



ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)
Grado en Ingeniería Electromecánica

**“Analysis of a hybrid, plug-in electric and full electric bus line in Spain,
Sweden and The Netherlands”**

Author: Laura Rivera Díez
laura.riv.diez@gmail.com

Director: Pablo Frías Marín
pablo.frias@iit.comillas.edu

Madrid
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Abstract in English and Spanish

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Resumen del proyecto

El objetivo de este proyecto es contribuir a un futuro sistema de transportes que no dañe el medio ambiente mediante el estudio de tres líneas de autobús en diferentes países europeos. Estas tres líneas funcionan en la actualidad con gasolina o diésel, y se pretende estudiar la posibilidad de sustituirlas por vehículos híbridos, enchufables o completamente eléctricos y analizar las diferentes opciones de recarga y tamaños de baterías para cada caso. El estudio se realizará mediante simulaciones con Matlab y Simulink, se recogerán los datos y se realizará una comparativa obteniendo una opinión final sobre cuál es la opción más viable y efectiva para introducir estos vehículos en la red de transporte pública.

En primer lugar, es necesario un análisis del estado del arte de la cuestión. Es un tema en auge, por lo tanto hay abundante información, proyectos, etc sobre la electrificación del transporte. Uno de los proyectos con los que se ha identificado el presente estudio es el proyecto MERGE, que busca preparar la red para el impacto de la inclusión a gran escala de los vehículos eléctricos en Europa. Por otro lado, es necesario también un análisis previo del estado actual de los vehículos híbridos y eléctricos. Los componentes, en especial las baterías han sido analizados para cada tipo de vehículo estudiado.

A continuación, se procede a modelar el autobús en Matlab. Para ello, hay que establecer primero una serie de parámetros físicos (área frontal, coeficiente de rozamiento, etc). Estos parámetros serán datos de entrada en el Simulink, que tras recorrer el ciclo correspondiente devuelve parámetros como el consumo de combustible o el estado de carga de la batería. Tres ciclos distintos han sido creados, uno para cada país de estudio (Suecia, España y Holanda). Estos ciclos se crean mediante la inclusión de datos sobre tiempo, velocidad, distancia recorrida y disponibilidad de recarga externa en una matriz en Matlab, que también será dato de entrada en el Simulink. Hay que tener en cuenta también las distintas opciones de recarga de la batería, que influirán de manera definitiva en el coste de la instalación.

Una vez que han sido establecidos todos los parámetros, se procede a simular distintos casos para cada tipo de vehículo estudiado. En cada caso se varían parámetros como la capacidad de la batería, la profundidad de descarga permitida o el estado inicial de carga, con el fin de encontrar una batería que no sea más grande de lo necesario pero que permita un cierto nivel de autonomía con una vida útil razonable. Los resultados de cada simulación se recogen, junto con el consumo de combustible en cada caso, en forma de tablas. Para el caso de vehículo híbrido se eligen baterías de capacidad alrededor de los 15 kWh. Para el caso de híbrido enchufable se eligen baterías con 30 kWh y para el caso de vehículo completamente eléctrico las baterías necesarias rondan los 90 kWh.

A continuación se analiza el contenido de las simulaciones y se elige un tipo de vehículo, una batería y una opción de recarga para cada país. La mejor opción parece ser la de un vehículo completamente eléctrico que obtiene energía de dos estaciones externas de recarga situadas en puntos estratégicos a lo largo de la ruta. Se puede comprobar que para los tres países el resultado es bastante similar, con lo cual se podría interpretar que únicamente un modelo podría ser suficiente para toda Europa. Una vez que se ha tomado la decisión sobre el tamaño de la batería, se procede al análisis financiero con datos actuales de los tres países de estudio sobre precios medios en electricidad y combustible.

Por último concluimos que la electrificación del transporte puede ser prevista en términos de costes mediante nuestro programa. Se han realizado simulaciones únicamente para tres líneas reales de autobús de Europa pero el programa es flexible y admite cualquier tipo de ciclo y vehículo. La continuación de este proyecto sería, por lo tanto, un estudio a gran escala de los costes y viabilidad de la electrificación por completo del sistema público de transportes en las grandes ciudades de Europa con el objetivo de reducir las emisiones contaminantes.

Abstract

The objective of this project is to contribute to a sustainable future transportation network by studying three bus lines in different European countries. These three lines are powered today by gasoline or diesel, and the purpose is to study the possibility of replacing them with hybrid, plug-in or full electric vehicles and analyse different recharging options, and sizes of batteries for every case. The study will be conducted through simulations with Matlab and Simulink, data will be collected and a comparison will be made to give a final opinion on what is the most viable and effective way to introduce these vehicles into the public transport system of the big cities studied.

First, an analysis of the state of the art in the matter is necessary. We face an issue on the rise, so there is plenty of information, projects, etc. regarding the electrification of transport. One of the projects that have been identified as relevant to this study is the MERGE project, which aims to prepare the network for the impact of large-scale inclusion of electric vehicles in Europe. A prior analysis of the current state of hybrid and electric vehicles is also necessary. The components, especially the batteries have been analysed for each type of vehicle studied.

After this analysis, we proceed to model the bus in Matlab. In order to do this, we first establish a series of physical parameters (frontal area, coefficient of friction, etc). These parameters are given as an input to the Simulink model, which after running the cycle returns parameters such as fuel consumption or the state of charge of the battery (SoC). Three different cycles have been created, one for each country of study (Sweden, Spain and the Netherlands). These cycles are created by including data on time, speed, distance and availability of external recharging in a matrix in Matlab, which will also be input to the Simulink. We also need to consider the various options for recharging the battery, which will influence definitively the cost of the installation.

Once all the parameters have been set, we simulate different scenarios for each type of vehicle studied. In every case, parameters such as the battery capacity, depth of discharge allowed (DoD) or SoC are varied, in order to find a battery that is not larger than necessary but allows a certain level of autonomy with a reasonable lifetime. Each simulation results are shown, together with the fuel consumption, in tables. Batteries of around 15 kWh are chosen for the hybrid case. Batteries of around 30 kWh are more suitable for the Plug-In hybrid case, and bigger batteries or 90 kWh are chosen for the full electric bus.

The contents of the simulations are then analysed and a type of vehicle, a battery and a recharging option for each country is chosen. The most viable option seems to be a full electric vehicle with two recharging stations strategically situated along the route. For the three countries the result is quite similar, which could be interpreted that only one model might be enough for all Europe. Once the decision on the size of the battery has been made, we proceed to the financial analysis with current data from the three countries of study in electricity and fuel prices.

Finally, we conclude that the electrification of transport can be predicted in terms of costs through our program. Simulations have been performed only three real bus lines in Europe but the program is flexible and supports any type of cycle and vehicle. The continuation of this project would be, therefore, a large-scale analysis of the costs and feasibility of electrifying the public transport network in major cities in Europe with the aim of reducing pollutant emissions to the atmosphere.

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Chapter 1

Introduction

1.1 General introduction

According to the U.N., about 6.8 million deaths a year are caused by air pollution. This means that air pollution kills more people every year than malaria and AIDS combined [1]. In 2013, more than a half of pollutant gases like carbon monoxide or nitrogen oxide emitted into our air came from the transportation sector [2]. Thus, it is urgent and of the most importance to create a new transport network that reduces drastically the pollutant gases emitted to the atmosphere and walks towards a future of zero contamination. This future can be reached sooner by replacing as quickly and effectively as possible all the transport based on fossil fuels by electrically driven vehicles, which are much more environmentally friendly than the traditional diesel and gasoline vehicles.

Even though the concept of an electrical engine seems like the future or at least the recent present, this kind of vehicles were invented over 100 years ago as an alternative to the old carriages pulled by horses. In the beginning of the XIX century, engineers in Hungary, The Netherlands and The United States started to design the first vehicles that used electricity as their energy supply. Around 1835, the Scottish Robert Anderson designed the first pure electrical vehicle, while in the US the chemist Williams Morrison developed a wagon for six people that could reach 22 km/h with a fully electrical engine. In the following years, electrical vehicles proliferated in the US, reaching even a float of nearly 100 electrical taxis in New York City [url1].

