EVALUATION OF ACCELERATION CHARACTERISTICS ON OPERATIONAL ECO - DRIVING

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Abstract

Greenhouse gasses is a main thread for global warming and there are several strategies that reducing GHG gasses especially in developing countries as using alternative fuel types, dealing with the congestion, maintaining the steady traffic flow, dealing with the maintenances of vehicle, managing desired speed and the acceleration rates and so on.

Eco-Driving is indicating any implementations which enables driving more economic and ecologic style. One of the main concepts of eco-driving is configuring driving behaviour to reduce consumption and emissions.

In this thesis, impact of driver's behaviour tried to be investigated by using an instantaneous emission modelling to obtain minimum acceleration-deceleration rate in generically created urban network.

Keywords: Eco - Driving, Acceleration trajectories, driving behavior

İVMELENME KARAKTERİSTİKLERİNİN OPERASYONEL EKO - SÜRÜŞ ÜZERİNE DEGERLENDİRİLMESİ

Özet

Sera gazları küresel ısınmanın ana tehdididir ve özellikle gelişmekte olan ülkelerde alternatif yakıt türlerini kullanmak, trafik sıkışıklığını önlemek, trafiğın akıcı bir şekilde devam etmesini sağlamak, araç bakımlarını yönetmek, istenilen hızı çıkmayı yönetmek ve bu hızda devam etmek gibi çeşitli stratejiler ile bu sera gazlarının ulaştırma sektöründe düşürülmesi amaçlanmaktadır.

Eko-Sürüş, daha ekonomik ve ekolojik sürüşü mümkün kılan uygulamaların bir bütünüdür. Eko-sürüşün operasyonel olarak temel kavramlarından birisi de sürücü davranışlarının yakıt tüketimi ve emisyonu azaltıcı şekilde düzenlemektir.

Bu tezde, kentsel ağdaki bir sürüş parkurunu taklit edici bir parkur dizayn edilerek ve emisyon modeli kullanılarak minimum düzeyde yakıt tüketimi ve emisyon elde edebilmek için burada hızlanma eğrilerinin etkileri değerlendirilmiştir.

Anahtar kelimeler: Eko - Sürüş, Hızlanma eğrileri, Sürücü davranışları

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List of Abbreviations

IPCC	**I**ntergovernmental **P**anel on **C**limate **C**hange
EPA	**E**nvironmental **P**rotection **A**gency
EEA	**E**uropean **E**nvironment **A**gency
ACS	**A**merican **C**hemistry **S**ociety

Chapter 1

Introduction

Any gas that traps heat inside and emits radiant energy within thermal infrared range is called as greenhouse gasses. These gasses are called as greenhouse gasses because they cause greenhouse effect. This effect could be defined as the processes which radiates from the atmosphere to increase Earth's surface. This effect is also critical for human life so the human activities that exist from mostly usage of fuels [1]. Greenhouse gasses is a main thread for global warming and there are several strategies that reducing GHG especially in developing countries.

Transportation has a remarkable impact on GHG emissions, especially in road transportation. It nearly manipulates whole transportation modes by itself and this problem is not based on vehicle types. Every type of fuel on road transportation has a contribution on GHG gasses. Eco - Driving, which is the one of the considered as significant operational mitigation strategy that aims to decrease individual emissions by changing acceleration pattern , avoiding unnecessary idling times [2]. In this project, Eco - Driving and its effects will be investigated and contributions about emission reductions will be analyzed.

1.1 Problem Definition and Background

In United States, a research conducted by Environmental Protection Agency (EPA) shows that, GHG emissions by sector comprised of 22% in industry,22%

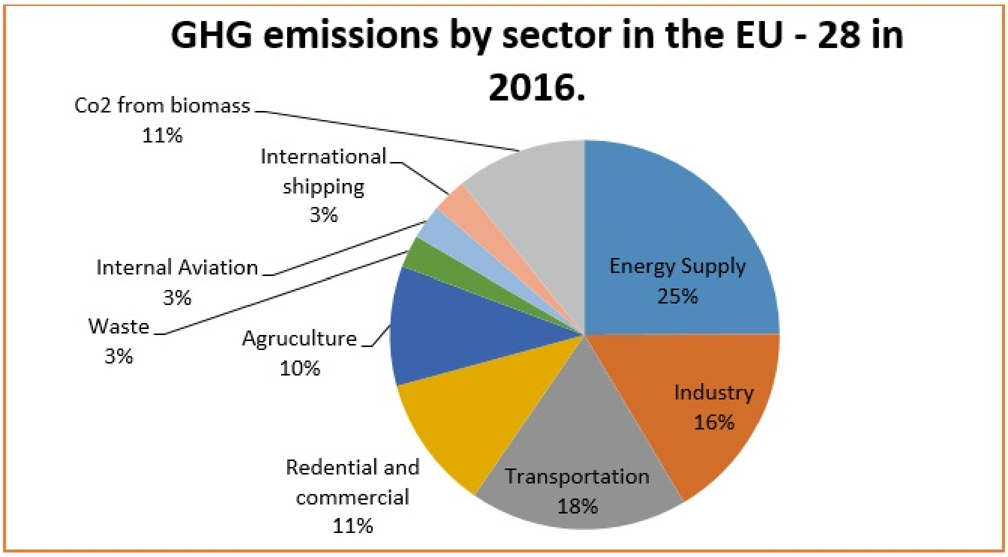


Figure 1.1: GHG emissions by sector in the EU-28 in 2016 [4].

in industry, 12% in commercial & residential 9% in agriculture sector respectively [3].

In Europe, Figure 1.1 demonstrates the data obtained from European Environment Agency (EEA) , equivalent percentage of GHG emissions by sector in 2016. As it is seen above, 25% of total emissions are emitted in energy supply, 18% of in transportation, 16% of in industry, 11% of used in both redential & commercial and CO2 from biomass, 10% in agriculture, and 3% each in international shipping, waste and internal aviation [4].

Both in Europe and United States, Transportation sector would be nominated as a main contributor in GHG.

Transportation sector comprised of any movement of people and goods by any using any mode. Transportation modes can be divided as 5 main categories which are road transport, maritime, aviation, railways. In this context, just to clarify the problem statement clearly, GHG share of transportation modes are used and demonstrated below.

Figure 1.2 demonstrates the share of modes of transportation sector according to their GHG share. From the figure, a 72.07% share of GHG's are constitute of in road transportation, 13.31% of it in aviation, 13.61% of in maritime, and both railways and other transportation has a share of 0.5% comparing to total. It can be seen that there is remarkable effect on road transportation in transportation sector with 72,07% of share [5].

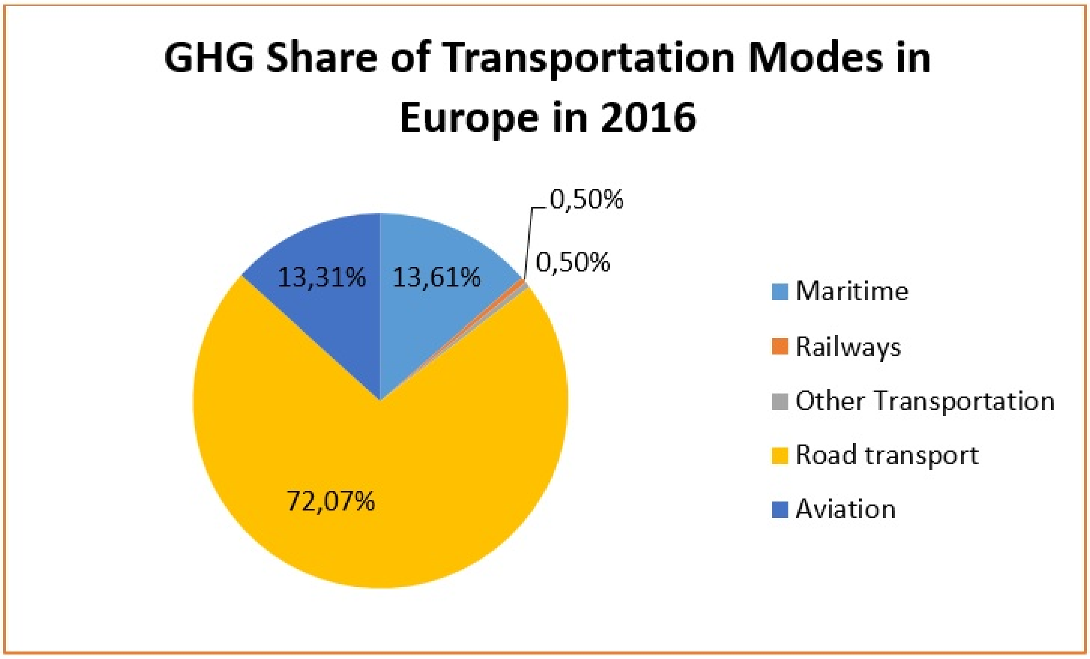


Figure 1.2: GHG Share of Transportation Modes in Europe in 2016 [5].

As a main contributor in transportation sector, it can be claimed that, road transportation nearly manipulates whole GHG share.

In order to investigate road transportation itself, data obtained from EEA used for demonstration. So in road transportation level, cars are mostly effecting the road transportation sector.

Figure 1.3 demonstrates the emission composition of road transportation. It can be seen from the figure that, Auto mobiles have the most contribution with a 61% of share, 26% of share by heavy duty trucks and buses, 12% of share by light duty trucks and 1% of share are constitute of motorcycles. From this figure, it can be said that, auto mobiles have the remarkable effect on greenhouse gas emissions [5].

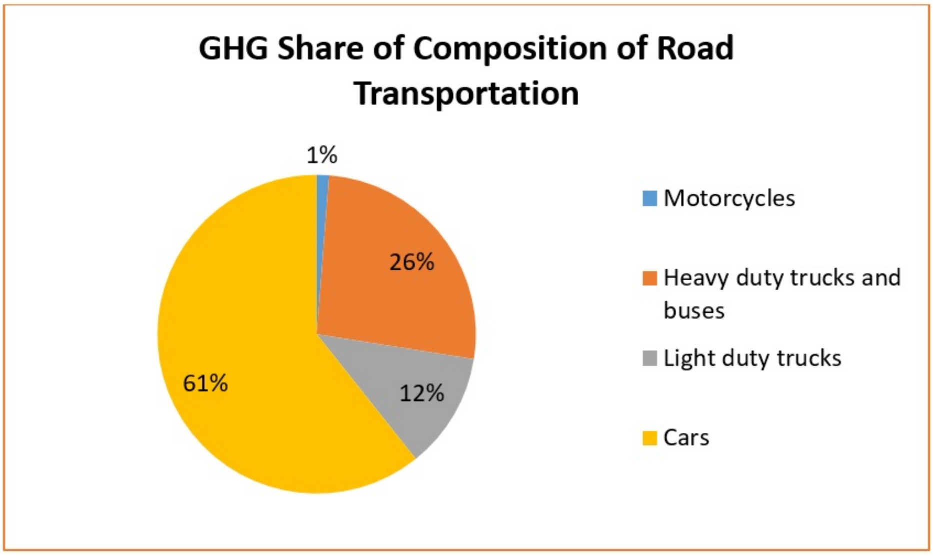


Figure 1.3: GHG Share of Composition of Road Transportation in 2016 [5].

Additionally, one of the main reasons that put us through to do this research, is demonstrated below. Turkey has a remarkable lead on emissions change between 1990 and 2016.

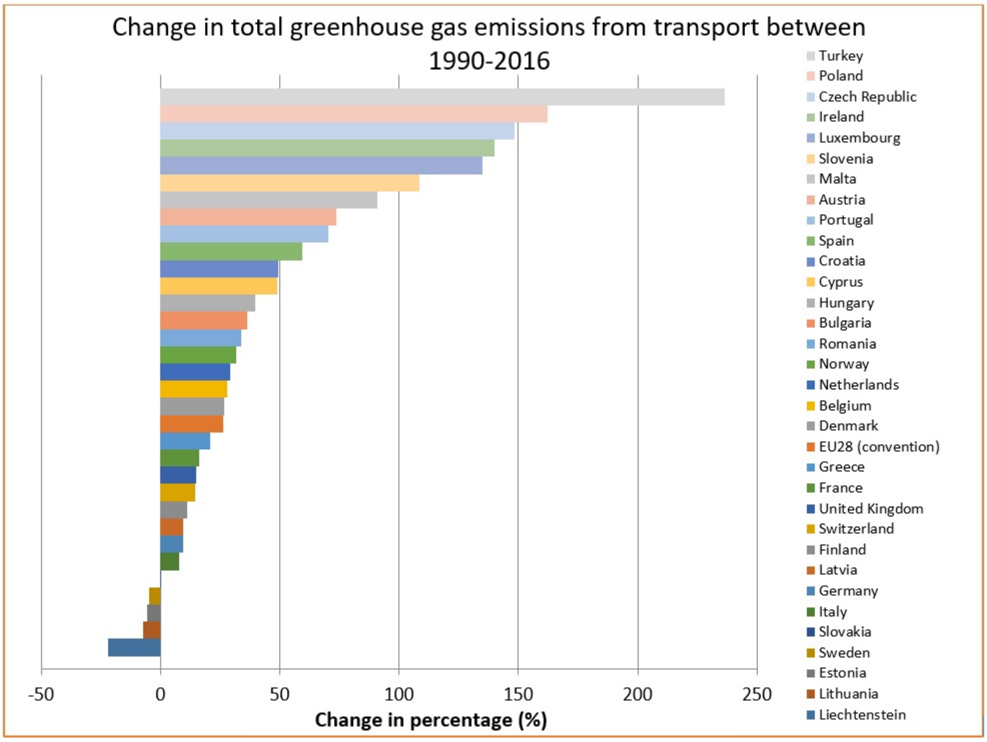


Figure 1.4: Change in total greenhouse gas emissions from transportation between 1996-2016 [4].

Figure 1.4 demonstrates the total change in greenhouse gas emissions from transportation in 1996 - 2016 years. It is seen that Turkey has a 236,6% change in emissions [4]. According to data, Turkey has a first place to total greenhose gas change in road transportation. In order to minimize the total GHG from transport sector, vehicle technologies and/or optimal driving schemes assesment programs can be implemented .

1.2 Thesis Statement and Hypothesis

Reports and figures in Chapter 1 states that, transportation sector has a lead contributor in greenhouse gas emissions in whole Europe and states the necessity of reduction in emissions in Turkey especially. As it is seen from the figures, road transport remarkably manipulates the total GHG emission by sector. In this context, from transportation point of view, the main thought is decreasing the emissions and fuel consumption in road transportation by introducing Eco - Driving which manipulates acceleration rates could decrease emissions in transportation sector itself, and even smaller individual fuel and emissions saves can reflect to remarkable changes in total emission release.

1.3 Objectives

Main goal of the thesis is, by implying different acceleration rates as mentioned in Eco - Driving concept in proposed driving – cycles, investigating and propounding best fit acceleration patterns for reducing emissions. On the other hand, while analysing emissions, travel time is also taken into an account for observing that there is a trade off or mutual relationship with emissions and travel time.

1.4 Summary of content

The remainder of project is planned as follows. In Chapter 2, environmental impacts of highway transportation is demonstrated. Emission mitigation strategies are explained, researches in the literature about Eco-Driving is gathered and demonstrated as a table. After that In Chapter 3 , referenced emission models are introduced and adaptation process to our project is explained. After that, by using driving – cycles and emission models combined, each driving cycle's total emissions will be derived for each vehicle type. At the results section, results are reviewed and discussed. At the discussion section, further researches and developments about this topic are mentioned.

