_{wheel}}{r_{tyre}} + m r_{tyre}}{N} + \frac{r_{tyre}}{N}\left(\frac{\rho C_d A_{front} V^2}{2} + mgsin\theta + fmgcos\theta\right) \qquad [Nm] \tag{A1.7}$$

$$P_{brake} = \frac{\omega_{eng} \cdot T}{1000} \qquad [kW] \tag{A1.8}$$

$$BSFC = f(N, T) \qquad [g/kWh] \tag{A1.9}$$

$$m_f = \frac{P_{brake} \cdot BSFC}{3600} \qquad [g] \tag{A1.10}$$

$$total\ m_f = \sum_{t_{start}}^{t_{end}} m_{f_{timestep}} \qquad [g] \tag{A1.11}$$

$$s_{tot} = \sum_{t_{start}}^{t_{end}} s_{timestep} \qquad [m] \tag{A1.12}$$

$$total\ CO_2\ emission = \frac{total\ m_f \cdot 3.088}{1000} \qquad [kg_{CO_2}] \tag{A1.13}$$

$$Overall\ Carbon\ Intensity = \frac{total\ CO_2\ emission}{s_{tot}} \qquad [g_{CO_2}/km] \tag{A1.14}$$

$$total\ CO_2e\ emission = \frac{total\ m_f \cdot LHV \cdot Carbon\ Intensity}{1000} \qquad [kg_{CO_2}] \tag{A1.15}$$