The 1900`s brought a boom in the electrical vehicle market, since the other alternative for the horse powered vehicles were the vapour driven engines, appearing in the latest years of the XIX century, which were not easy to use and quite expensive. Around this time, the first gasoline cars were starting to be developed also independently by the German engineers Karl Benz, Gottlieb Daimler and Wilhelm Maybach. The main drawback of this gasoline vehicles, which contributed to the rising of the electrical vehicles around this time, was that those cars were very hard to drive and the change of gear was done through a handle, which made it also very uncomfortable for the driver. In addition, they were very noisy and expelled quite a lot of smoke. It is not a surprise then that consumers chose the electrical vehicles over the fossil fuels. The electric cars were specially promoted as vehicles for women, silent, easy to drive and suitable for short travels in the city. Quite well known companies nowadays, like Porsche, started to invest in the electrical technology, attracted by the high demand. Thomas Edison was also a great enthusiast, and worked in several prototypes with his friend Henry Ford [url2].

Ironically, Ford would be the one to create the first gasoline car able to cover a mile in less than 40 seconds, which promoted him to be known all over The States. The Ford T was developed, being the first gasoline car with the steering wheel on the left side and a closed transmission system for the gears. It was a cheap, easy to drive and repair car that boosted the sales of the fossil fuel vehicles and started the decline of the electrical vehicles. At the same time, deposits of crude oil were discovered and the price of the gasoline went down drastically, while electricity was only available in the cities and did not

offer a lot of autonomy for long distance travelling. Finally, around 1930, the electrical vehicle was consigned to oblivion.

In 1977, the renaissance of the electrical vehicle was started by Toyota with their Prius model, first released in Japan and massively produced in the whole world around 2000. The increase of gasoline prices and the general and growing awareness about the environment contributed to its success, with over 9 million units of hybrid vehicles sold by Toyota up to April 2016 [url3]. Around the same time, Tesla Motors was born in Silicon Valley and turned out to be one of the biggest promoters of electrical technology nowadays.

The growth of the electrical market over the past couple of decades in transportation is undeniable, but the users still have to face a huge problem: where to recharge the batteries and how to do this in a quick and effective way. regarding the public network, several research projects in electric buses trying to establish the best way for the energy supply infrastructure are being conducted. Since 2012, big companies like Siemens and Volvo are investing in introducing electric buses in European cities like Hamburg, Stockholm or Gothenburg. Recent research conducted in Gothenburg by Volvo has shown that their electric-hybrid bus can reduce fuel and CO₂ consumption up to 90% compared to diesel buses [url4].



Fig 1. Thomas Edison with his first electrical car.

Source: General Photographic Agency

1.2 Objectives

The aim of this project is to contribute to the creation of a sustainable transportation network in the cities of Europe by performing an analysis in three different European countries about the technical feasibility and cost of replacing a traditional urban bus line with electrical or hybrid vehicles.

- This three countries will be Sweden, The Netherlands and Spain, with the intention to cover three different climate characteristics as well as fuel and electricity pricing conditions. Different cycles in Matlab for each country will be created and the vehicle data will be updated accordingly (following the Matlab script attached in the Annex).
- Simulations for one way of three different lines with similar distance and duration will be conducted and compared. The physical path followed and the details of these lines in real life can be found in Chapter 5.
- An evaluation and comparison of different charging strategies and battery sizes will be conducted, seeking to conclude with the best model for each of the three countries studied.

The continuation of this project, out of scope for the moment, would be to scale this up, first to a local level and eventually to a national level, with the purpose of reaching a non-contaminant public transport network in the whole Europe.

1.3 Structure of the document

In order to cover the previous objective this document is structured as follows:

- Chapter 2 presents an analysis of the current state of the electrical transportation sector. First, a state of the art is performed and several research projects and studies related to the matter are mentioned. After, the proper electrical vehicle is studied, first explaining the three types of vehicle that we will take into consideration, then their components and after a special attention is given to the battery.
- In Chapter 3, the technical analysis is performed. First we explain the data requirements for the Matlab program as well as the process in the Simulink. Then, the creation of the different Matlab drive cycles is explained. They will match three bus lines that are currently working with fuel powered vehicles in the cities of Gothenburg, Madrid and Amsterdam. With the official data from the transportation webpages of the three countries, the original cycles have been created. Finally, the different options of recharge for the battery are analysed.
- Chapter 4 includes the specific description of every case taken into account, as well as a summary of the results obtained from the model once every case has been ruined through it and all the data has been collected.
- In Chapter 5, the technical analysis of the results obtained in the simulations is performed. A decision is made and a specific vehicle is chosen as the most suitable for each of the three countries studied.
- In Chapter 6, the economical analysis for the chosen model in each of the three countries is performed.
- Finally, Chapter 7 regards the final conclusions and the consideration of future improvement that could be done in this area.

Chapter 2

Analysis of electrical transportation

2.1 Introduction

This chapter aims to present the current state of art on the matter of hybrid and electric vehicles from two different points of view. First, in section 2.2, research regarding other similar projects that have been done related to the topic will be performed. This will help the whole development of our project, avoiding the repetition of work that has already been done and providing with several sources of information for our own research. After, in section 2.3, the state of the art regarding the technical aspects of the matter will be performed, meaning, at which point of development are electric and hybrid vehicles today, their components, the batteries, etc. A brief conclusion will be included at the end of the chapter as a summary of all the research done in the following sections.

2.2 State of the art

As mentioned in the introduction, this is an emerging topic and lately more and more companies are investing in efficient and less contaminating means of transport. The whole transport system is evolving, moving away from the traditional fossil fuels and facing a new electrical future. Therefore, many studies and projects about it can be found. Most of the projects that have been consulted are related to *Project Merge, Preparing Europe's grids for electrical vehicles* [url5]. The most relevant projects that have been found related to our topic of interest are:

- *“Scenarios and roadmap for deployment of EV in three european regions: Recommendations for policy makers and regulations”*, performed by several authors coming from the Pontifical University Comillas, NTUA, TU Berlin and other universities, as well as professionals from the company Iberdrola in the year 2012. As described by them, this projects provides a roadmap for EV penetration from a policy and regulatory point of view. The interesting conclusion about this project is that it arrives to similar conclusions as of ours, since they establish that no major differences are detected between the studied European countries so a common model can be introduced [3].
- *“Assessing impacts from EV presence”*, performed by authors from the Pontifical University Comillas and the TU Berlin. This project has its focus a bit further from our than the previous one, but it is also interesting in the sense that it studied the impact of electrical vehicles on the common grids and how they need to evolve in order to be able to adapt to this new load and efficiently satisfy the demand of electricity coming from the market [4].
- *“Diseño y construcción de un vehículo eléctrico con variador de velocidad mediante un convertidor dc-dc”* is a thesis presented in the Technological University from Mixteca, that goes further than we do in technical aspects such as developing a PWM wave for the speed control of the engine, but has a very interesting introduction related to the importance of reducing pollution towards the environment caused by transportation [5].

- “*Procesos de recarga de autobuses eléctricos y viabilidad de funcionamiento en una red de transporte público de superficie*” is a thesis performed for the University of Barcelona, which performs a study of eight different scenarios of recharge for an electric bus in Barcelona. In a higher level, it even takes into account the expected time that the bus is stopped in the traffic lights. The final conclusion is, as expected, that an electrical public transport network is cheaper in the long term [7].
- “*Integrated, feed-forward hybrid electric vehicle simulation in SIMULINK and its use for power management studies*” is a project realised by several authors for the University of Michigan. A hybrid electric vehicle simulation tool very similar to our own Simulink tool is used to study the fuel economy potential of hybrid military/civilian trucks. The parallel hybrid-electric vehicle system is described, together with dynamic equations that are also used in this project [8].
- “*An End has a Start – Investigating the Usage of Electric Vehicles in Commercial Fleets*” is a study performed by authors of the universities of KTH and Linköping, both in Sweden. This paper is focused specially in a Plug-In hybrid fleet of buses in Sweden, also taking into account meteorological conditions, and concludes that smaller batteries than the ones being used now for this kind of transport could be used and still fulfil the demand of energy [9].

2.3 Electrical vehicle modelling

We aim to evaluate and compare different charging strategies and battery types and sizes, seeking to conclude with the best model for each of the three countries studied. In order to do that, a model has been created which simulates the whole behaviour of a vehicle through a given route. The model needs to have input data with the weight of the vehicle, the type of fuel, the size of the battery, the roll and drag coefficient, the maximum speed, the number of gears, etc. Therefore, a study regarding the different types of vehicles, their components and the batteries has been performed and is hereby summarised.