Chapter 2

Literature Review

Road transport emission amount caused by many aspects. Review articles have separated these aspects into three groups as vehicle characteristics, driving behaviour and meteorological conditions [6].

In Turkey nearly all auto mobiles have internal combustion engines with a distribution of gasoline (26.6%), diesel (33.9%), LPG cars (39.1%) and others as (0.4%) respectively [7]. As it is mentioned, vehicle characteristics and meteorological conditions are also decisive parameters for observing the emissions. According to the turkish vehicle composition, light duty vehicles comprise of nearly 73% is in mini, small and lower medium segment. In this point of view, turkish vehicle compositions can be assumed as mostly composed of Renault Fluence and Fiat Linea vehicle models. Additionally, 95% of newly registered cars in Turkey below 1.6 liters or less [8].

Increasing strict and systematical regulations results in more fuel efficiency, less noise and safer road vehicles. Consequently, the average vehicle's age could be an indirect indicator of economical and ecological performance.In Turkey, the average age of total registered vehicles were 12 years old in 2004 and 13,1 in 2017 . In light duty vehicles, this value is ranging between 10 and 12,4 in 2004 and 2017 respectively. In EU-27 conventional , the average age of passenger cars was 7,4 years old in 2014. In according to vehicle average age, it can bee seen that there is a remarkable difference [9].

In this context vehicle characteristics are also important for emissions and calculations and vehicle composition tried to be demonstrated in detail. In literature review part, researches that indicates the reduction of emissions by changing driving behaviour and by considering vehicle characteristics grouping as Diesel, Petrol Car and LPG are reviewed.

2.1 Environmental Impacts of Highway Transportation

Records and figures demonstrates that, transportation has a remarkable impact on releasing GHG to the nature. So environmental impacts of highway transportation is directly related to impacts of GHG [10].

Greenhouse gasses can be thought as a blanket to the Earth that is not allowing heat to escape from Earth. So this effect leads to increase the temperature of Earth itself. This loop basically changes the radiative balance of Earth, hence climate and weather patterns changes at global scale [11].

As GHG continues the thicker this Earth blanket means hotter Earth Surface. This inequality will cause more warming so the climate change, including surface air and ocean temperatures, precipitation, drought, wildfires, diseases, from less efficient to the no agricultural productions, human health occasionally [12].

2.2 GHG Mitigation Strategies in Transportation

Price of fuel does not effect car owners to use their cars, so in transportation, regulations usually resulted as very expensive solutions on reducing GHG[13].As soon as transportation is a derived demand, reducing this demand directly seems impossible unless the source of transportation need is manipulated. In other words, demand has to be controlled in order to mitigate emissions in transportation.

The figure below demonstrates that; strategies are actually decrease vehicle emissions with same average speeds [14] . And this is only possible with more smooth traffic flow, so acceleration-deceleration rates .

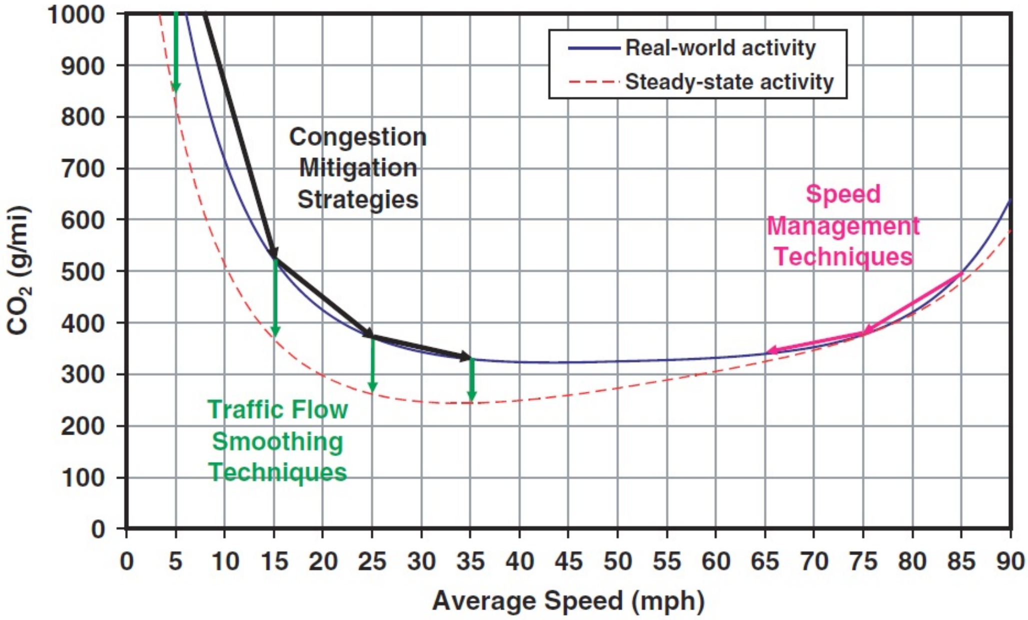


Figure 2.1: Impact of Operational Strategies on road CO_2 emissions [14].

GHG Mitigation Strategies can be categorized as public transportation incentives, Green transportation policies, Pricing and subsidies, Land Use, Parking management, Motor vehicle access and use, System operations and management, Roadway capacity, Vehicle energy efficiency and fuel switching [15].

Public Transportation Incentives : This strategy basically aims to support commuters to use public transportation instead private vehicles. Main idea is making public transportation a reasonable and viable choice by ensuring not to lose existing public transportation commuters. A scenario based about public transportation incentives demonstrates that ,14% of reductions on emissions are achievable by changing passenger modes only [16].A research about replacing private cars with public transport demonstrates that 10% of private car replacement with public transports can decrease 6% of fuel consumption and CO_2 [17].

Green transportation policies : This strategy offers non motorized commuting modes, and basically any policy that encourages people to choose commuting mode as by walking, biking etc ... to reduce the usage of motorized vehicles so the emissions.

Pricing and subsidies : Converting environmental impact into an economic value, and implying pricing strategy and determining the price according to environmental impact of individual commuter. With this strategy congestion could be decreased, network quality can be enhanced. Fuel taxes and congestion pricing can be given as an example for this mitigation strategy [18].

Fuel Taxes : Fuel taxation is a methodology for governments get a revenue from networks and their maintanence. If taxation system is used strategically, it may discourage commuters and changing their desicions to use alternative transportation modes.

Congestion pricing : Congestion pricing is a travel demand management strategy that mostly applied for reducing a highly demanded network. This can be thought as a road toll but main difference difference is road toll is mostly static price that increases when the demand increases, but congestion pricing is a thing that applied on a network dynamically to reduce traffic flow to shift the demand to less congested networks or event different transportation modes [18]. According to study conducted in London, there is 15.9% of reductions in London in charging zone, and 6.8% in inner ring roads[19]. Another study supports congestion pricing has remarkable impacts on reducing emisisons. A range from 0-12% and 0-3% of emissions reduction is obtained in congestion pricing, Additionally, by relying on scenearios between 10-30% of emissions can be reduced by supporting more efficinet use of networks by implying congestion pricing and indicates individual economic surplus [20].

Cordon pricing : Cordon pricing is an entrance fee that is required to enter a specified congested area

Land use strategies : This strategy basically aims to reduce congestion in a network by transforming areas more efficient land use areas. This strategy is a designation type that forces commuters to not to use auto mobiles or encourages commuters to use a planned commuting mode as walking, biking or public transportation.

Parking pricing and management : This strategy can have an important impact on congestion by allowing circulation and reducing stopping times.

Motor vehicle access and use : In this strategy, charging taxes and and implying penalties to car owners and rewarding situations for not owning car thought as a main idea. Car - sharing applications, harder licence plate procedures can be given as an example for this strategy. A study conducted about car sharing demonstrates a 252% of emissions efficiencies can be obtainable [21].

System Operations And Management: Reducing the emissions by any practice while operating the vehicle as avoiding unnecessary start-stops, avoiding sudden acceleration-decelerations, maintaining desired speeds are aimed in this strategy. Eco - Driving, which is the main topic of this thesis categorized under this strategy type.In literature there are several researches about related topic which will be demonstrated in Section 2.3.

Intelligent Transportation Systems : This system offers by using information technologies to come up with a solution in congested areas, staging commuters dynamically to optimize transportation network [22]. An ITS strategies may include, real time congestion, traveller information, showing incidents dynamically, dynamic signal timing, adaptive controlling, any dynamic directing techniques by steering commuters to reduce congestions.

Roadway capacity configuration : This strategy aims reduce congestion by expanding roadway capacities, removing bottlenecks.

Green vehicle energy efficiency and fuel switching : This strategy aims to reduce GHG emissions by changing fuel types to less-carbon intensive gasses from gasoline and diesel. With this option, reduced GHG emissions occur, this strategy could be expanded as rather than switching fuel types, source of energy of vehicles could be also changed to electric vehicles to reduce GHG emissions significantly.

2.3 Eco - Driving

There are various definitions in literature about Eco - Driving. According to one study, eco driving is explained with characteristics. Moderate acceleration, complying and maintaning steady speed and traffic flow, avoiding sudden start stops so the accelerations [2]. Another study conducted explains Eco - Driving as various driving techniques that reduces fuel consumption and emissions by thanging driver's behaviour [23]. (Kobayashi et. al) defines Eco - Driving as minimaztion of economic and environmental impact of fuel consumption [24]. (Beusan et. al) explains Eco- Driving as any polivies that reduces emissions on transportation by teaching drivers [25]. (Sivak et. al) defines the eco driving as any influencements and decisions made by a driver to reduce fuel economy in light duty vehicles [26] and seperates this decisions as strategic tactical and operational.

In strategic decisions, the main objective is reducing the fuel usage and emissions by satisfying the vehicle maintenances. In this type, making a decision of annual maintenances, tyre pressure, maintenance of emission control system is included.

Tactical decisions are the decisions that made during the trip. Selection of road type, selected road's grade profile and dealing with the congestion and the decisions which has to be made among the trip is named as tactical decisions.

Operational Decisions are decisions that while operating the vehicle. In this decision type, idling, acceleration-deceleration rate, speed, engine rpm, usage of vehicle utilities like air conditioner, cruise control etc. and aggressivity of driver [26].

There are several researches about Eco-Driving which relates about operational decisions, Table 2.1, Table 2.2 and Table 3.1 demonstrates the number of studies measuring the effect of eco-driving implications with two methodologies which are field trials and simulations respectively.

Table 2.1 and Table 2.2 covers experimental studies with a procedure of before and after eco-driving training by setting a control group the analyse impacts after training. In these kind of studies, output of the efficiency is nearly the same and ranging between 5% - 10%. On the other hand, Table 3.1 covers the simulation studies with a procedure of collecting data and implementation on traffic software or analytical experiments to obtain an output. In these kinds of studies, which is demonstrated in Table 3.1 , efficiency findings are also close to each other and ranging between 10% - 20%.

Our contribution to literature is, by using different trajectory optimization strategy, identifying the best fit acceleration pattern to reach a desired speed by using an instantaneous traffic emission model's function. In this respect, our analysis is closest to a methodology used by Barth (2011) [27].

Author	Modeling Approach	Results
Beusen et al. (2009) [25]	Monitoring the behaviours of drivers with an on board device before and after eco-driving training, and comparing the outputs.	5.8% reduction in fuel consumption.
Boriboonsomsin (2010) [28]	Investigating the impacts of on-board eco driving device that obtains the instantaneous emissions and providing feedbacks that affects driving behaviour.	6% of improvement in fuel economy in city streets, while 1% in highways.
Rutty et al. (2013) [29]	3 phase study was implied. At first phase, collecting a pre-training data by using a device that reads vehicle and fuel usage information of participants an, at second phase eco-driving training is given to participants, at last phase phase 1 is re-implied. At last phase 1 and phase 3 are compared.	Reduction of 1.7 kg of average CO2 emission per vehicle per day.
Vagg et al. (2013) [30]	Driving Assistance System were developed. Light commercial vehicle's selected and proposed system were installed. 4 weeks of trial which comprised of first 2 weeks as gathering baseline data without assisting the driver, and last 2 weeks were collecting the data with assistance system online.	Average reduction is 7.61% between 15 vehicles with the maximum reduction of 12.03%
Rolim et al. (2014) [31]	Control group and experimental group is identified in 20 participants which 9 of them were. experimental and 11 of them were controll group. At first period, 2-3 months of data collection duration for experimental and 10-15 days of duration for control group. After the first period, experimental group had recieved an eco driving training while controll group recieved none. Then second monitoring period is applied in both groups. And outputs are compared.	Experimental group : 4.8% reduction in l/100 km , 8% of reduction in NO_x, 6.56 grams of CO_2 is reduced in one kilometer. Control group: 0.2% reduction in l/100 km , 9% of reduction in NO_x, 0.12 grams of CO_2 is reduced in one kilometer.
Ho et al. (2015) [32]	By collecting data from 116 participants from 2 different cycles which the first one is before training cycle and the second is after eco-driving training cycle.	10% reduction of after training immediately. It is mentioned that related value can be vary between 16%-12%.

Table 2.1: Eco Driving with a Field Trial Methodology in Literature.

Author	Modeling Approach	Results
Ozatay et al. (2014) [33]	By proposing an algorithm that obtains the optimal velocity profile that minimizes fuel consumption for highway and urban ares then applying this velocity profiles in real life driving trials then comparing with natural driving.	12.6 % of fuel economy in highway, 7.4 % of fuel economy in urban driving conditions.
He et al (2015) [34]	Proposing an advisory velocity projection in a signalized arterial. Comparing this projection with selected standart driving behaviour.	9% of travel time increase for 29% of fuel consumption efficiency and this relates as 41% of fuel economic efficiency calculated.
Schall et al.(2016) [35]	By creating 91 drivers into 2 groups which 1/3 of them is control group to see the changes between training and non training drivers.	No change is observed.
Barla et al. (2017) [36]	By creating 59 driver into 2 groups which 41 of them is eco-driving trained group and the rest is control group	4.6% of fuel consumption reduction in city and 2.9% is in highway.
Tatjana et al. (2019) [37]	Bus Drivers that have eco-driving training has been conducted to a test in real world driving conditions with a route length of 14 km.	Reduction of 8.61% on average on both fuel consumption and CO_2 emissions on busses.
Louis et al. (2019) [38]	By using the trials of real world data, determining the influencements on eco-driving.	After the driver training course, 7% of reduction in fuel consumption is observed.

Table 2.2: Eco Driving with a Field Trial Methodology in Literature -2.

Author	Modeling Approach	Results
Kobayashi (2007) [24]	Obtaining the traditional driver pattern and eco-driving pattern individually. Then by creating an algoritm, evaluating the eco-driving efficiencies in whole network created in VISSIM,PTV for 3 scenearios as full eco, full normal and 50% eco distribution.	Normal : 4729.49 grams of CO_2 per hour, 15.26 grams of NOx per hour Eco-driving : 4681.83 grams of CO_2 per hour, 15.09 grams of NO_x per hour. 50% eco-driving : 4680.26 grams of CO_2 per hour, 15.09 grams of NO_x per hour.
Barth (2009) [23]	Eco-Driving Assistance instanteneously have been proposed. Simulations are took place with PARAMICS and CMEM in different level of services. Comparison of traditional driving and eco-adviced have been done. Field experiments have implemented in order to validate the results.	10-20% reduction of CO_2 consumption in simulation, slightly smaller degrees of efficiencies have observed in field experiments.
Barth (2011) [27]	Eco-driving speed planning algorithm has been proposed. Simulations have designed for different sceneraios which all include signalization. Comparison have been done with and without speed planning algorithm.	Averagely, 12.3% Fuel efficiency, 14.1% CO2 and 1.06% travel time efficiency have been acquired.
Qian (2011) [39]	Real-Time traffic data is gathered in specific intersection. Intersection is modeled in Aimsun and real-time data is implied. For different demand scenarios at the intersection, proposed eco-driving techniques were adopted and implied in simulation.	Smooth accelerations on normal traffic condition leads 11% of fuel saving with a 3% of increased travel time.