2.3.1 Types of vehicles

Three versions of the vehicle will be considered: Hybrid, Plug-In Hybrid and Full Electric

A **hybrid vehicle** is not plugged-in to any outlet. It's batteries are charged by the ICE itself when there are power exceeds coming from breaking. A hybrid vehicle aims to reduce fuel consumption about 30% with respect to a vehicle with traditional ICE, but it is not designed to be able to circulate in exclusively electric mode. A hybrid vehicle usually uses a battery of about 10 kWh, and has typically an autonomy in electric driving of about

2 or 3 km, but the latest improvements in the efficiency of the batteries point to larger



Fig 2. Toyota Prius, hybrid electric.
Source: <http://www.toyota.com/prius/>



Fig 3. Toyota Prius, plug-hybrid.
Source: <http://www.toyota.com/prius/>

autonomy to be reached in the following years.

Plug-In Hybrid vehicles are commonly said to be “taking the best of both worlds”. They have an electric engine and a traditional ICE. You charge the battery as full electric vehicles do and also by taking power exceeds from the ICE (specially when breaking). Greater autonomy is achieved by increasing the battery’s capacity, with the consequent increase in the size of the battery. A Plug-In Hybrid will have a battery that has approximately 15-45 kWh of capability, and will be able to reach around 25-50 km autonomy in fully electric driving.

In **Full Electric** vehicles, all the energy is provided by the batteries. They don’t have any other engine or source of power. Those batteries are charged by plugging them in, obtaining up to 160 km of autonomy. Full electric vehicles do not pollute, they are completely silent and have lower maintaining costs. Also, they are able to provide all the torque since the first moment, so driving them is easier and more dynamic.



Fig 4. The two full electric cars most sold in the world. The Nissan Leaf (left), with global sales of 200,000 units, and the Tesla Model S (right), with about 100,000 units in December 2015.

Source: <http://www.hybridcars.com/plug-in-pioneers-nissan-leaf-and-chevy-volt-turn-five-years-old/>

2.3.2. EV components

The electrical part of a vehicle is roughly composed by the following elements [url6]:

Charger: Also called transformer converter, is the element that absorbs the electricity directly from the grid, normally in AC, and transforms it into CC for it to be able to recharge the principal battery.

Battery: Element in charge of storing the energy provided by the charger in DC mode. It is the main energy supply source. If the engine of the vehicle is a continuous current engine, the battery will be directly connected to it. Otherwise, the battery is connected to an inverter. A more complete analysis of the batteries will be performed later in this document.

Converter: It transforms the high voltage CC given by the battery into low voltage CC, used to feed the auxiliary batteries of 12 V in charge of providing energy to the rest of elements in the vehicle besides the engine.

Inverters: They are in charge of transforming the CC given by the principal battery into AC if the engine requires this type of current.

Engine: The electrical engine can either be driven by alternate or continuous current. The basic difference between them is the way to supply the energy and the use of an inverter in the case of AC.

A schema showing the connections between this components in a vehicle can be found in figure 5.1, and a more specific diagram for a hybrid electric bus can be found in 5.2, showing that the distribution is very similar in every case.

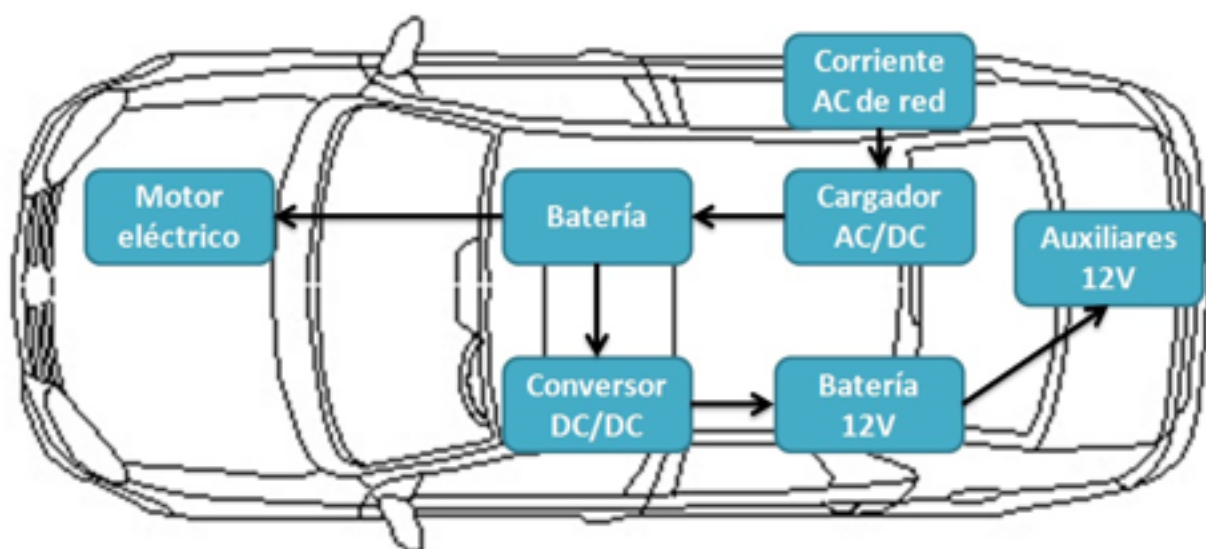


Fig 5.1. Schema of an electric vehicle. The energy is supplied by the grid (Corriente AC de red) and reaches the charger (Cargador AC/DC). After the charger there is the main battery (Batería), which is connected to the engine (Motor eléctrico) and the converter (Convertor DC/DC). The additional smaller batteries (12V) are connected to the auxiliary features of the vehicle (Auxiliares).

Source: Endesa

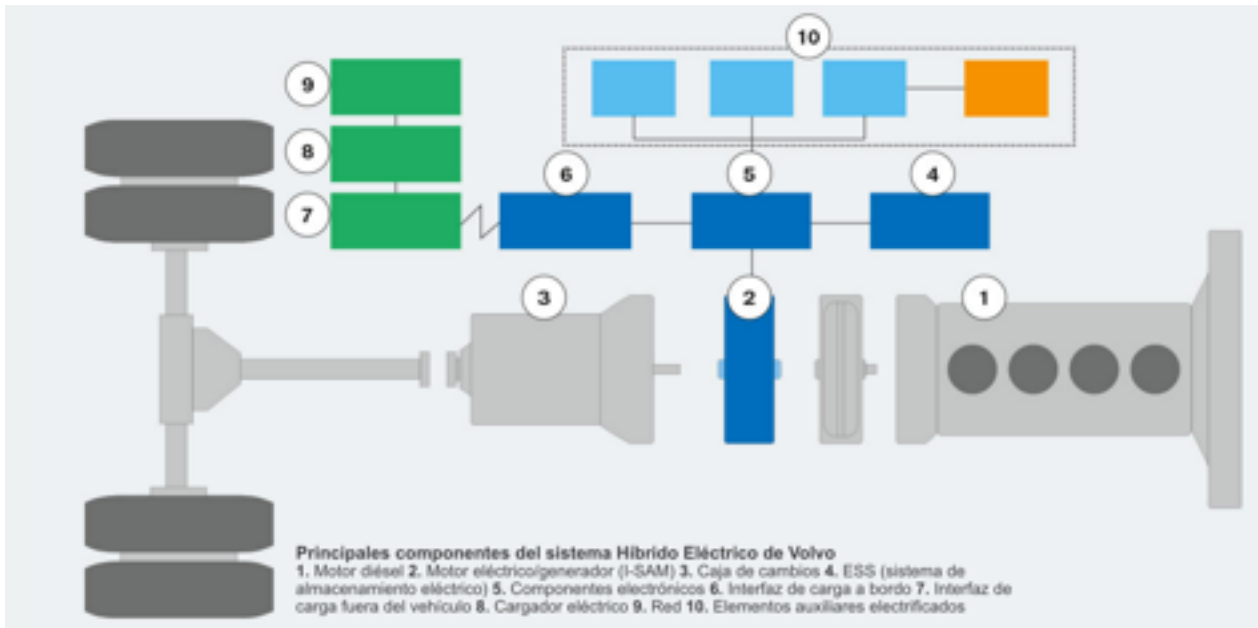


Fig 5.2. Schema of an electric bus, provided by Volvo, corresponding to the Volvo 7900 hybrid electric. As we can appreciate by comparing images 5.1 and 5.2, the electrical scheme is practically the same.

Source: Volvo

2.3.3 Batteries

As explained before, the main battery of the vehicle is the element in charge of storing the energy provided by the charger in DC mode. It is the main energy supply source, therefore, a thorough analysis has to be performed in order to choose the most suitable one.