Table 2.3: Eco Driving with a Simulation Methodology in Literature.

Chapter 3

Methodology

As it is explained in Thesis Statement and Hypothesis and Objectives part in Chapter 1, our aim is by implying different acceleration rates in proposed driving - cycle which satisfies daily urban road network conditions, determining a best fit acceleration trajectories which gives the most efficient emissions output. In order to perform this hypothesis, it is required an emission model , driving cycle and eco - driving practices which will be demonstrated as aggressiveness in acceleration rate's steepness.

3.1 Emission Model

Emission models are methods that calculates or measures the pollutants which is released to the air from vehicle. Emission model's can be created by using different approaches in order to fit the scope of calculation.Review articles have covered emission models into three gropus as emission factor models, average speed models and modal models [40].

Emission Factor Models : Emission factor is a representative value that calculated with a simple set of input data. These emissions factors are derived from a mean values from a repeatedly done measurements. These types of models are used in more general requirements like deriving regional networks or national emission inventories and these kind of models are not fit to use in microscale [41].

Average Speed Models : Average Speed Models are based on speed related measurements of the different speed levels in different trips. These models are often used in road network scale. In these models, operational changes does not include so it is not recommended in microscale use [42].

Modal Emission Models: There are several types of modal emissions models in literature. Modal emission models are more complex than other methods reviewed. In this emission models, characteristics like acceleration/deceleration or idling during the road tip can be analysed instantaneously in microscopic level. This kind of models are dependent into a function which is obtained from regression methodology which is implied on repetitive emission measurements. In these kinds of models, different velocity and acceleration values could provide a more reliable outputs than average speed or emission models. Second – by – second emission or fuel consumption output can be obtained in this emission models [43].

But in this approach, other tactical decisions cannot be taken into account like road grade, use of accessories like air conditioner etc. In order to overcome this challenge, engine load and speed related emission functions could be derived in order to acquire other parameters [40].

There are several researches on emissions modelling based on modal emission model approach. In this thesis, an emission model that uses instantaneous acceleration and speed value of different vehicles types is required. In this case Panis et al. [44] proposed a microscopic emission model that calculates CO_2, NO_x, VOC, $PM_{2.5}$ instantaneously.

In this context, emissions of road transport vehicles are calculated with respect to the fuel type, acceleration-deceleration rate and speed by using experimental equations modified from the studies of Panis et al [44].

In order to explain referred emission modelling in detail, table below demonstrates the general emission function and regression coefficients.

Emissions	Vehicle type	f1	f2	f3	f4	f5	f6
CO_2	Petrol Car	5,53E-01	1,61E-01	-0,03E-01	2,66E-01	5,11E-01	1,83E-01
CO_2	Diesel Car	3,24E-1	0,86E-1	-0,05E-01	0,59E-01	4,49E-01	2,30E-01
CO_2	LPG Car	6,00E-01	2,19E-01	0,08E-05	3,56E-01	5,14E-01	1,70E-01
NO_x	P.Car (a$\geq 0,5$)	6,19E-04	8,00E-05	-4,03E-06	4,13E-04	3,80E-04	1,77E-04
NO_x	P.Car (a<0,5)	2,17E-04	0	0	0	0	0
NO_x	D.Car (a$\geq 0,5$)	2,41E-03	-4,11E-04	6,73E-05	-3,07E-03	2,14E-03	1,50E-03
NO_x	D.Car (a<0,5)	1,68E-03	-6,62E-05	9,00E-06	2,50E-04	2,91E-04	1,20E-04
NO_x	LPG Car (a$\geq 0,5$)	8,92E-04	1,61E-05	-8,06E-07	-8,23E-05	7,60E-05	3,54E-05
NO_x	LPG Car (a$\geq 0,5$)	3,43E-04	0	0	0	0	0
VOC	P.Car (a$\geq 0,5$)	4,47E-03	7,32E-07	-2,87E-08	-3,41E-06	4,94E-06	1,66E-06
VOC	P.Car (a<0,5)	2,63E-03	0	0	0	0	0
VOC	D.Car (a$\geq 0,5$)	9,22E-05	9,09E-06	-2,29E-07	-2,20E-05	1,69E-05	3,75E-06
VOC	D.Car (a<0,5)	5,25E-05	7,22E-06	-1,87E-07	0	-1,02E-05	-4,22E-06
VOC	LPG Car (a$\geq 0,5$)	1,44E-02	1,74E-07	-6,82E-09	-8,11E-07	1,18E-06	3,96E-07
VOC	D.Car (a<0,5)	8,42E-03	0	0	0	0	0
PM	Petrol Car	0	1,57E-05	-9,21E-07	0	3,75E-05	1,89E-05
PM	Diesel Car	0	3,13E-04	-1,84E-05	0	7,50E-04	3,78E-04
PM	LPG Car	0	1,57E-05	-9,21E-07	0	3,75E-05	1,89E-05

Table 3.1: Emission Model Coefficients for each pollutant.

$$E_n(t) = max[E_0, f_1 + f_2 v_n(t) + f_3 v_n(t)^2 + f_4 a_n(t) + f_5 a_n(t)^2 + f_6 a_n v_n(t)] \quad (3.1)$$

where E_0 is minimum emission value g/s, f1 - f2 - f3 - f4 - f5 - f6 is referred regression coefficients, v_n(t)(m/s) is instantaneous velocity of vehicle and a_n(t) is instantaneous acceleration of vehicle.

For more information, please check Panis et al. (Modelling instantaneous traffic emission and the influence of traffic speed limits.)

3.2 Driving Cycles

After modal emission model is obtained, investigation of eco-driving efficiency became possible. This investigation could be pursued by doing field trials to obtain speed-time graph based on real world data, or the other option is, by using driving cycles as an input to our referenced emission simulation model, changes in instantaneous speed in time could be reflected as an driving behaviour and this manipulated speed-time changes will be resulted as different emission outputs. In the end, it will be possible to analyse the impact of driver's behaviour to the emission outputs.

Driving cycles are series of data that demonstrates vehicle's speed over time. These cycles are used and differentiated for each designed scenario to calculate emissions fuel consumption or vehicle simulations [45].

There are different driving introduced cycles for different scenarios for different regions listed below.

ECE 15 : ECE 15 is a driving cycle for obtaining the emissions of a vehicle which mimics the typical usage of a driver in Europe. It is an urban driving cycle as known as UDC designed for mimic the urban driving conditions. Cycle is demonstrated below.

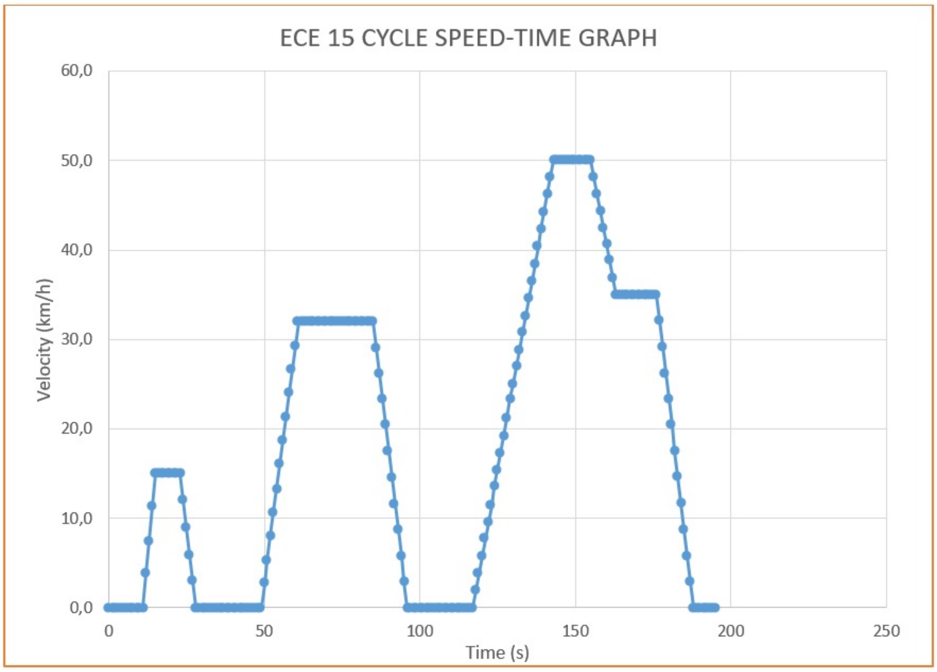


Figure 3.1: ECE - 15 Driving Cycle.

EUDC : Extra Urban Driving Cycle is created for aggressive and high speed driving cycles which is created for highways Cycle is demonstared below.

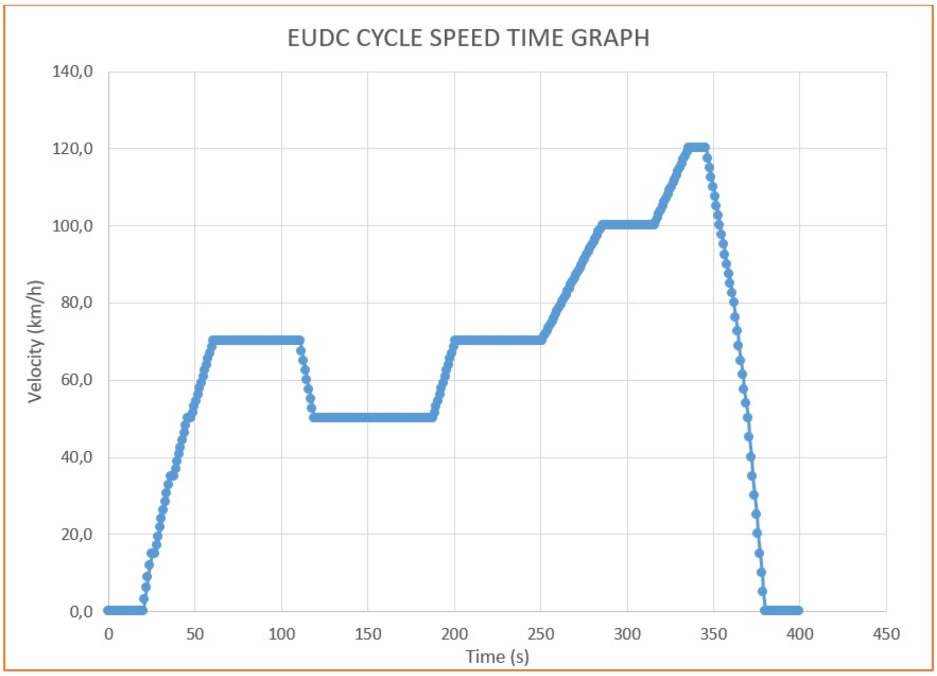


Figure 3.2: EUDC Driving Cycle.

NEDC : It is an alternative cycle of EUDC which created for low powered vehicles with an maximum speed limited to 90 km/h. Cycle is demonstrated below.

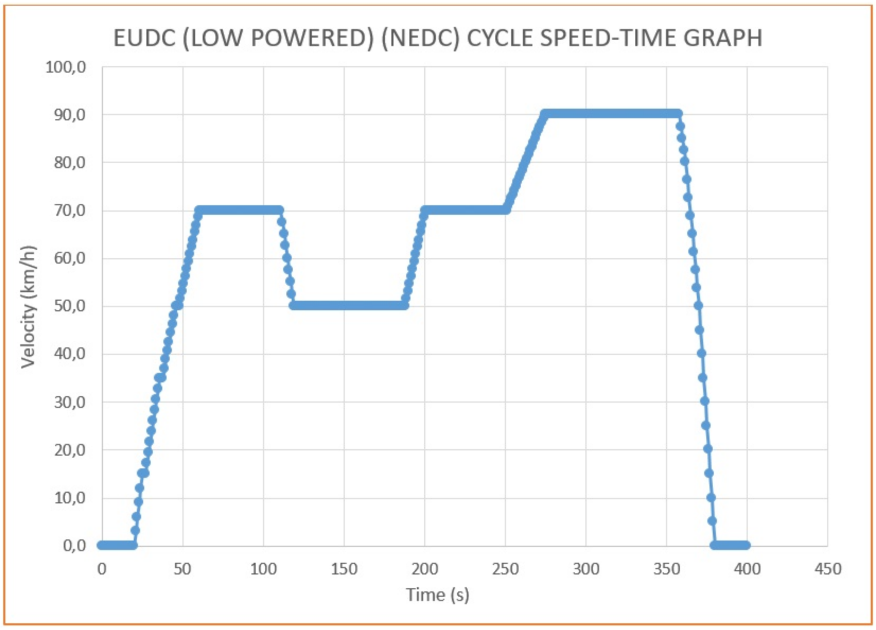


Figure 3.3: NEDC Driving Cycle.

In United States, there are different driving cycles that differentiated for every different conditions listed below.

FTP – 75 : Federal Test Procedure cycle is used for light duty vehicles to obtain their emission level. It consist of 3 different phases as cold start, stabilized phase and hot soak. It is converted to km/h, originally driving cycle is in mile/h. Cycle is demonstrated below.

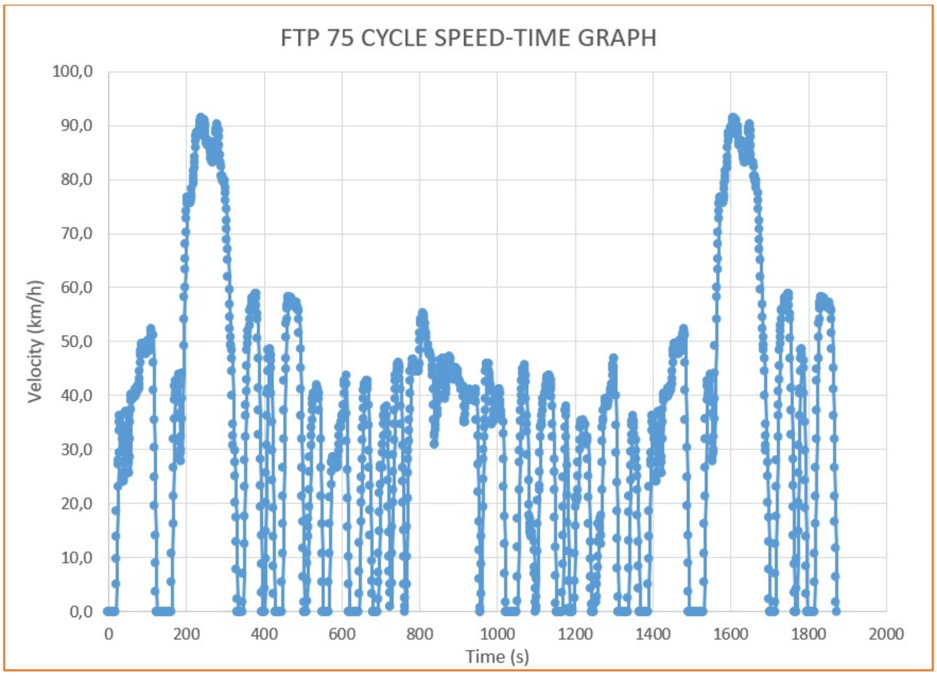


Figure 3.4: FTP - 75 Driving Cycle.