A rechargeable battery for a vehicle has two electrodes that are placed in an ion-rich solution called the electrolyte [url7]. The positive electrode is called the cathode and the negative electrode is called the anode. There is a separator between the cathode and the anode, called polymer film, that does not allow them to touch each other in spite of being very close, since this would cause a short circuit. Lithium ions have the lowest energy when they are in the cathode and the highest energy when they are in the anode. When the battery is being charged, the external current running through it forces the lithium ions to move from the cathode to the anode. During discharge, ions move spontaneously from the anode to the cathode creating the flow of current that will generate power (see figure).

Depending on the size of the battery, it will have a single cell (like the battery for a smartphone) or several individual cells working together to produce larger amounts of power. Batteries are specified by three main characteristics: chemistry, voltage and specific energy or capacity [url8].

The cycle life of a battery is commonly expressed in number of cycles. The number of cycles that a battery can sustain depend on factors like the power level of operation, the depth of discharge (DoD), the external temperature, the speed of discharge, etc. The

same battery will for example be able to perform 1000000 cycles with a 5% DoD but only 2000 cycles with an 80% DoD. We will therefore allow a maximum of 10% DoD in our simulations. The curve that shows the lifetime of a battery regarding the number of cycles can be observed in the graph presented in figure 6 in the following page.

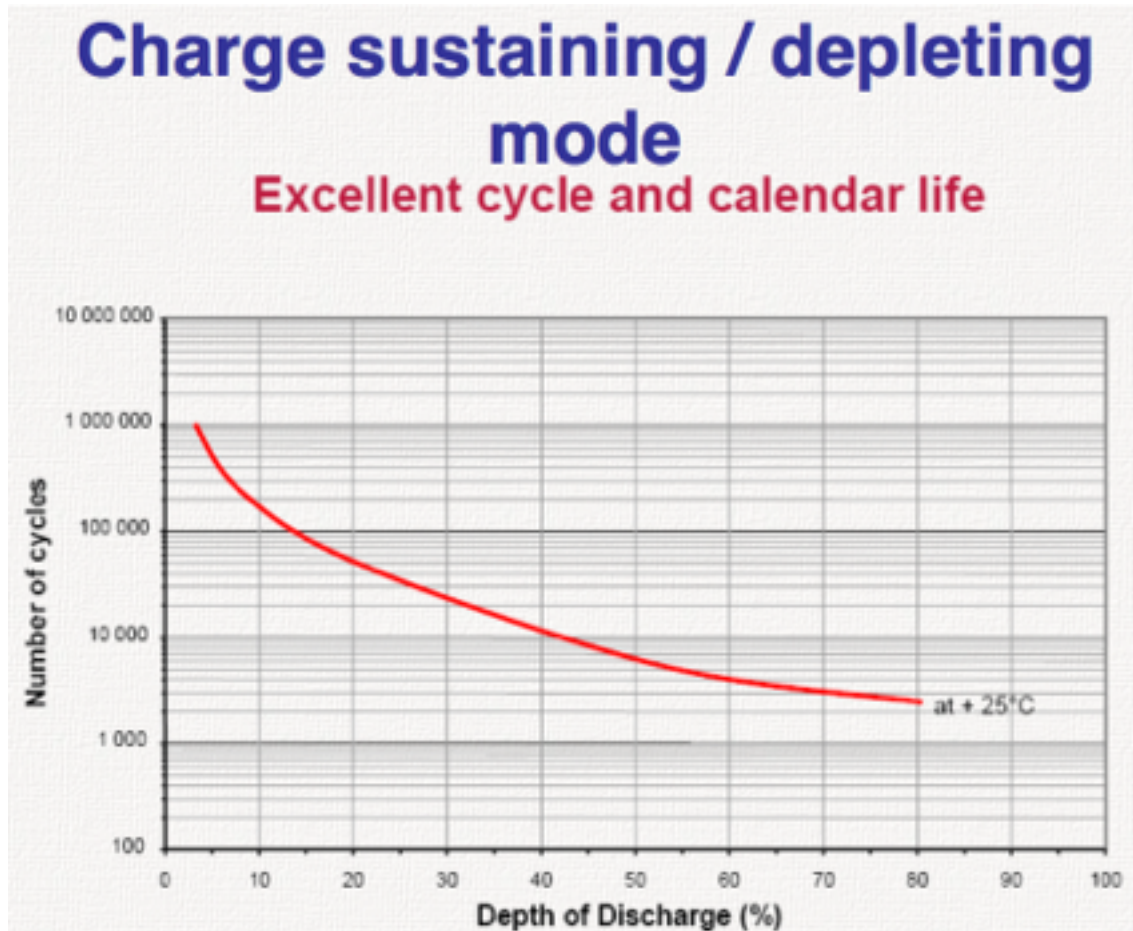


Fig 6. This graph shows the number of cycles a Li-Ion battery can sustain regarding the DoD.

Source: Lunds Tekniska Högskola

Regarding the chemistry, the two most common battery types for vehicles are the Lithium Ion (Li-ion) batteries and the Nickel-metal-hydride (Ni-MH) Batteries.

Li-ion batteries, invented by Gaston Planté in the 1860's, have a higher energy density than any other type. They have around two times as much energy as the previous generation of Ni-MH batteries, they can be recharged very quickly and they have almost no memory effect, which makes them very suitable for vehicles. The two best-selling electric vehicles in the world (shown in image 4) are the Nissan Leaf and the Tesla Model S, both powered by Li-ion batteries. There is not only one type of Li-ion batteries. The anode is typically made of graphite, but the cathode can vary, and this variations will in the end determine the cell's capacity. For traditional vehicles, the most common are Li-ion batteries based on lithium iron phosphate (LiFePO₄). For electric vehicles NMC lithium-ion

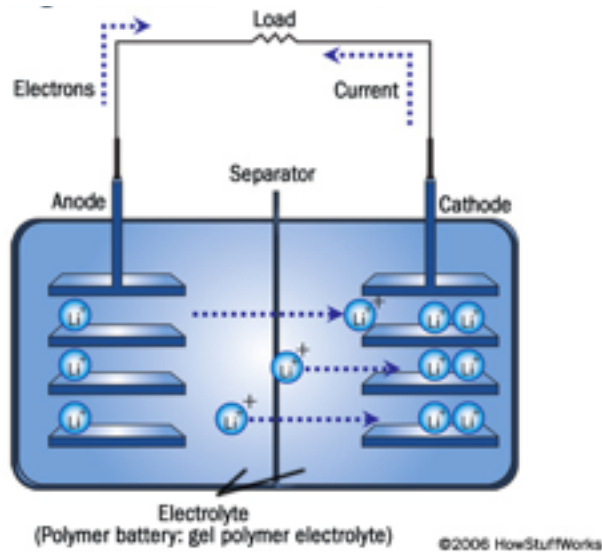


Fig 7. Lithium Ion rechargeable battery

Source: HowStuffWorks

batteries are being used recently. The main disadvantage of this type of batteries is their high production cost compared to other types of batteries, and the fact that they are very susceptible to ageing due to heat exposure and they quickly lose energy capacity, being necessary to change them before than, for example, the Ni-MH batteries [url9].

The **Ni-MH batteries**, a lot cheaper to manufacture than Li-ion batteries, are still used in a lot of current hybrid vehicles, though Li-ion are slowly taking up the market. Their main advantage is their durability, much longer than Li-ion, and the fact that the nickel contained in them is easily recycled. Their main drawback is their low energy density, only about 60% of Li-ion batteries. Therefore, they will need to be big and heavy in order to produce enough energy for a vehicle, plus, they generate quite a lot of heat while being discharged so a cooling system is needed, adding even more weight and space taken by them.

Two other important parameters of a vehicle's battery are its total energy (Wh), which determines the vehicle's electric range, or by the available power (W), which will determine the capability of acceleration.

Based on the literature presented above, we decide that our batteries will be Li-ion, which maximum output power is about the double compared to Ni-MH. Their energy density is commonly around 150 Wh/Kg, with a number of cycles of about 5000. Since a great development is currently taking place in this field and their price is expected to drop in the next few years, the economic disadvantage is considered to be less important than the great advantage of their higher capability.

We still have to make a choice for the type of cells: power optimised or energy optimised. A cell with high rate capability is able to generate a considerable amount of

power, and is considered to be “power optimised”. It suffers from little polarisation or voltage loss even at high current loads. Low rate-capability cells, called energy optimised, has the opposite behaviour. They are able to supply more energy but only for mild loads.

Thus, energy optimised cells are more suitable for loads that require low energy, like smartphones, while power optimised cells are more suitable for high energy demands like in the case of a hybrid-electric vehicle [url10].