NYCC : New York City Cycle is created for light duty vehicles to mimics urban driving with low speeds and frequent start-stops. Cycle is demonstrated below.

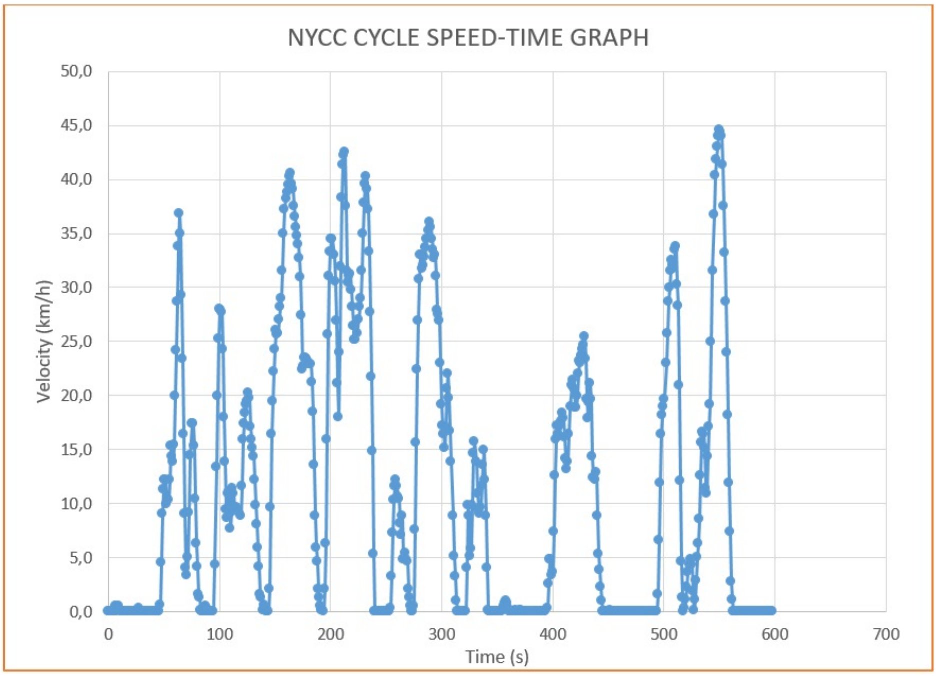


Figure 3.5: NYCC Driving Cycle.

IM 240 : This cycle is developed and recommended for emission tests for light duty vehicles in inspection and maintenance programs.

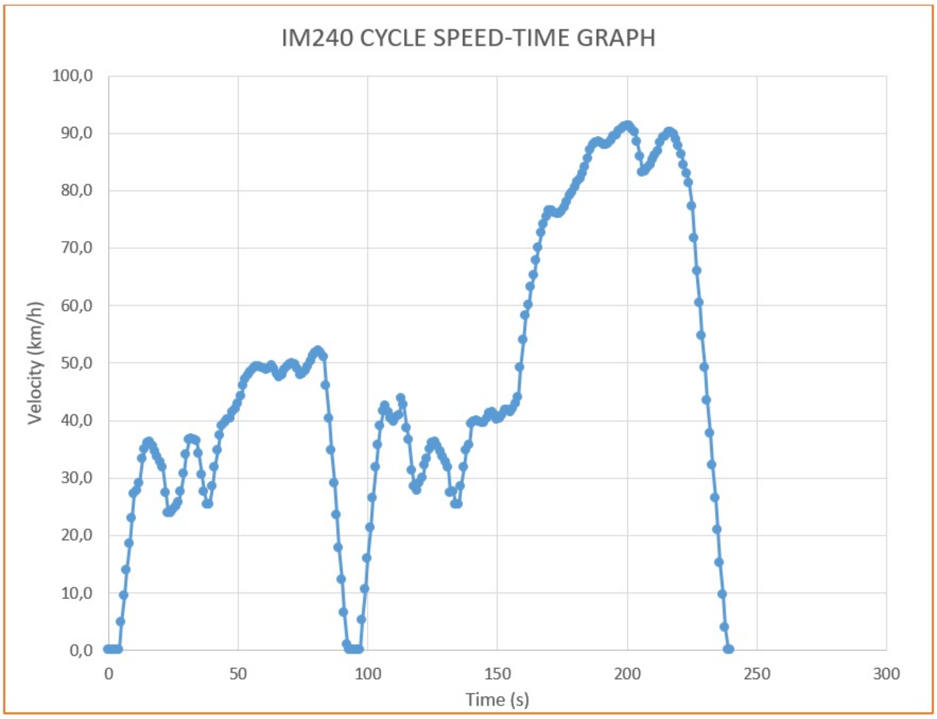


Figure 3.6: IM240 Driving Cycle

In Japan, there are also driving cycles that used for emission and fuel economy determination for light duty vehicles.

Japanese 10 Mode : This cycle is used in emission testing and certifications for light duty vehicles. This cycle basically simulates urban driving conditions. This is a repetitive cycle that repeats itself six times to obtain emissions. Lately this cycle is replaced by 10-15 driving cycle.

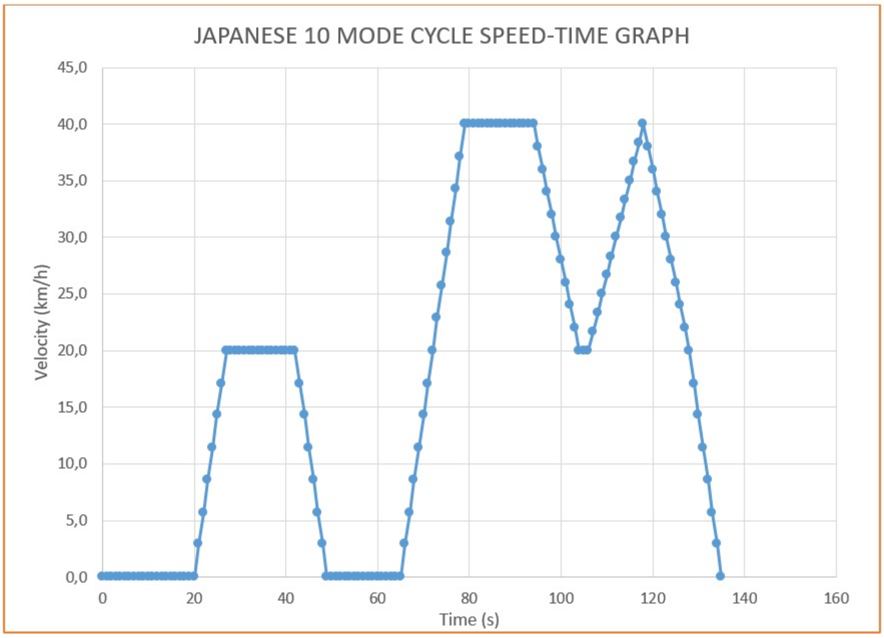


Figure 3.7: Japanese 10 Mode Driving Cycle.

Japanese 10 – 15 Mode : This cycle is a replacement for 10 mode cycle which is again used for emission and fuel consumption tests for light duty vehicles. In demonstration, only 15 mode part is demonstrated. Originally after 3 repetitions of 10 mode, one 15 mode is added and emissions are calculating in mixed 10-15 mode.

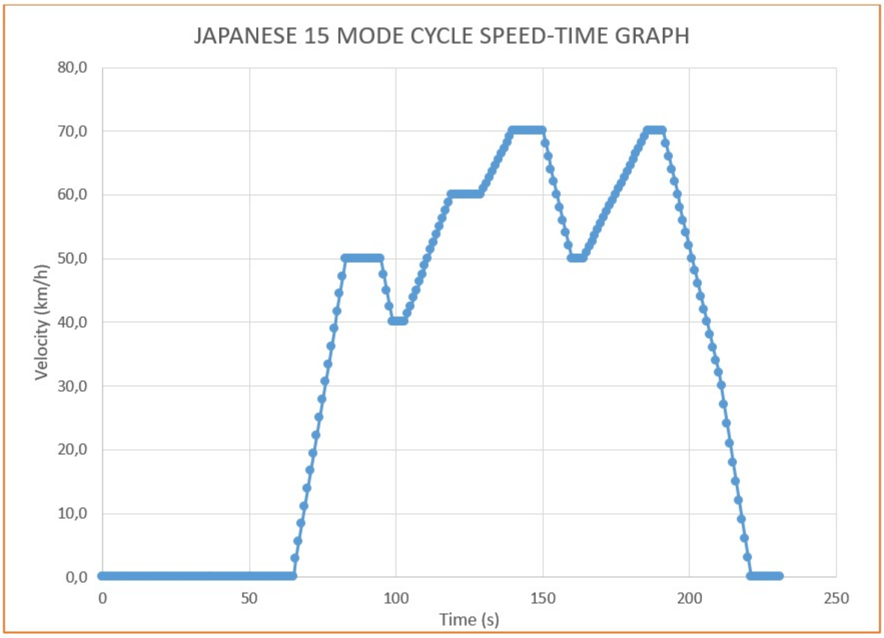


Figure 3.8: Japanese 15 Mode Driving Cycle.

3.2.1 Derivation of Customized Driving Cycle

In Section 3.2 , driving cycles that already created for modelling are proposed. Each driving cycle will be investigated and emission outputs will be noted in Results. Beyond that, there are not such driving cycle that mimics urban roadway that has signalization and and slowing on the junction and has a speed limit of 70 km/h. Proposed driving cycle will include speed limit of 70 km/h, signalization and imaginary junction for deceleration in urban roadway. This kind of driving cycle design will mimic the standard driving curve in urban roadway and will be used as a parkour in analysis.

The figure below demonstrates the proposed driving cycle.

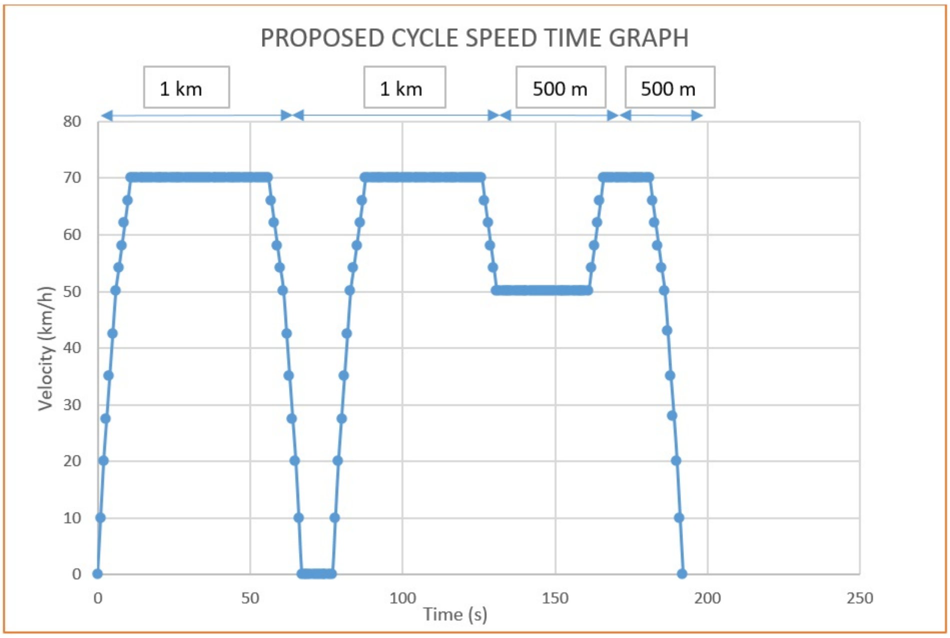


Figure 3.9: Proposed Driving Cycle.

3.3 Field Measurements

In this section, in according to analyse the impact of acceleration patterns on an operational eco - driving, base scenario has to be obtained. We conducted our measurements on Kartal - Kadıköy coastal road. Here we took 1 hour recording in order to obtain standart acceleration pattern for a section of road. We intentionally decided Kartal - Kadıköy coastal road because, it has signalization, similar to urban road, there were no traffic so interaction of vehicles each other is negligible, has a speed limit of 70 km/h and has a pedestrian crossing which forces vehicles to reduce their speed. We measured and seperated the road into every 35 meters and marked it. After we recorded road which is seperated and marked in every 35 meters. Recording was able to give us the second by second motion so we were able to calculate the total time elapsed when the vehicle passed every 35 meters. So we were able to determine the speed pattern from 0 to 70 km/h. A screenshot is shared from the recording.

Figure 3.10: A screenshot from Field Measurements.

Streetlights are placed in every 35 meters so, it is derivable the perception of distance from the video. But there was a critical problem that leads our measurement biased. Commuters were slowing down after he sees the recording camera and sudden decelerations are observed. There was no place to hide the camera so we were forced to change the measuring methodology.

Our second field measurement methodology was measuring the time inside the vehicle. We were able to see the vehicle speed instantaneously so we recorded time every 10 km/h increment in same road. In this way we obtain the time elapsed for each 0-10-20-30-40-50-60-70 km/h and linear accelerations assumed in every partial speed interval. In order to give an example, it is averagely recorded that 1 second is elapsed when the vehicle reach 10 km/h from 0 km/h. This way linear 10 km/h/s is assumed in 0-10 km/h interval and our acceleration trajectories consists of combination of different linear accelerations in every speed interval. Averagely, 1 second is elapsed from 0 to 10 km/h, 1 second is elapsed 10 to 20 km/h, 1 second is elapsed 20 to 30 km/h, 1.5 seconds are elapsed 30 to 40 km/h, 1.5 seconds are elapsed 40 to 50 km/h, 2 seconds are elapsed 50 to 60 km/h and 2 seconds are elapsed 60-70 km/h. The figure below demonstrates the average velocity pattern to reach 70 km/h.

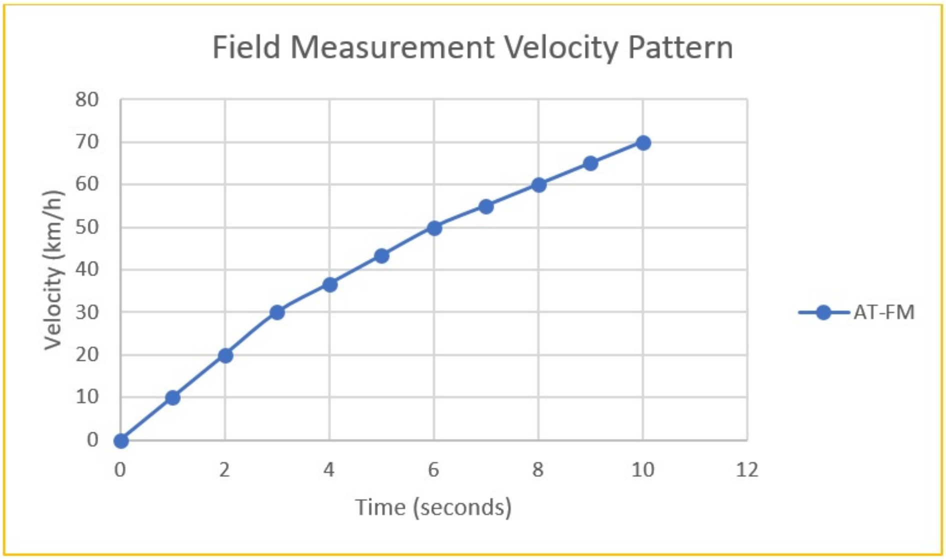


Figure 3.11: Field Measurement Velocity Pattern.