The price, autonomy and power of our vehicle will be highly dependent on the choice of the capacity for the battery, so, in order to reach an appropriate capacity, several different values will be tried in the Matlab model and the outcome of the simulations will be taken into consideration for the final choice.

Our simulations will be based on Kokam batteries data of Large Capacity Lilon cells as of February 2010. With Power/energy ratios above 5 W/Wh Power Optimised batteries are assumed with 130 Wh/kg and 1300 W/kg. Otherwise, for low capability, Energy Optimised cells are used, with 160 Wh/kg and 500 W/kg. Except in the extreme case of using a very small battery for the hybrid case, most of the simulations will be conducted for power optimised cells then.

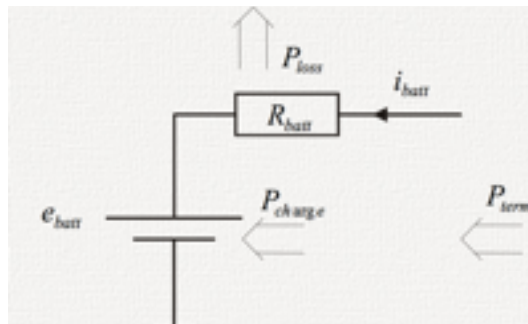


Fig 8. Schematic model of the battery used for our simulations.

Source: Lunds Tekniska Högskola

2.4 Conclusions

The information presented in this chapter has related to hybrid and electrical vehicles in general, but it can be applied both for cars and buses. The difference is that of course, since a bus is bigger and heavier, the engine and the batteries will need to be more powerful than in the case of a particular car.

With the help of the projects shown in section 2.2 and other information found in the internet and with the help of the universities of Lund LTH, TU Delft and Universidad Pontificia Comillas, we will update our model with the parameters presented in section 2.3 and we will arrive to a conclusion on which model suits best the european conditions for introducing the electrical vehicles as the main way of public transport, replacing the traditional fuel fossil engines for a more environmentally friendly way of transport. The three vehicles studied will be Hybrid, Plug-In Hybrid, and Full Electric. The components are defined in the model, and the batteries chosen will be formed by large capacity Li-Ion cells.

Chapter 3

Technical analysis

3.1. Introduction

The analysis carried out in this document is based on Software resources for the simulations and research regarding prices and current technologies that can be applied to our efficient vehicle. Therefore, Matlab (version R2015b) and Simulink (version R2012b) are used, as well as excel for some extra calculations, data storing and and graph creation.

Later in this chapter we will also explain the different case studies that will be taken into consideration and thoroughly analysed. There are two different subcategories in which we divide our research. On one hand, as explained before, we will consider three different european countries: Sweden, Spain and The Netherlands. This pursues a general view about Europe and we expect to arrive to a conclusion on if the same model applies to the whole area or there are significant differences that make different models suitable for each country. The three different cycles are explained in section 4.2. On the other hand, the second classification regards the ways of recharge for the batteries, which are of course different depending on the type of vehicle, as explained in chapter 2. The hybrid vehicle will have no external recharge, while the plug-in and the full electric will indeed need some ind of external source for recharging the batteries. All of this will be explained in detail in section 4.3.

3.2 Bus modelling in Matlab

The input data for modelling our bus in Matlab is detailed in section 3.2.1, and the Simulink model is explained in section 3.2.3. The main source for information and research will be the internet and specialised books on the topic found on TU Delft's library, as well as the theory book "Hybrid Drive Systems for Vehicles" from Lunds Tekniska Högskola by professor Mats Alakula [6]. The basic Simulink model for the vehicle has also been obtained from this course and was originally created to represent a Swedish cycle. Later it has been modified to represent the three countries and updated with accurate data for a city bus. The whole Matlab script showing how the inputs are settled and the outputs are obtained can be followed in the Annex of this document.

3.2.1 Data requirements

The specific steps for performing a whole case of the simulation are as follows:

First, the data for the vehicle are introduced in Matlab. An example for the Swedish case is presented here.

- $M_v = 14000$. This parameter represents the vehicle weight in Kg, considered with an average of half of the passengers the bus is able to transport at once.
- $R_w = 0.30$. This parameter represents the wheel radius in meters.

- $C_d = 0.26$. This parameter is related to the air resistance. Drag resistance measures how much an object resists movement through a fluid. It is mainly determined by the drag coefficient (C_d) and the frontal area. Basically, a vehicle with a lower C_d can “slip” better through air.
- $C_r = 0.009$. This parameter represents the roll resistance. Rolling resistance is the force resisting motion when a body rolls on a surface. It is considered constant, and proportional to the vehicle weight, the gravitation, the speed (only at very low speeds, below 1m/s) and the roll resistance coefficient of the tyres (C_r). C_r depends on the sinkage depth and the diameter of the rigid wheel. Research conducted by The Society of Automotive Engineers (SAE) range C_r on values from 0.0062 to 0.015.
- $A_v = 2.550 \times 2.92$. This parameter represents the frontal area of the vehicle, in this case the Swedish bus Volvo FE6x2.
- $V_{max} = 172/3.6$. Maximum speed attainable by the vehicle. We introduce it in km/h and by dividing it by 3.6 we turn it into m/s, unit used later in the Simulink.
- $P_{max} = 200000$. Maximum battery size tolerable by the vehicle.
- $Number_of_gears = 6$. We will consider the number of gears to be 6 in every case.
- $P_{aux} = 1000$. Energy provided by the secondary batteries of 12V that are connected to the auxiliary devices from the vehicle, in this case without considering the air conditioning.

3.2.2 Simulink model

After the Matlab is set, all the data is sent to the Simulink model, which runs the vehicle and gives out data regarding the fuel consumption, the State Of Charge from the battery, the lost power, etc. This data is stored and compared for different battery scenarios, allowing us to arrive to a final conclusion about the best choice. The main screen of the Simulink and the most important component diagrams are shown and explained in the graphs below, all configuring figure 9. Every coloured box has its own diagram inside, creating the battery, the engine and other components from the vehicle. The inputs and the outputs are shown as figures called “from workspace” or “to workspace”, meaning, that they are obtained or returned to the Matlab program that we are running at the same time as this Simulink. The Matlab Code can be seen in the Annex attached at the end of this document. The detailed process for every important step performed by the Simulink is explained below with the help of the images.

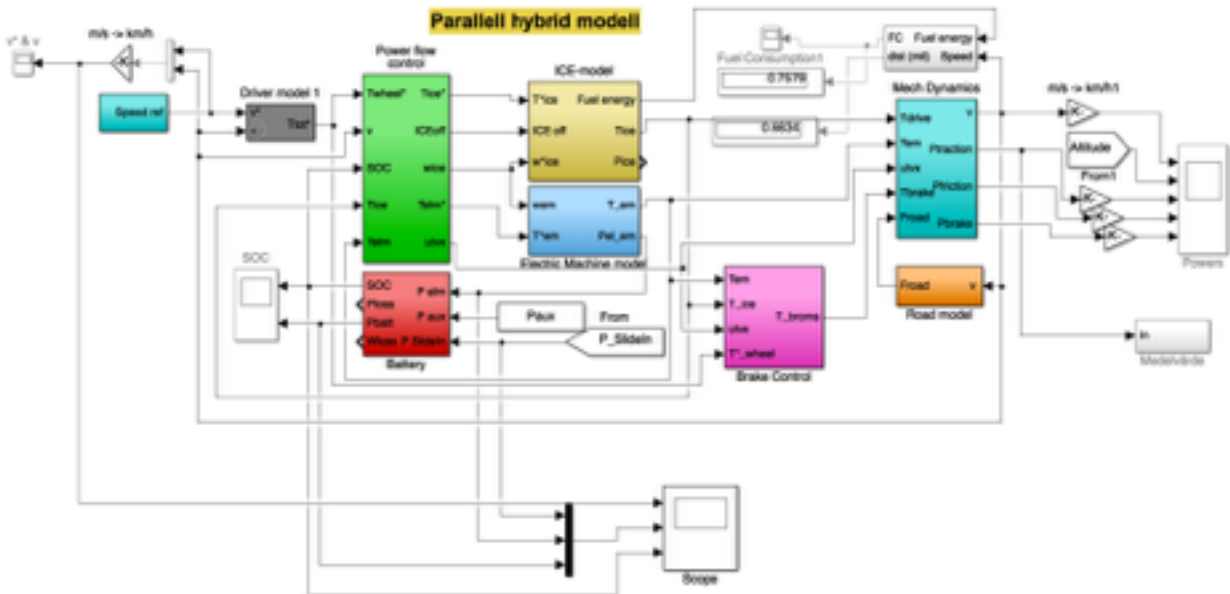


Fig 9: Screenshot of the main screen for our Simulink model.