The figure above is used as test bed to our comparison for different velocity patterns.

3.4 Experimental Design

Lastly in methodology section, after driving cycles and emission models are obtained, it is required to combine them in order to calculate total emission output for each mentioned driving cycles. In order to do that, it is required an experimental design to do so. Experimental design is proposed as follows.

1. Implementation of Emission Modeling,
2. Designing and Calculation of Cumulative Emission Output,
3. Implementation of Driving Cycles,
4. Derivation of Acceleration Curves,
5. Obtaining Total Emission outputs,

3.4.1 Implementation of Emission Modeling

In this section, referred modal emission model is implemented as it is proposed at [44]. Emission function is implemented on Excel for each pollutant and vehicle type. By implementing proposed emission model directly, it is possible to acquire instantaneous emission outputs as in grams per second. But, in order to conduct our proposition, it is required a total emission output from implemented cycle. In order to achieve total emission outputs, it is required configurations which will be explained in the next section.

3.4.2 Designing and Calculation of Cumulative Emission Output

As it is mentioned in previous chapter, total emission outputs is required in order to obtain the total emissions after a cycle is driven. In order to overcome this challenge, distance, cumulative distance, and cumulative emissions for each pollutants as a parameter are defined in proposed emission model.

$$E_{total}(t) = \sum_{t=0}^{t-1} E_{initial}(t) \tag{3.2}$$

In Eq. (3.2), total emission outputs will become available, as soon as proposed emission modeling gives the emission outputs as grams per second. Instantaneous values for each seconds can be summed and thus, total emission outputs at time t can be derivable.

The other challenge was availability of travelled distance after releasing emissions. In referred emission model, relationship of distance travelled with emission output was not available. It is enhanced and distance parameters are added by using motion formulas.

$$X_{initial}(t) = V_{initial}(t-1) * (1s) + (1/2 * a_{initial}(t-1) * (1s)^2) \qquad (3.3)$$

In Eq. (3.3) where $X_{initial}(t)$ is distance travelled after at time t, $V_{initial}(t-1)$ is velocity of vehicle at time $(t-1)$, and $a_{initial}(t-1)$ is acceleration of vehicle at time $(t-1)$, initial distance travelled at time t can be calculated.

For last challenge, derivation of total distance travelled has to be obtained. In order to do it, initial distance travelled for each second can be summed up in order to get total distance travelled.

$$X_{total}(t) = \sum_{t=(t-1)}^{t} X_{initial}(t) \qquad (3.4)$$

In Eq. (3.3) total distance travelled at time t will be equal to initial distance travelled between time t and $(t-1)$.

3.4.3 Implementation of Driving Cycles

After enhancing instantaneous emission model with the proposed equations, it is available to obtain total distance travelled, total emission output for each pollutants with respect to instantaneous velocity and acceleration at time t. After these configurations and enhancements, it will be possible to obtain total emission outputs for any speed and time value. As it is explained in Section 3.2, driving cycles are datasets which consist of speed over time.

It is required to derive an acceleration value at time t. By using motion formula again, it can be derived as follows.

$$a_{initial}(t) = V_{initial}(t) - V_{initial}(t-1)/(t-(t-1)) \tag{3.5}$$

where $a_{initial}(t)$ is initial acceleration at time t, $V_{initial}(t)$ is velocity at time t, t is time in seconds.

The figure below demonstrates the enhanced and modified emision model.

3.4.4 Simulations with Different Acceleration Trajectories

After deriving customized driving cycle, different acceleration trajectories will be executed and outputs will be investigated in order to find the most efficient curve that reduces emissions and travel time. From the emission function, infinitely many solutions can be derived. In this thesis, linear accelerations and random acceleration trajectories which estimated as most possible acceleration patterns in field. And this curves will be compared with the actual acceleration curves which is measured on site. Mentioned linear acceleration curves and acceleration trajectories will be demonstrated in Chapter 4

3.4.5 Obtaining Total Emission outputs

As a last part, by implying driving cycles as a route, which is only a dataset of speed over time, it is now possible to obtain total emission output and total distance travelled for each driving cycle implemented. Additionally it is effective to bound total emission outputs to an index of 1 km of distance travelled in order to obtain effectiveness of driving cycle pattern.

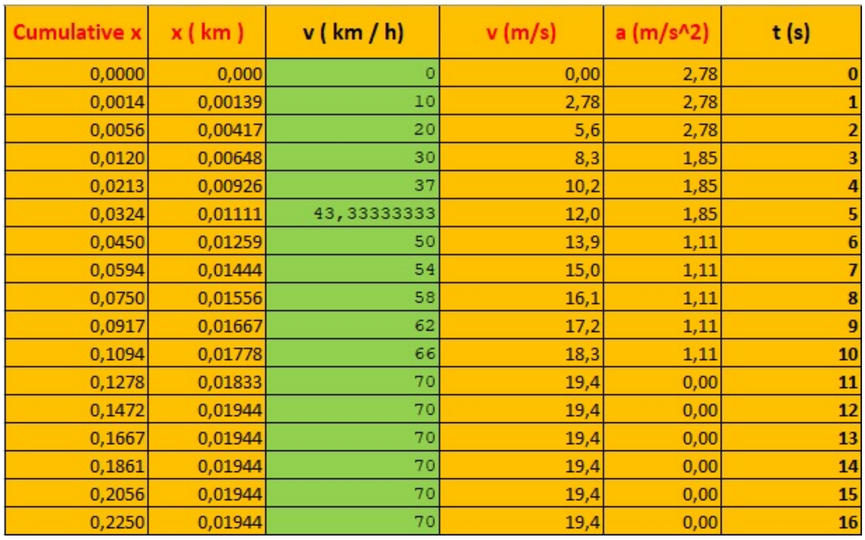
$$E_{index} = E_{total}(t)/X_{total}(t) \tag{3.6}$$

In Eq. 3.5 is used in order to obtain emission outputs as a unit of g/km for each pollutant modelled.

3.5 Sample Emission Calculation

In this section, as it is proposed in experimental design, a sample calculation process which is designed in Microsoft Excel in parts as distance calculations process and emission calculation process is demonstrated as a figure below.

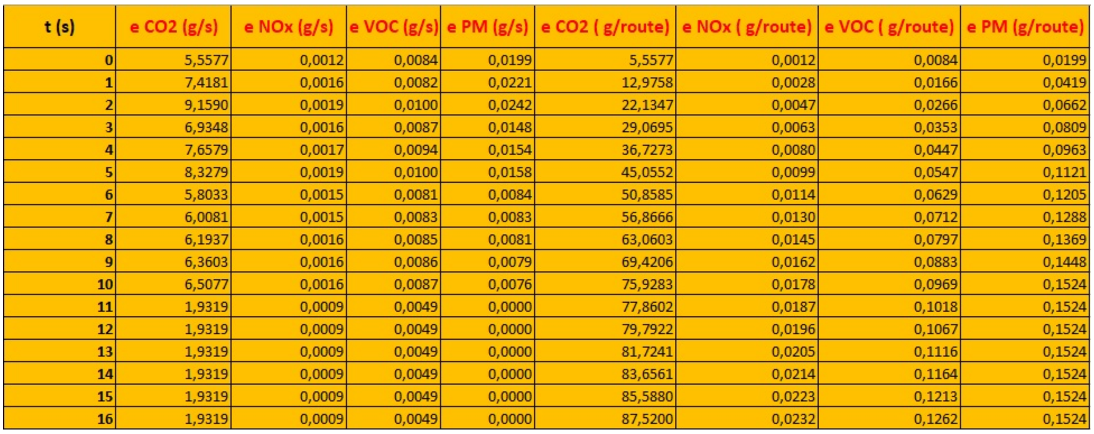
In figure 3.12, calculation process can be seen below. In this figure Cumulative x , demonstrates the total distance travelled in each second cumulatively, x (km) demonstrates the distance travelled in each second. v (km/h) is our input parameter to the model that demonstrates the vehicle in each second defined in t (s) column. v (m/s) is velocity value which is used in emission model converted from km/h value and a is the acceleration parameter derived between each second by calculating total velocity change in each second. This way we were able to calculate the total distance travelled and elapsed time in each second instantaneously and cumulatively at the same time. From the sample below, it can be easily derived that vehicle's acceleration pattern and total distance travelled with respect to velocity input.



Cumulative x	x (km)	v (km / h)	v (m/s)	a (m/s^2)	t (s)
0,0000	0,000	0	0,00	2,78	0
0,0014	0,00139	10	2,78	2,78	1
0,0056	0,00417	20	5,6	2,78	2
0,0120	0,00648	30	8,3	1,85	3
0,0213	0,00926	37	10,2	1,85	4
0,0324	0,01111	43,33333333	12,0	1,85	5
0,0450	0,01259	50	13,9	1,11	6
0,0594	0,01444	54	15,0	1,11	7
0,0750	0,01556	58	16,1	1,11	8
0,0917	0,01667	62	17,2	1,11	9
0,1094	0,01778	66	18,3	1,11	10
0,1278	0,01833	70	19,4	0,00	11
0,1472	0,01944	70	19,4	0,00	12
0,1667	0,01944	70	19,4	0,00	13
0,1861	0,01944	70	19,4	0,00	14
0,2056	0,01944	70	19,4	0,00	15
0,2250	0,01944	70	19,4	0,00	16

Figure 3.12: Distance Calculation Process.

Secondly, in figure 3.13 implemented emission mode can be seen below. In this figure, instantaneous and total emissions in each selected pollutants according to implemented velocity pattern is demonstrated. In our referenced model, it was only available to obtain instantaneous emission data in grams per second and we just enhanced it by adding cumulative monitoring part to obtain total emissions with a given velocity pattern. Gram/second data of pollutants are calculated by using emission model which is explained in Emission Model section. Cumulative part, which is demonstrated as g/route columns is nothing by adding each seconds pollutants cumulatively. From the example below, combining figure 3.12 and 3.13 it can be derived that, 87,520 grams of CO_2, 0,0232 grams of NO_x, 0,1262 grams of VOC and 0,1524 grams of PM is emitted by travelling 0,2250 kilometer in 16 seconds with an implemented velocity pattern for LPG cars which is also modeled in excel to determine the which coefficients will be take place explained in Section 3.1.



t (s)	e CO2 (g/s)	e NOx (g/s)	e VOC (g/s)	e PM (g/s)	e CO2 (g/route)	e NOx (g/route)	e VOC (g/route)	e PM (g/route)
0	5,5577	0,0012	0,0084	0,0199	5,5577	0,0012	0,0084	0,0199
1	7,4181	0,0016	0,0082	0,0221	12,9758	0,0028	0,0166	0,0419
2	9,1590	0,0019	0,0100	0,0242	22,1347	0,0047	0,0266	0,0662
3	6,9348	0,0016	0,0087	0,0148	29,0695	0,0063	0,0353	0,0809
4	7,6579	0,0017	0,0094	0,0154	36,7273	0,0080	0,0447	0,0963
5	8,3279	0,0019	0,0100	0,0158	45,0552	0,0099	0,0547	0,1121
6	5,8033	0,0015	0,0081	0,0084	50,8585	0,0114	0,0629	0,1205
7	6,0081	0,0015	0,0083	0,0083	56,8666	0,0130	0,0712	0,1288
8	6,1937	0,0016	0,0085	0,0081	63,0603	0,0145	0,0797	0,1369
9	6,3603	0,0016	0,0086	0,0079	69,4206	0,0162	0,0883	0,1448
10	6,5077	0,0016	0,0087	0,0076	75,9283	0,0178	0,0969	0,1524
11	1,9319	0,0009	0,0049	0,0000	77,8602	0,0187	0,1018	0,1524
12	1,9319	0,0009	0,0049	0,0000	79,7922	0,0196	0,1067	0,1524
13	1,9319	0,0009	0,0049	0,0000	81,7241	0,0205	0,1116	0,1524
14	1,9319	0,0009	0,0049	0,0000	83,6561	0,0214	0,1164	0,1524
15	1,9319	0,0009	0,0049	0,0000	85,5880	0,0223	0,1213	0,1524
16	1,9319	0,0009	0,0049	0,0000	87,5200	0,0232	0,1262	0,1524

Figure 3.13: Emission Calculation Process.

Chapter 4

Analysis and Results

In chapter 4, proposed experimental design will be executed on driving cycles which is explained in Section 3.2. Evaluation of acceleration characteristics will be available and investigation of eco - driving efficiency will become possible. Simulation based results will be derived and at the end test bed will be chosen by relying on a field measurements.

Field measurements held on a coastal road that has signalization and has a pedestrian crossing in order to reduce vehicle velocity at the middle of the cycle and has a speed limit of 70 km/h. In according to one hour recording after a signalized area on a left line, average acceleration curve is measured as AT(10) . This acceleration trajectories will be explained in Section 4.2.2.

After obtaining outputs for each proposed acceleration patterns, by relying on field measurements as a test bed, comparisons will be held on and evaluation of acceleration patterns on operational eco driving will be precisely compared and efficiencies and trade offs will be demonstrated.

4.1 Analysis of Driving Cycles

Selected cycles are used as the test bed. The driving behaviour is altered by changing acceleration in order to find the minimum emission output.As a second analysis, different acceleration characteristics are assumed as the representing driving behaviour therefore driving behaviour changes yields in the change of emission output.

The table below demonstrates the, total distance travelled, output of total emissions released on air during the trip, and index values of emissions respectively for each vehicle type.

Petrol Car	Length	E_{CO_2}	E_{NO_x}	E_{VOC}	E_{PM}	I_{CO_2}	I_{NO_x}	I_{VOC}	I_{PM}
EUDC	6,609	945,926	0,311	1,708	0,010	143,125	0,047	0,258	0,002
IM240	3,152	569,807	0,261	1,000	0,018	180,782	0,083	0,317	0,006
JAP15	2,174	399,265	0,202	0,948	0,009	183,680	0,093	0,436	0,004
FTP-75	17,769	3587,955	1,793	7,894	0,116	201,922	0,101	0,444	0,007
ECE 15	0,994	263,646	0,161	0,801	0,009	265,211	0,162	0,806	0,009
JAP10	0,664	183,596	0,111	0,539	0,007	276,542	0,167	0,811	0,011
NYCC	1,898	759,242	0,523	2,509	0,031	399,938	0,275	1,322	0,016

Table 4.1: Emisssion - Travel Time Outputs of Driving Cycles for Petrol Car.

In Table 4.1 emission outputs for vehicle type is demonstrated as a table. For EUDC, most efficient CO_2 emission is acquired in one kilometre, and for a least efficient CO_2 emission is acquired in one kilometre is NYCC driving cycle. Between these two cycle, NYCC produces nearly three times more CO_2 compared to EUDC. In order to give a precise results, there are 2,777 times more emissions are released on air in NYCC cycle compared to EUDC.

As it is explained in Section 3.2, NYCC imitates the city traffic pattern, and EUDC cycle reflects the typical driving pattern in highways. It can be derived that, in traffic flow compared to highway flow, there are much more of emission released to the air and congestion is a serious issue for environmental impacts.

Diesel Car	Length	E_{CO_2}	E_{NO_x}	E_{VOC}	E_{PM}	I_{CO_2}	I_{NO_x}	I_{VOC}	I_{PM}
JAP15	2,174	447,458	2,045	0,033	0,180	205,851	0,941	0,015	0,083
JAP10	0,664	144,617	0,524	0,016	0,140	217,829	0,789	0,024	0,211
ECE 15	0,994	216,974	0,808	0,024	0,186	218,262	0,812	0,024	0,187
FTP-75	17,769	3886,648	17,418	0,273	2,306	218,732	0,980	0,015	0,130
IM240	3,152	694,929	3,361	0,039	0,355	220,479	1,066	0,013	0,113
EUDC	6,609	1502,072	8,249	0,067	0,209	227,273	1,248	0,010	0,032
NYCC	1,898	579,377	2,307	0,068	0,623	305,192	1,215	0,036	0,328

Table 4.2: Emisssion - Travel Time Outputs of Driving Cycles for Diesel Car.

In Table 4.6, Diesel Car's emission outputs can be seen on different driving cycles. It has a most efficient CO_2 emission on JAP15 cycle and has a least efficient CO_2

emissions on NYCC cycle. There are 1,482 times more emissions released on air compared to JAP 15 cycle with NYCC cycle. There is also huge efficiency differences between cycles but it can be said that, diesel cars are not sensitive as petrol car in different patterns for CO_2 emissions.

LPG	Length	E_{CO_2}	E_{NO_x}	E_{VOC}	E_{PM}	I_{CO_2}	I_{NO_x}	I_{VOC}	I_{PM}
EUDC	6,609	680,937	0,346	5,509	0,010	103,030	0,052	0,833	0,001
IM240	3,152	511,005	0,217	3,229	0,017	162,126	0,068	1,024	0,005
JAP15	2,174	372,657	0,197	3,063	0,009	171,439	0,090	1,409	0,004
FTP-75	17,769	3588,491	1,793	7,898	0,115	201,952	0,101	0,444	0,006
ECE 15	0,994	285,194	0,165	2,592	0,009	286,887	0,166	2,608	0,009
JAP10	0,664	202,441	0,110	1,740	0,007	304,927	0,165	2,622	0,010
NYCC	1,898	830,626	0,523	8,085	0,031	437,540	0,275	4,259	0,016

Table 4.3: Emisssion - Travel Time Outputs of Driving Cycles for LPG.

In Table 4.3, same analysis is demonstrated with LPG vehicle type. Results are very similar with gasoline cars. It can be seen that, LPG cars are more sensitive in emission outputs for different driving cycles. For EUDC, most efficient CO_2 emission acquired in one kilometre, for a least efficient CO_2 emissions acquired in NYCC and there are nearly 5 times more emissions release on air is found between two cycles for comparison for LPG. Precisely, there is 4,246 times more emissions are released on NYCC cycle compared to EUDC for one kilometer.

As a result, same cycles are implemented for each vehicle type. In all vehicle types, least efficient driving cycle is found as NYCC which imitates traffic conditions in urban roadway. Additionally it is found that, each vehicle type reflects different in different cycles are found as LPG is the most sensitive for different conditions with 4,246 times more emission release between best and worst cycles for CO_2, gasoline cars have 2,794 times more emissions release between best and worst cycles, and lastly diesel cars have 1,482 times more emission release between best and worst cycles.

In Figure 4.1 , it can be seen that CO_2 emissions are in decreasing trend while average speed increases in 0 - 70 km/h band. Trendlines and CO_2 values are similar to study of (Barth et al.) 2009 .

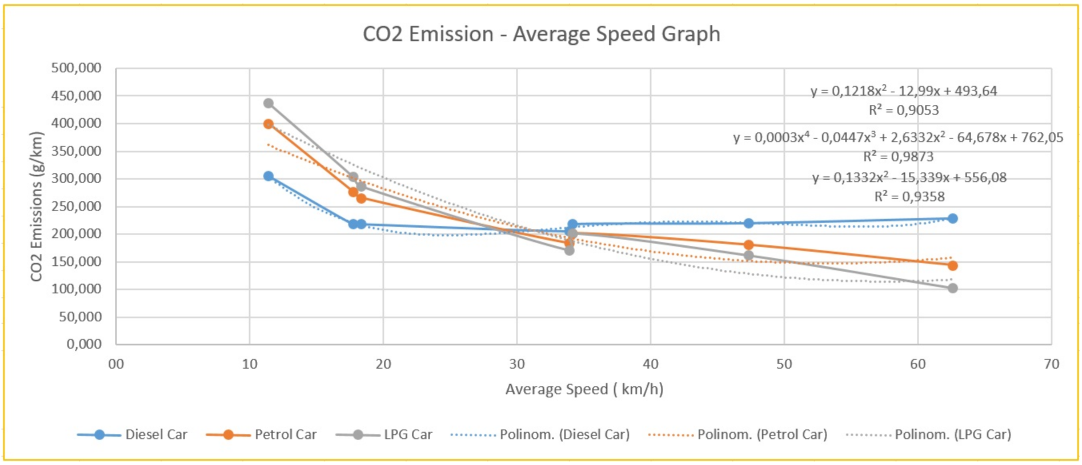


Figure 4.1: CO_2 Emission - Average Speed Graph.

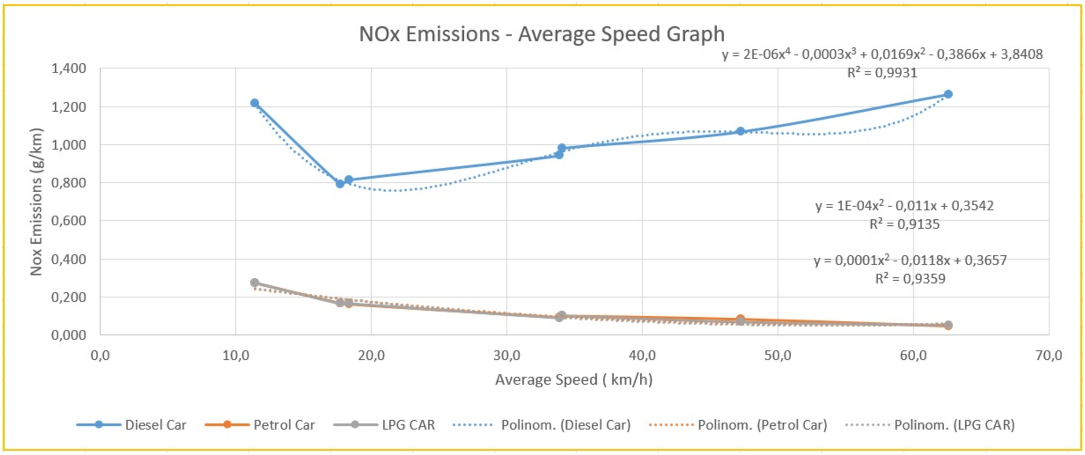


Figure 4.2: NO_x Emission - Average Speed Graph.

In Figure 4.2 , as it is expected, values are nearly 10 times bigger at diesel vehicles. Gasoline And LPG Car trends are behaving similarly.

In Figure 4.3, it can be ssen that, every vehicle type has a decreasing pattern in VOC Emissions. But, LPG Cars have the most low-tolerant pattern which changes remarkably during average speed, Diesel Cars have the most high tolerant pattern which means, VOC Emissions are not changing with respect to speed.

In Figure 4.4, same trend with different orders are observed. PM is also decreasing when the speed increases in every vehicle type. But this pollutant type again has nearly 15 times higher in Diesel Cars.

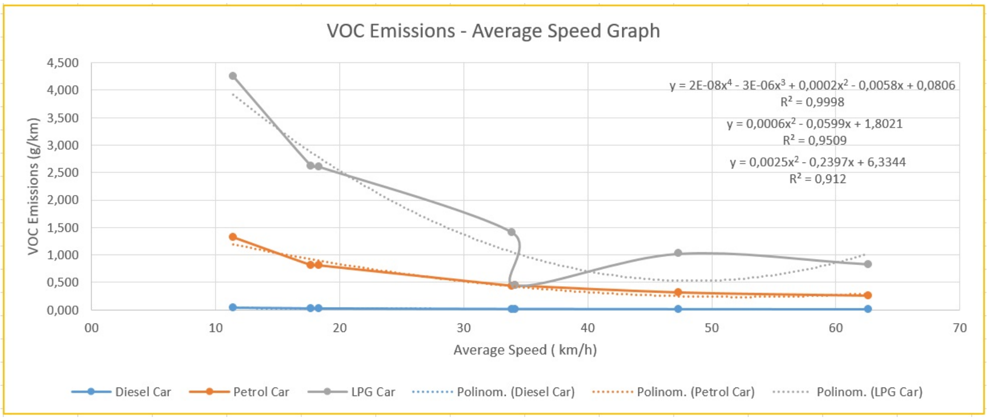


Figure 4.3: VOC Emission - Average Speed Graph.

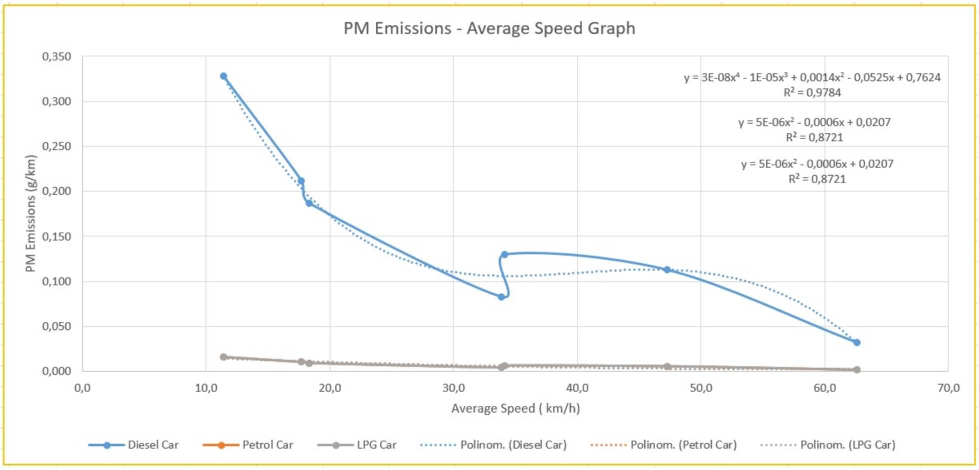


Figure 4.4: PM Emission - Average Speed Graph.

For one step further, as it is proposed in 1 evaluation of acceleration characteristics will be investigated on same proposed cycle.

4.2 Evaluation of Acceleration Trajectories

In this section, different linear acceleration curves will be aplied on proposed driving cycle. As it is mentioned in section 3.2, it is required a customized cycle that mimics a parkour that has signalization, slowing urban road dynamics. It is necessary to have such customized cycle that requires urban freeflow traffic because, in our thesis, effect of vehicles to each other is not included. In other words, car following effect is neglected which means no vehicle is dependent on other vehicle in same network.

There are 4 linear acceleration curves which consist of 4 - 7 km/h/s and 11 acceleration trajectories which have unique patterns will be applied on customized cycle. In each simulation one acceleration pattern is investigated.

4.2.1 Analysis of Linear Acceleration Curves

In this section, results of linear acceleration curves will be investigated.

The figure below demonstrates the acceleration curves in proposed cycle. For each linear acceleration curve, analysis has been conducted. Deceleration values are also implemented in cycle, but same deceleration values are assumed with acceleration curves.

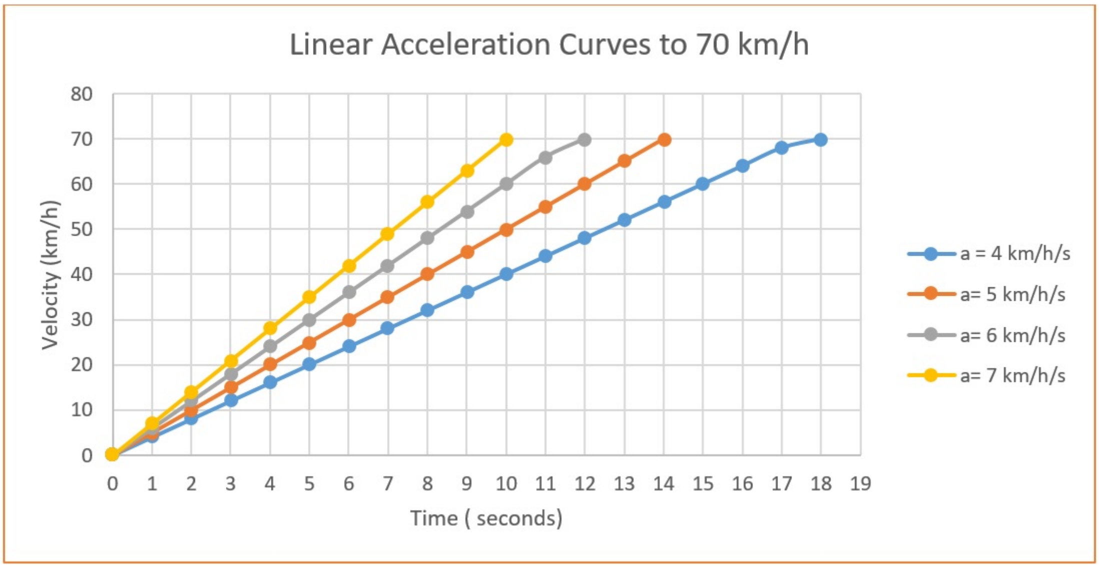


Figure 4.5: Linear Acceleration Curves to 70 km/h.

The table below demonstrates the outputs of emissions and travel times for petrol car in customized driving cycle. The figure of emission and travel time for each trial is included in Appendix for each vehicle type.

Linear Acceleration	Travel Time	E_{CO_2}	E_{NO_x}	E_{VOC}	E_{PM}
a = 4 km/h/s	209	502,903	0,216	0,035	0,013
a = 5 km/h/s	201	514,030	0,217	0,035	0,014
a = 6 km/h/s	197	522,753	0,218	0,035	0,015
a = 7 km/h/s	193	533,219	0,220	0,035	0,016

Table 4.4: Emisssion - Travel Time Outputs of Driving Cycles for Petrol Car.

For petrol cars, there are most efficient for emissions and least efficient for travel time is acquired in 4 km/h/s linear acceleration curve, and least efficient for emissions and most efficient for travel time is acquired in 7 km/h/s linear acceleration curve. The table below demonstrates the net change in emissions and travel time for each trial and comparison is conducted with AT-FM.

Linear Acceleration	Travel Time Save (%)	Net E_{CO_2} Change (%)
a = 4 km/h/s	-10	5,173
a = 5 km/h/s	-5,790	3,075
a = 6 km/h/s	-3,68	1,430
a = 7 km/h/s	-1,579	-0,542

Table 4.5: Emisssion - Travel Time Efficiencies of Driving Cycles for Petrol Car.

It can be seen that , there is a trade off between travel time and CO_2 in each trial compared with AT-FM except a = 7 km/h/s. In order to explain the Table 4.5 for example, if a driver accelerates linearly with 5 km/h/s compared to AT-FM, there is 5,173% of CO_2 emisisons be saved as a cost of 10% of travel time for proposed cycle for petrol cars.

Figure 4.6 demonstrates the trade off for CO_2 in linear acceleration grouped each other. If a driver decides to accelerate linearly with 5 km/h/s against 4 km/h/s, 3,98% of travel time can be saved with a cost of extra 2,16% of CO_2 emissions.