In the main screen of our model, shown in figure 9, we can see the whole parallel hybrid diagram. As explained more thoroughly later in section 3.4.1, in a parallel model the ICE is connected to the wheels via the gearbox, which in this case is contained in the green box named “Power flow control”. The only variable direct inputs appreciated in this stage are the speed reference and the P_SlideIn. The speed reference is coming from the second column of our data matrix created in the Matlab specifically for every country, while the P_SlideIn is a value that determines if the bus is receiving external recharge at every point of the cycle, and that comes from the sixth column of our data matrix. The Paux is also an input that is constant for the vehicle and establishes the additional power used for the accessories of the vehicle, like music or GPS. The rest of the inputs belong inside of one of the coloured boxes and will be explained later. The outputs obtained in this screen are the real speed (trying to follow the speed reference but not always capable of it), the fuel consumption and distance travelled, the SoC of the battery, the different powers of the engine.

In figure 9.1 we can see the modelling of the battery. The input values, received from the main screen as shown in figure 9, are the powers provided by the engine. Since our battery is considered to be discharged while the vehicle is running normally, they are multiplied by -1 to invert the sign before the add of all the powers enters the whole circuit. Several lookup tables are included to conform the model of a Li-Ion battery and the outputs of this box are the lost power and the SoC of the battery.

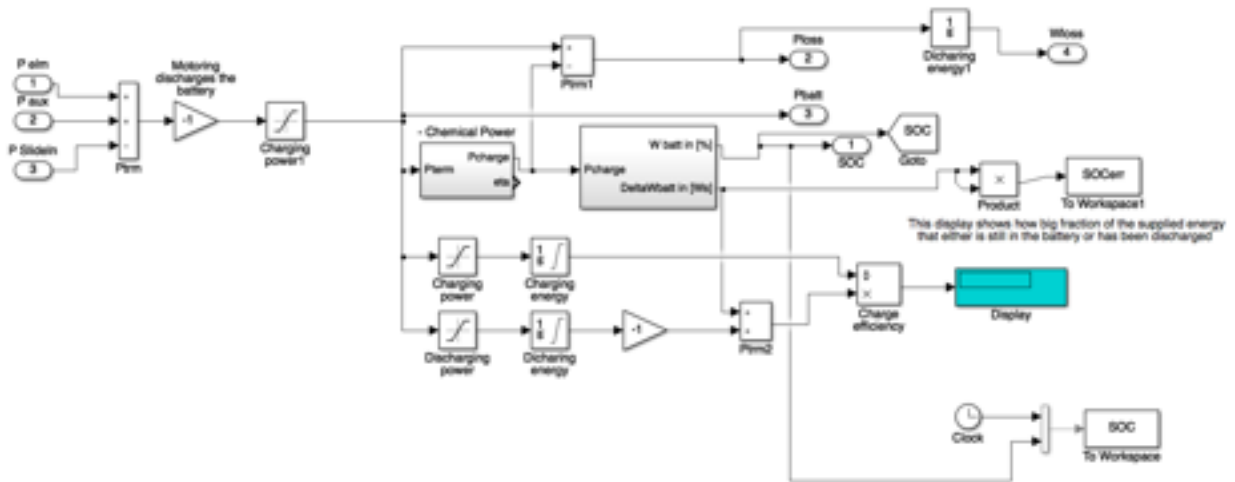


Fig 9.1: Screenshot of the diagram for the battery.

In figure 9.2 the model for the ICE is shown, only active in the hybrid and plug-in hybrid case. The most important output variable obtaining through it is the fuel consumption. As we can see, the input variables are the torque and the power of the engine, coming from the Matlab.

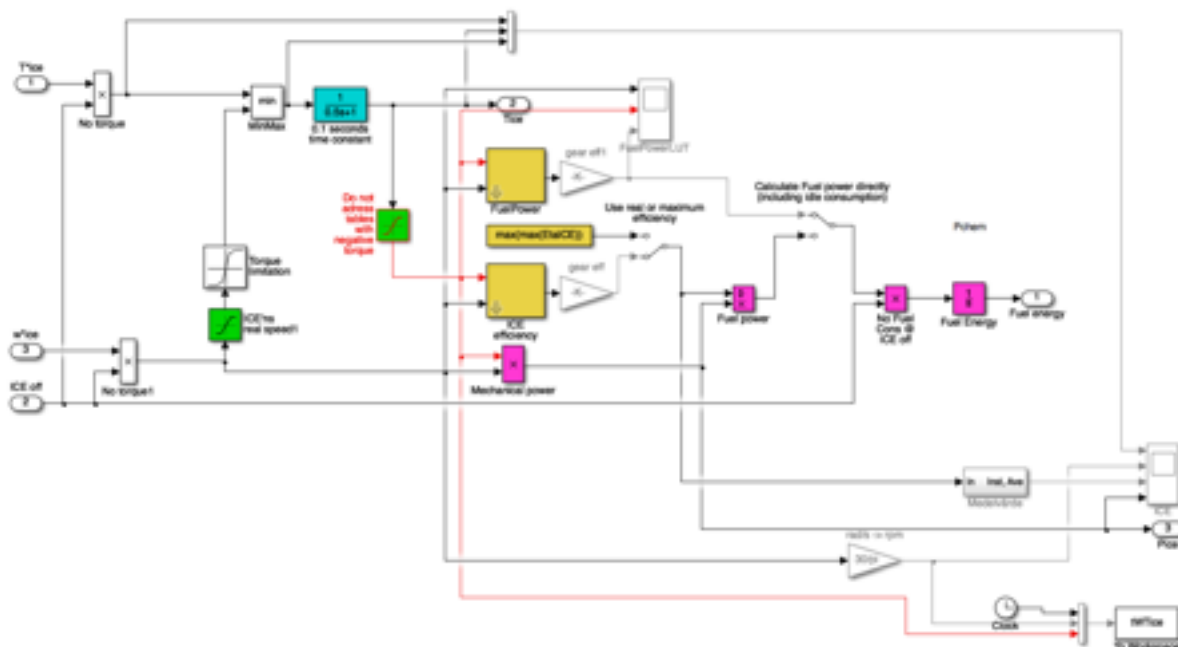


Fig 9.2: Screenshot of the diagram for the ICE (traditional Otto engine).

In figure 9.3 we can see the model for the electrical machine, meaning, the electrical engine of the vehicle. The maximum torque of the machine is delimited by the speed and power available, therefore, the maximum torque can be calculated if the speed and the maximum torque are known. If the vehicle is not in the hybrid operation, the electric motor is not working. The electric power drawn from the battery is estimated from the shaft output and the efficiency of the EM. In engine operation, the electrical power supplied will be higher than the shaft power. In generator mode, on the contrary, the discharged electric power will be lower than the shaft power.

The inputs for the EM diagram are the torque and power of the EM, which can be seen in figure 9, and we obtain as an output the power delivered considering losses and the efficient torque.