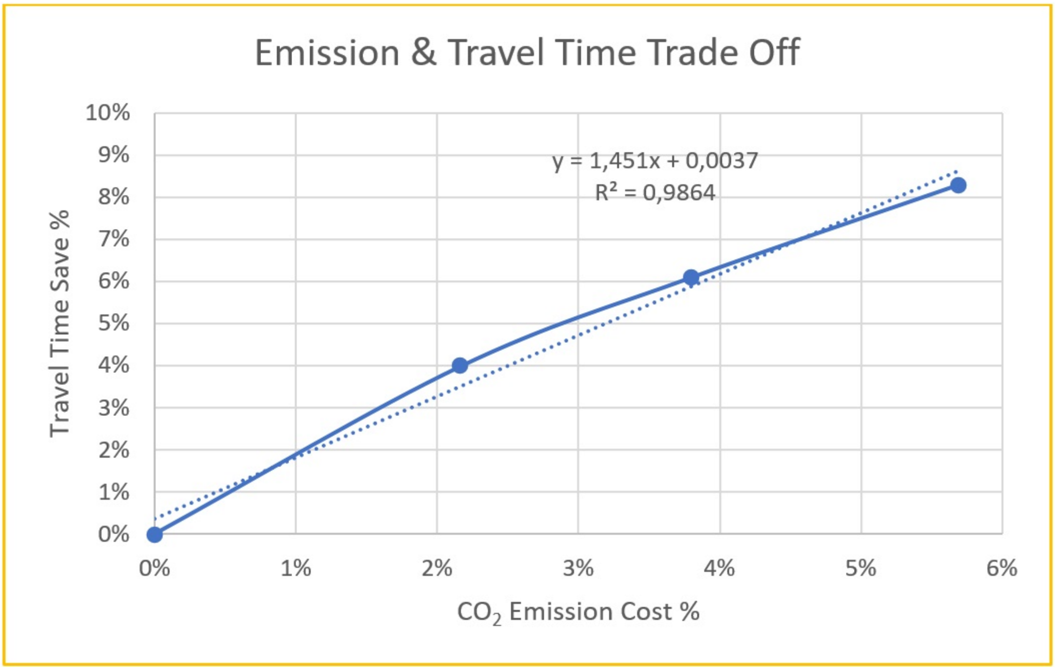


Figure 4.6: Linear Acceleration Emission & Travel Time Trade Off for Petrol Car.

In Table 4.6, there is again a trade off is obtained. Travel time saves are resulted in extra emission release on air.

Linear Acceleration	Travel Time	E_{CO_2}	E_{NO_x}	E_{VOC}	E_{PM}
a = 4 km/h/s	209	622,282	3,050	2,765	0,320
a = 5 km/h/s	201	644,081	3,158	2,703	0,341
a = 6 km/h/s	197	658,554	3,229	2,670	0,355
a = 7 km/h/s	193	672,761	3,298	2,642	0,383

Table 4.6: Emisssion - Travel Time Outputs of Driving Cycles for Diesel Car.

This trade of as it is seen in Table 4.7, is more sensitive than petrol cars. For diesel cars, 3,827% travel time save can be acquired with extra 3,503% of E_{CO_2} release. This ratio is higher than petrol cars so , more sensitive results are obtined compared to petrol cars.

Linear Acceleration	Travel Time Save (%)	Net E_{CO_2} Change (%)
a = 4 km/h/s	-10	6,506
a = 5 km/h/s	-5,790	3,231
a = 6 km/h/s	-3,684	1,056
a = 7 km/h/s	-1,579	-1,078

Table 4.7: Emisssion - Travel Time Efficiencies of Driving Cycles for Diesel Car.

Figure 4.7 demonstrates the trade off for CO_2 in linear acceleration grouped each other for diesel cars. If a driver decides to accelerate linearly with 5 km/h/s against 4 km/h/s, 3,98% of travel time can be saved with a cost of extra 3,38% of CO_2 emissions.

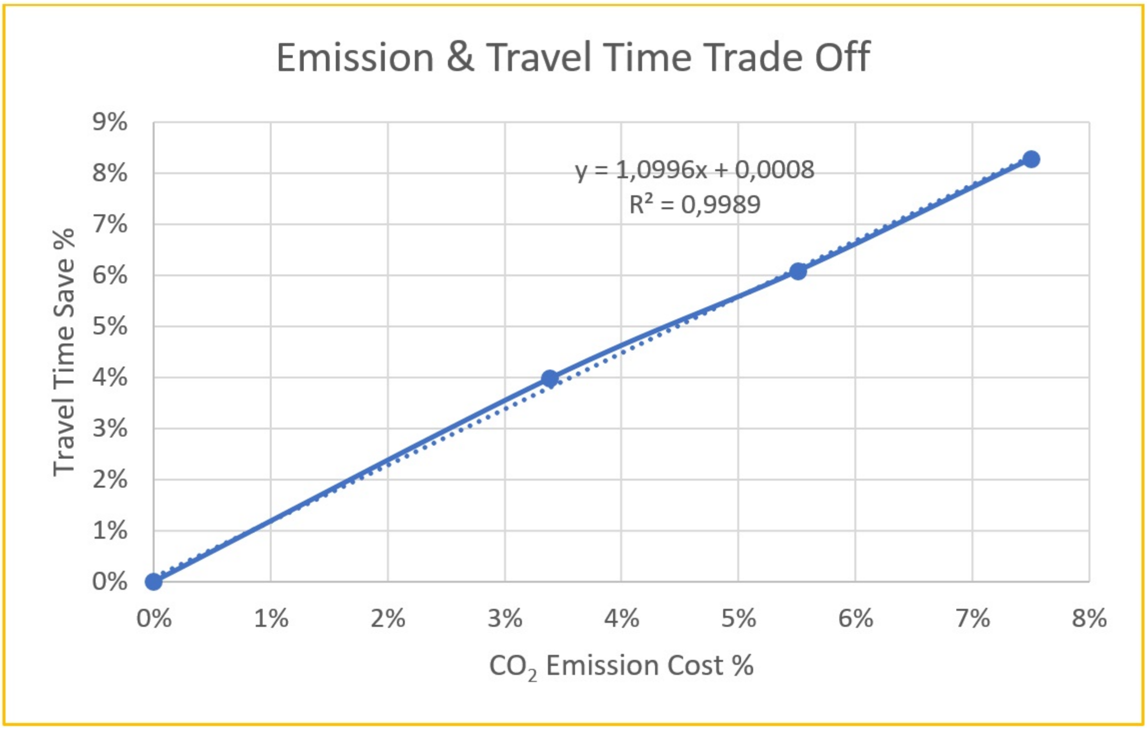


Figure 4.7: Linear Acceleration Emission & Travel Time Trade Off for Diesel Car.

In LPG Cars, same results are obtained. There is a trade off between travel time and CO_2 emissions. But this change is slightly robust compared to other vehicle types.

Linear Acceleration	Travel Time	E_{CO_2}	E_{NO_x}	E_{VOC}	E_{PM}
a = 4 km/h/s	209	443,290	0,186	1,009	0,314
a = 5 km/h/s	201	448,318	0,184	0,970	0,337
a = 6 km/h/s	197	453,298	0,183	0,950	0,352
a = 7 km/h/s	193	461,032	0,183	0,932	0,383

Table 4.8: Emisssion - Travel Time Outputs of Driving Cycles for LPG.

This trade of as it is seen in Table 4.9, is least sensitive than petrol and diesel cars. As it is seen below, if a driver chooses accelerate at 5 km/h/s instead 4 km/h/s in a proposed cycle, 3,827% of travel time save can be acquired by releasing extra 1,134% of CO_2 emissions.

Linear Acceleration	Travel Time Save (%)	Net E_{CO_2} Change (%)
a = 4 km/h/s	-10	3,567
a = 5 km/h/s	-5,790	2,473
a = 6 km/h/s	-3,684	1,389
a = 7 km/h/s	-1,579	-0,293

Table 4.9: Emisssion - Travel Time Efficiencies of Driving Cycles for LPG

Figure 4.8 demonstrates the trade off for CO_2 in linear acceleration grouped each other for LPG Cars. If a driver decides to accelerate linearly with 5 km/h/s against 4 km/h/s, 3,98% of travel time can be saved with a cost of extra 1,12% of CO_2 emissions.

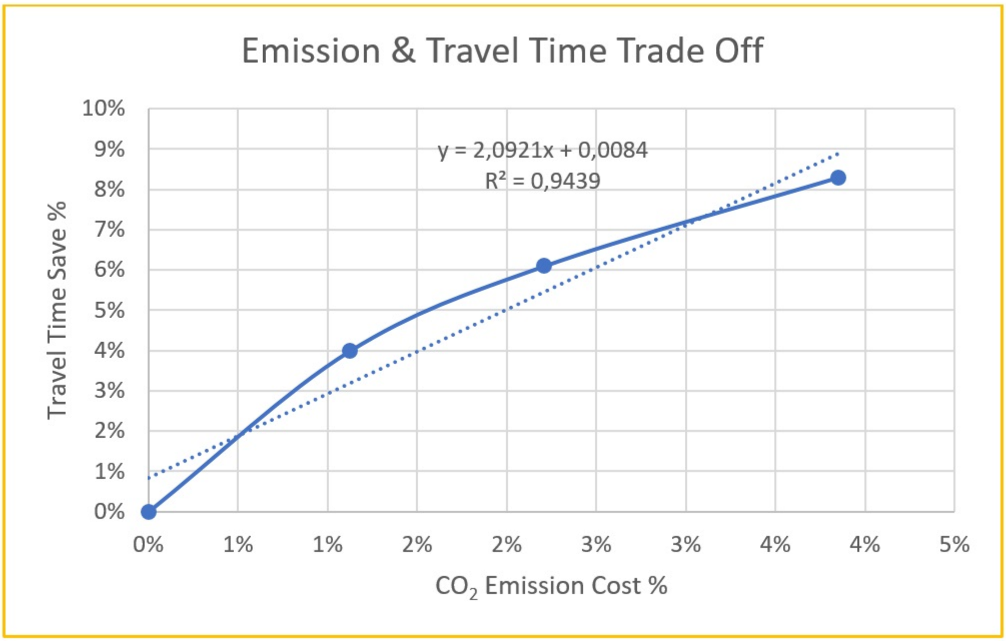


Figure 4.8: Linear Acceleration Emission & Travel Time Trade Off for LPG Car.

4.2.2 Analysis of Acceleration Trajectories

As it is explained in Section 4.2 same analysis will be conducted on acceleration trajectories that imitates possible driving patterns. We defined speed leverage points as 20 - 30 - 50 - 70 km/h and different acceleration values are implied to the reach defined speed leverage points. Figure below demonstrates the acceleration trajectories.Acceleration pattern which is derived from field measurements is similar to our proposed acceleration trajectories AT(10) .

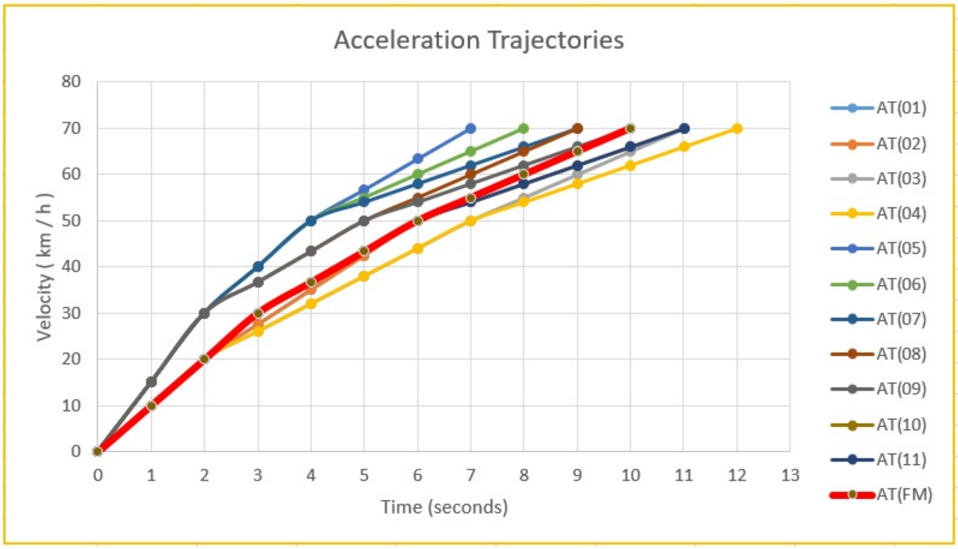


Figure 4.9: Acceleration Trajectories.

In Figure 4.9 every acceleration curve which will be implemented as an acceleration pattern to our proposed driving cycle. Emission outputs will be derived and results will be demonstrated. In order to clarify the meaning of the table 4.10, AT(01)-10-7,5-5 means that, a vehicle will be accelerate by a= 10 km/h/s between 0 - 20 km/h , then at the 20 - 50 km/h interval, acceleration will be decreased to 7,5 km/h/s and, between 50-70 km/h interval, acceleration will be 5 km/h/s and the vice versa at deceleration. In such logic, 11 acceleration trajectories are implemented as a acceleration trajectory that mimics the standart acceleration pattern in urban freeflow road.

Speed Points	Linear Acceleration	Travel Time	E_{CO_2}	E_{NO_x}	E_{VOC}	E_{PM}
20-50-70	AT(01)-10-7,5-5	191	529,271	0,219	0,035	0,019
20-50-70	AT(02)-10-7,5-4	192	522,049	0,217	0,035	0,019
20-50-70	AT(03)-10-6-5	192	524,270	0,218	0,035	0,019
20-50-70	AT(04)-10-6-4	194	517,567	0,217	0,035	0,019
30-50-70	AT(05)-15-10-7	186	583,544	0,244	0,035	0,029
30-50-70	AT(06)-15-10-5	187	551,722	0,227	0,035	0,027
30-50-70	AT(07)-15-10-4	188	544,085	0,225	0,035	0,027
30-50-70	AT(08)-15-6,67-5	188	552,886	0,226	0,035	0,027
30-50-70	AT(09)-15-6,67-4	189	540,806	0,223	0,035	0,027
30-50-70	AT(10)-10-6,67-5	191	530,342	0,220	0,035	0,019
30-50-70	AT(11)-10-6,67-4	192	530,895	0,221	0,035	0,019

Table 4.10: Emisssion - Travel Time Outputs of Customized Cycle for Petrol Car.

Table 4.10 demonstrates the emission - travel time outputs for each acceleration trajectory in a proposed driving cycle for petrol car. For petrol cars, most efficient acceleration curve between acceleration trajectories is calculated as AT(04) with 517,578 grams of CO_2. If a driver hits 20 km/h in 2 seconds, 20 to 50 km/h in 4 seconds and 50 - 70 km/h in 4 seconds, most efficient trajectory can be obtained. And similar pattern has more aggresive and sudden accelerations has the worst efficient emission output with 583,544 grams of CO_2, in according to test bed, in real life, average consumption will be around 530,342 and 530,895 grams of CO_2 emissions.