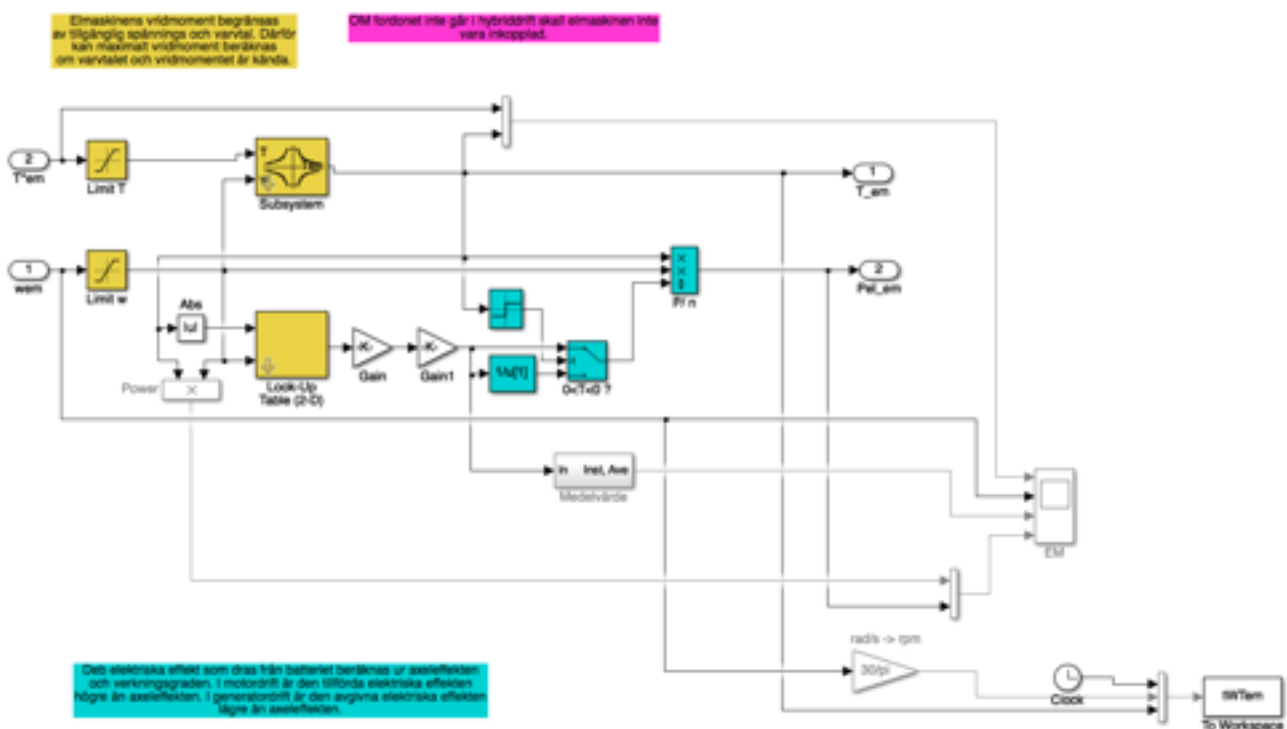


Fig 9.3: Screenshot of the diagram for the EM (Electrical Machine).

Finally, in figure 9.4 we have the diagram of the general Power Flow Control for the vehicle. This part combines the effect of the EM and the ICE. For example, it is the box in charge of switching to ICE mode when the EM can not continue or the responsible for introducing the P_SlideIn, which is the external recharge from a station or from ERS. This box has several inputs, such as the speed, the SoC of the battery and all the torques from the ICE, the EM and the wheels. The basic output is the real torque provided by the EM and the ICE.

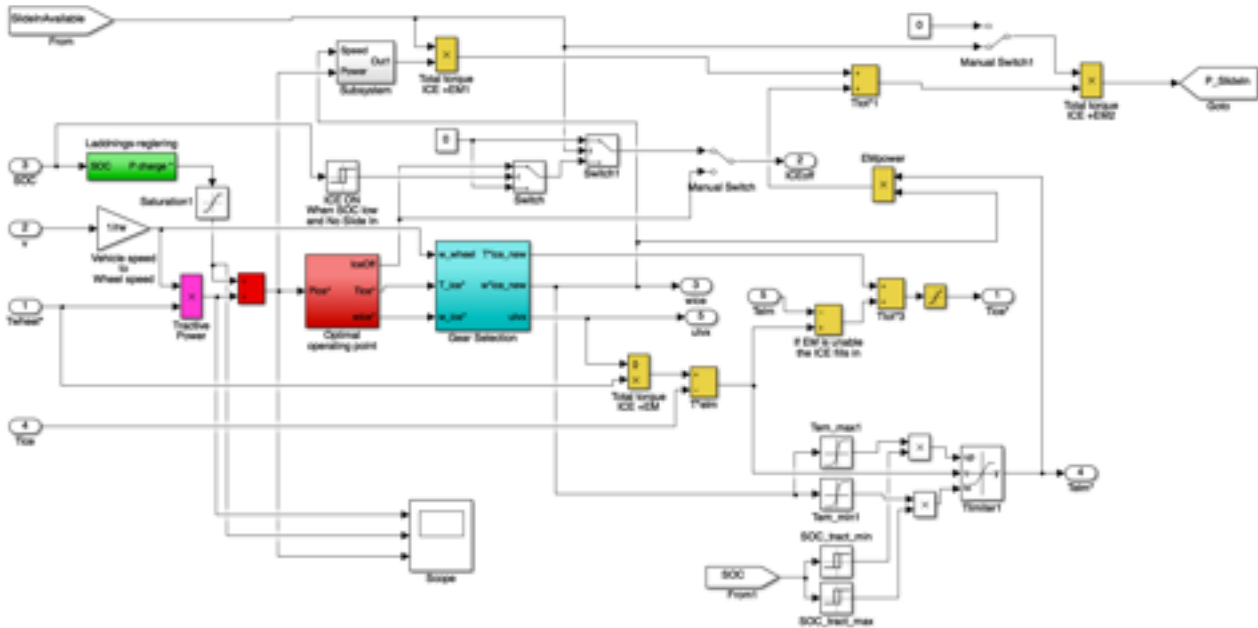


Fig 9.4: Screenshot of the diagram for the general power control of our vehicle.

3.3 Driving patterns

As explained before, three different cycles, one for each country, have been created. These cycles are created by filling a six column matrix in which the first row corresponds to the time, the second row corresponds to the speed, the third row corresponds to the distance travelled, the fourth and the fifth row are in our case kept as zero but would represent the differences in altitude and slope, and the sixth column will determine if the vehicle is receiving external recharge or not for every second of the cycle. The time for the stops has been slightly modified compared to the real schedule, in order to make the line more efficient in terms of fuel consumption. The maximum speed for each stop has been tried to be kept as homogeneous as possible, while reducing the acceleration the bus needs to perform to arrive to the next station on time. The specific data for the real bus lines in Gothenburg, Madrid and Amsterdam are detailed in the following sections. For the summarised data of the three cycles see tables 1,2,3 in annex I.

3.3.1 Sweden

For the Swedish cycle, line 702 from Söne Träfilken in Mariestad has been chosen. This line has a distance of around 15 km divided in 12 stops and the time for one ride is about 25 minutes. The details are hereby presented.

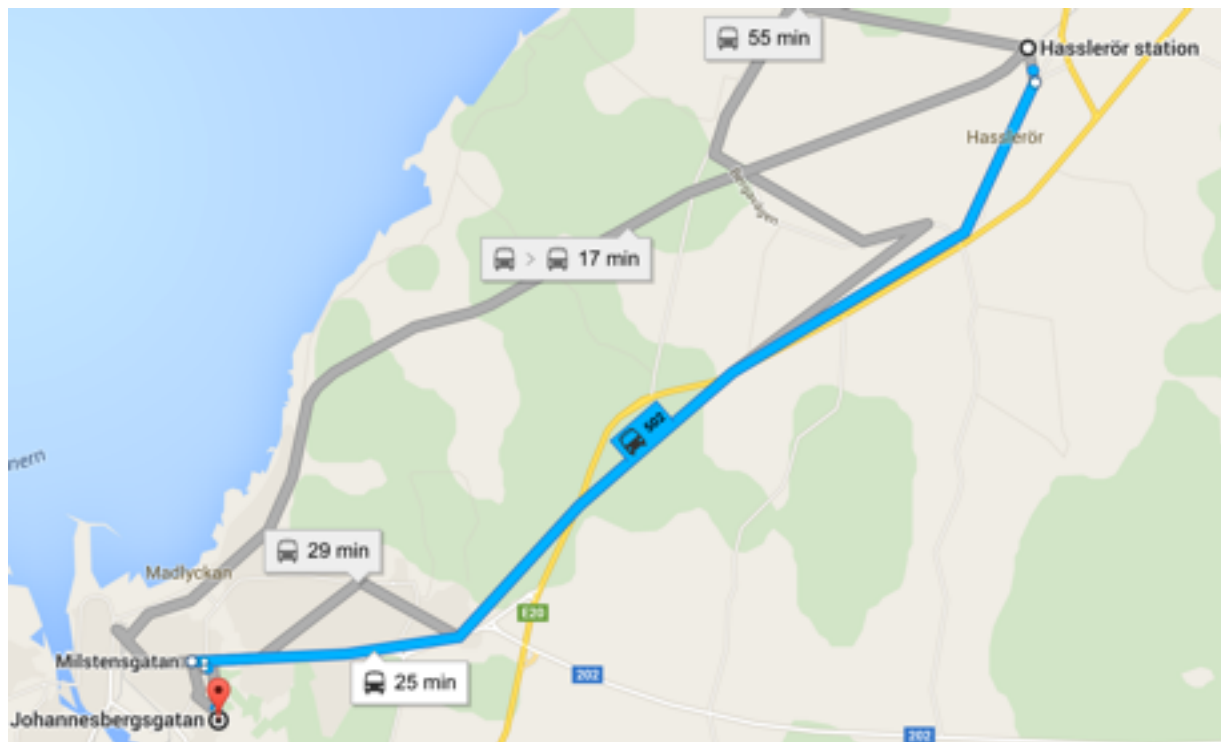


Fig 10: Map of the Swedish line. **Source:** Google Maps.