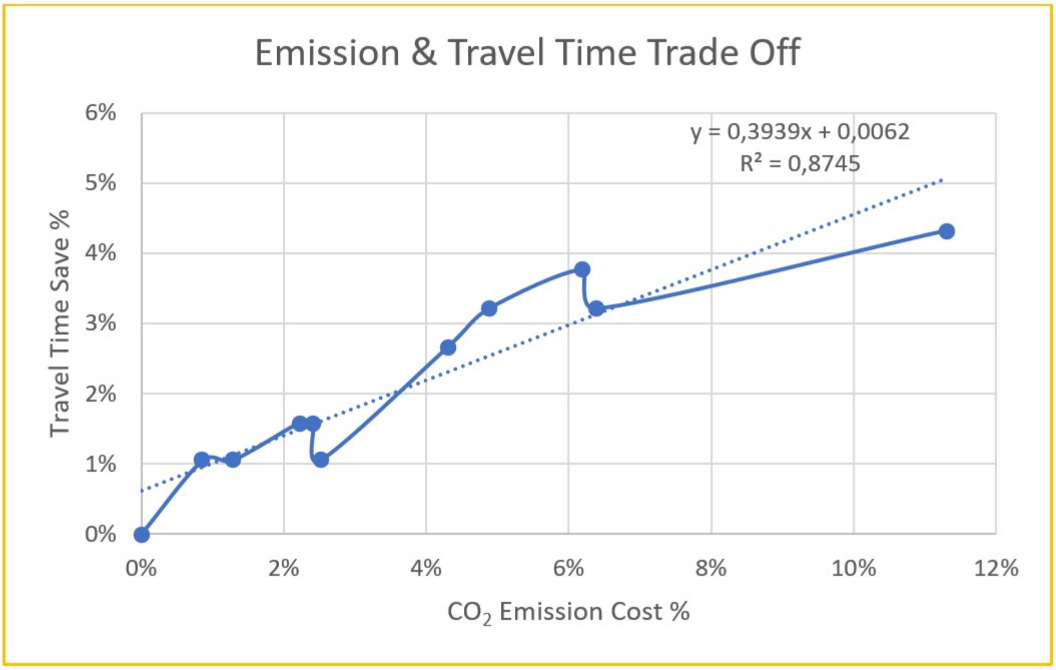


Figure 4.10: Linear Acceleration Emission & Travel Time Trade Off for Petrol Car.

In Figure 4.10 , relationship between CO_2 and travel time is demostrated for petrol cars. In order to explain the table with examples, with a 11,31 % cost of emissions, there is 4,32 % of travel time is available.

Table 4.11 demonstrates the emission - travel time outputs for each acceleration trajectory in a proposed driving cycle for diesel car. For diesel cars, most efficient acceleration curve between acceleration trajectories is calculated as AT(04) with 649,257 grams of CO_2. If a driver hits 20 km/h in 2 seconds, 20 to 50 km/h in 4

Speed Points	Linear Acceleration	Travel Time	E_{CO_2}	E_{NO_x}	E_{VOC}	E_{PM}
20-50-70	AT(04)-10-6-4	194	649,257	3,178	2,606	0,369
20-50-70	AT(02)-10-7,5-4	192	656,001	3,215	2,589	0,381
20-50-70	AT(03)-10-6-5	192	658,992	3,220	2,595	0,378
30-50-70	AT(11)-10-6,67-4	192	659,995	3,223	2,595	0,407
30-50-70	AT(10)-10-6,67-5	191	665,587	3,254	2,593	0,398
20-50-70	AT(01)-10-(7,5)-5	191	666,060	3,259	2,593	0,390
30-50-70	AT(09)-15-6,67-4	189	672,421	3,270	2,558	0,442
30-50-70	AT(07)-15-10-4	188	677,819	3,310	2,550	0,449
30-50-70	AT(06)-15-10-5	187	688,552	3,354	2,553	0,460
30-50-70	AT(08)-15-6,67-5	188	688,824	3,342	2,574	0,454
30-50-70	AT(05)-15-10-7	186	724,574	3,533	2,563	0,549

Table 4.11: Emisssion - Travel Time Outputs of Customized Cycle for Diesel Car.

seconds and 50 - 70 km/h in 4 seconds, most efficient trajectory can be obtained. More aggresive acceleration pattern which has more aggresive and sudden accelerations over time has the worst efficient emission output with 724,574 grams of CO_2 as imitated in AT(05). In according to test bed, in real life, average consumption will be around 659,995 and 665,587 grams of CO_2 emissions as it is demonstrated in AT(10).

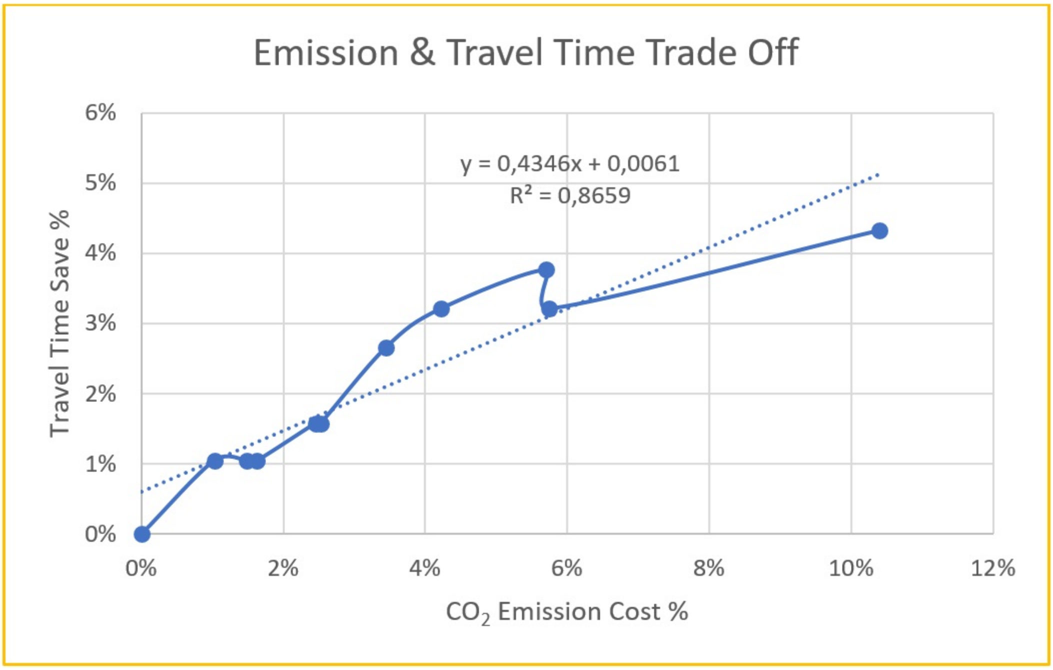


Figure 4.11: Linear Acceleration Emission & Travel Time Trade Off for Diesel Car.

In Figure 4.11 , relationship between CO_2 and travel time is demostrated for diesel cars. In order to explain the table with examples, with a 10,39 % cost of emissions, there is 4,32 % of travel time is available.

Speed Points	Linear Acceleration	Travel Time	E_{CO_2}	E_{NO_x}	E_{VOC}	E_{PM}
20-50-70	AT(04)-10-6-4	194	649,257	3,178	2,606	0,369
20-50-70	AT(02)-10-7,5-4	192	656,001	3,215	2,589	0,381
20-50-70	AT(03)-10-6-5	192	658,992	3,220	2,595	0,378
30-50-70	AT(11)-10-6,67-4	192	659,995	3,223	2,595	0,407
30-50-70	AT(10)-10-6,67-5	191	665,587	3,254	2,593	0,398
20-50-70	AT(01)-10-(7,5)-5	191	666,060	3,259	2,593	0,390
30-50-70	AT(09)-15-6,67-4	189	672,421	3,270	2,558	0,442
30-50-70	AT(07)-15-10-4	188	677,819	3,310	2,550	0,449
30-50-70	AT(06)-15-10-5	187	688,552	3,354	2,553	0,460
30-50-70	AT(08)-15-6,67-5	188	688,824	3,342	2,574	0,454
30-50-70	AT(05)-15-10-7	186	724,574	3,533	2,563	0,549

Table 4.12: Emisssion - Travel Time Outputs of Customized Cycle for LPG.

Table 4.12 demonstrates the emission - travel time outputs for each acceleration trajectory in a proposed driving cycle for LPG. For LPG , most efficient acceleration curve between acceleration trajectories is calculated as AT(04) with 449,937 grams of CO_2. If a driver hits 20 km/h in 2 seconds, 20 to 50 km/h in 4 seconds and 50 - 70 km/h in 4 seconds, most efficient trajectory can be obtained. More aggresive acceleration pattern which has more aggresive and sudden accelerations over time has the worst efficient emission output with 507,149 grams of CO_2 as imitated in AT(05). In according to test bed, in real life, average consumption will be around 458,069 and 459,685 grams of CO_2 emissions as it is demonstrated in AT(10).

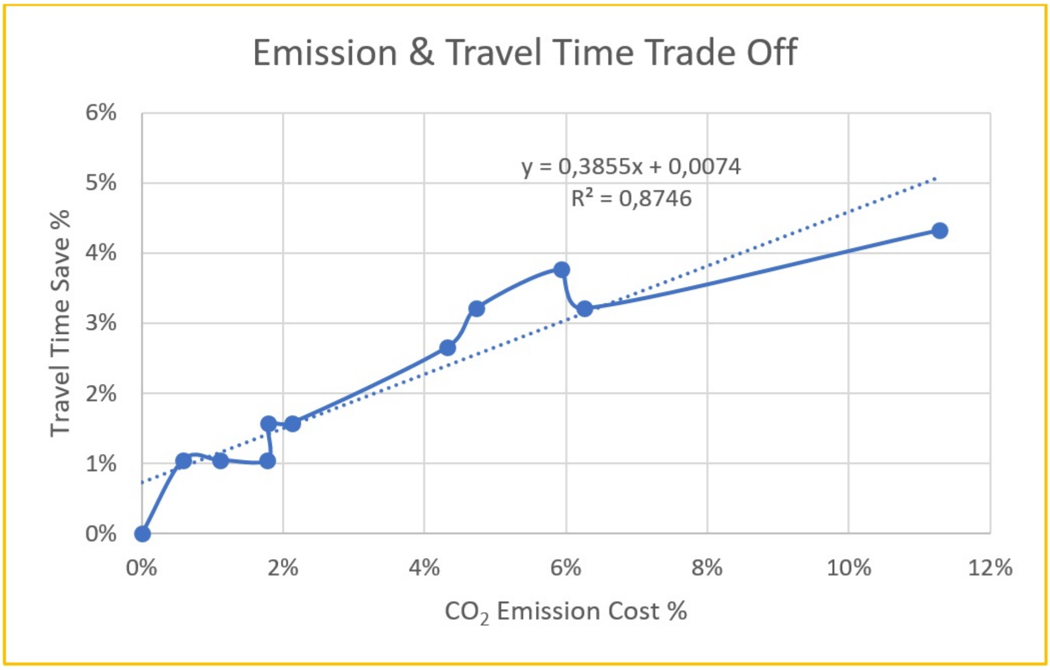


Figure 4.12: Linear Acceleration Emission & Travel Time Trade Off for LPG Car.

In Figure 4.12 , relationship between CO_2 and travel time is demostrated for LPG cars. In order to explain the table with examples, with a 11,28 % cost of emissions, there is 4,32 % of travel time is available.

Chapter 5

Conclusion and Discussion

In this thesis we tried to demonstrate the impact of accelerations on emissions. Our first analysis was demonstrating the following the different cycles hence complying on different acceleration and speed patterns has enormous impact on emissions. Then, by applying customized driving cycle that imitates freeflow urban road in order to neglect the relationship between vehicles, we analysed the impact on different acceleration rates on same cycle in order to obtain the relationship between travel time and emissions in a micro scale. In this chapter, review of the results will be summarized, discussions will be made in order to obtain demonstrate the challenges and what can be done in order to get better and more precise results. In Section Further Studies, ideas and thoughts about related topic will be shared to develop and expand the study.

Our results was close to studies of (Qian et al) 2011 with a approximately 11% of emisisons can be saved from worst case to best case scenario for each vehicle type with an increase of 4,32% travel time.

5.1 Review of Results

Firstly in this thesis, as it is explained, referred emission model is only available to obtain emissions on g/s which requires instantaneous speed and acceleration to calculate an emission in an only given moment of time. It is enhanced by applying the distance parameter and calculating cumulative emissions second by second to cancel out the second parameter in g/s. Then, in order to convert the emission output unit of $g/route$, driving cycles are applied and customized in order to obtain an emission output from a desired cycle.

Our first analysis was calculating the emission outputs of driving cycle that imitates different scenarios. Our point was determining the comparing those cycles to have an insight of most efficient driving pattern.In according to analysis,

143,125 g/km of CO_2 is obtained as best efficient in EUDC and 399,938 g/km of CO_2 is obtained as worst efficient in NYCC for petrol car. Between those two different cycles there are 279% change in efficiency.

205,851 g/km of CO_2 is obtained as best efficient in JAP15 and 305,192 g/km of CO_2 is obtained as worst efficient for diesel car. Between those two different cycles there are 148% change in efficiency.

103,030 g/km of CO_2 is obtained as best efficient in EUDC and 437,540 g/km of CO_2 is obtained as worst efficient for petrol car. Between those two different cycles there are 424% change in efficiency.

Secondly, In order to demonstrate the decisions clearly, custom driving cycle is customized for modelling the standard urban driving pattern. On field measurements are referred as the test bed and assumed as a standard driving pattern and analysis have been conducted.

For gasoline cars, by comparing the test bed with all created possible standard driving patterns, 2,515% of CO_2 net save is observed as the best efficiency with AT(04) by accepting %1,047 delay and maximum 1,66% CO_2 net save is observed without any travel time loss with AT(02) .

For diesel cars, by comparing the test bed with all created possible standard driving patterns, 2,454% of CO_2 net save is observed as the best efficiency with AT(04) by accepting 1,579% delay.

For LPG, by comparing the test bed with all created possible standard driving patterns, 2,120% of CO_2 net save is observed as the best efficiency with AT(04) by accepting 1,571% delay.

Beyond these, constant linear acceleration with a = 4 km/h/s gives the 5,272% CO_2 efficiency on gasoline, 6,506% CO_2 efficiency on diesel, 3,567% on LPG. But this acceleration pattern is unrealistic doesn't take into an account in comparison.

5.2 Discussions

In this thesis, our expectation was determining an acceleration pattern which gives the best emission output. It is wanted to be a both practical and efficient trajectories so it is derived from trials and applicability was one of the main priorities. There are infinite ways to reach from 0 to 70 km/h and there are probably most efficient near optimal solutions that can be calculated from various optimization techniques.

Secondly, we referred and emission model and enhanced it. But this emission model calculating implied fleet. Additionally, validation and accuracy of emission model was not validated. We conducted our analyses by relying on emission model. So, there is a possibilty that different and more precise results can be obtained with different emissions models.

Thirdly, more precise results can be obtained and test bed could be derived differently. As it is explained in field measurements, biased measurements are observed. Image recognition systems or drones could be used in order to record the section of the road.

We were assuming different acceleration trajectories for each vehicle type and characteristics. In recording, this parameters could be taken into an account and same acceleration trajectory is assumed as test bed.

5.3 Further Studies

As it is mentioned, there are infinite ways to reach desired speed and optimal solution is differentiated with the cycle type. Algorithms and artificial intelligence approaches could be implemented to this idea to obtain best possible output in every different situation hence a device can be designed by relying on this idea to provides more efficient and sustainable environment.

In our thesis, strict driving cycle is assumed. This means this analysis is only available on proposed acceleration pattern. It is possible that by defining a start point and endpoint, cycle could be automatically created and by using algorithms, automatically a speed pattern can be derived and implied on a vehicle for further studies analysis.

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