Linjesträckning

Johannesberg - Brodderud - Ingarud - Ingarud* - Brodderud* - Lövåsen - Torstentorp - Backen - Sörgården* - Storegården - Berga vägskäl - Hasslerörs skola*
MÅNDAGAR - FREDAGAR

Hållplats	Km-Ack	Tid	På	Av	Byte
Johannesberg	0	7.05			
Brodderud	2.89	7.08			
Ingarud	4.51	7.10			
Ingarud*	5.84	7.15			
Brodderud*	7.24	7.17			
Lövåsen	8.69	7.20			
Torstentorp	10.1	7.22			
Backen	10.83	7.23			
Sörgården*	11.87	7.25			
Storegården	13.2	7.27			
Berga vägskäl	14.06	7.28			
Hasslerörs skola*	15.47	7.30			

Fig 11: Stops for the Swedish line. **Source:** Lund University.

3.3.2 Spain

For the Spanish cycle, line 149 from the EMT (Empresa Municipal de Transportes) in Madrid has been chosen. This line has a distance of around 6,5 km divided in 22 stops and the time for one ride is almost half an hour. The details are hereby presented:



Fig 12: Stops for the Spanish line. Source: EMT Madrid.

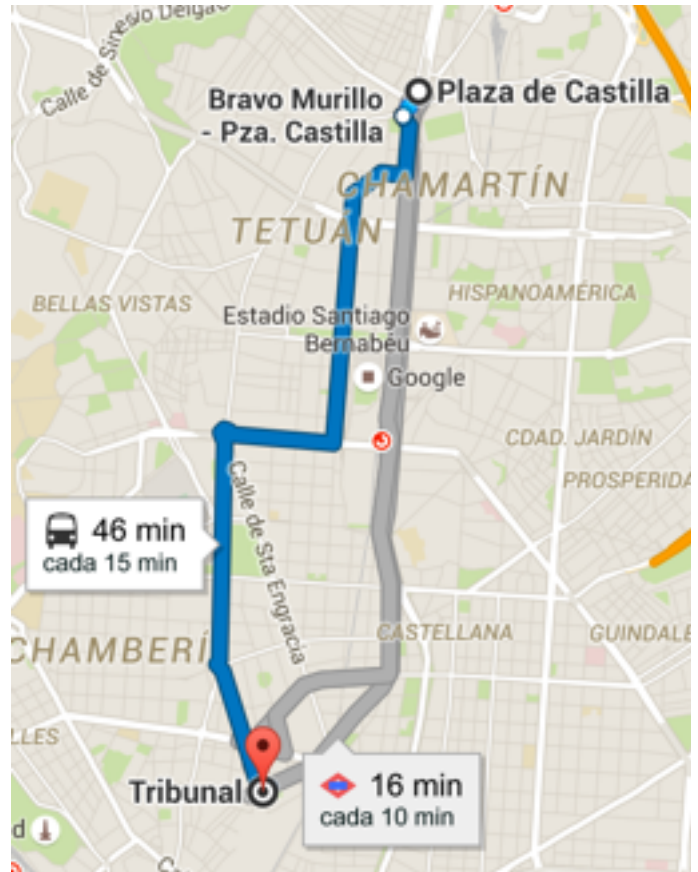


Fig 13: Map of the Spanish line. Source: Google Maps.

3.3.3 The Netherlands

For the Dutch cycle, line 18 from the in Amsterdam has been chosen. This line has a distance of around 10 km divided in 26 stops and the time for one ride is around 36 minutes. The details are presented below:

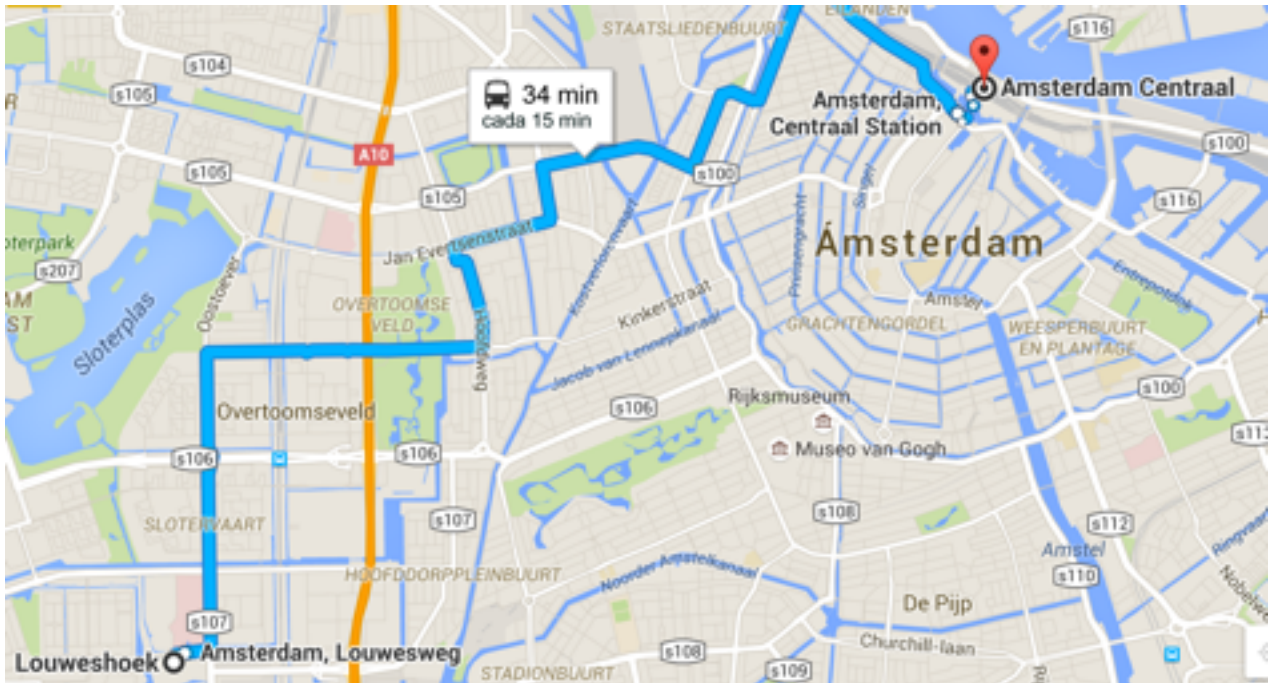


Fig 14: Map of the Dutch line. Source: Google Maps.

18
Slotervaart > Centraal Station

28 April 2016 - 10 December 2016

18	Slotervaart > Centraal Station																		maandag t/m vrijdag		
Louweshoek	05:45	06:00	06:15	06:27	06:37	06:47	06:57	07:07	07:17	07:27	07:37	07:47	07:57	08:07	08:17	08:27	08:37	08:47	08:57	09:07	
Cornelis Lelylaan	05:48	06:03	06:18	06:31	06:41	06:51	07:01	07:11	07:21	07:31	07:41	07:51	08:01	08:11	08:21	08:31	08:41	08:51	09:01	09:11	
Mercatorplein	05:57	06:12	06:27	06:42	06:52	07:02	07:12	07:22	07:32	07:42	07:52	08:02	08:12	08:22	08:32	08:42	08:52	09:02	09:12	09:22	
Fred. Hendrikplants.	06:04	06:19	06:34	06:50	07:01	07:11	07:21	07:31	07:41	07:51	08:01	08:11	08:21	08:31	08:41	08:51	09:01	09:11	09:21	09:31	
Centraal Station	06:13	06:28	06:43	06:58	07:11	07:21	07:31	07:41	07:51	08:01	08:11	08:21	08:31	08:41	08:51	09:01	09:11	09:21	09:31	09:41	
Louweshoek	09:17	09:27	09:37	09:47	09:57	10:07	10:17	10:27	10:37	10:47	10:57	11:07	11:17	11:27	11:37	11:47	11:57	12:06	12:16	12:26	
Cornelis Lelylaan	09:21	09:31	09:41	09:51	10:01	10:11	10:21	10:31	10:41	10:51	11:01	11:11	11:21	11:31	11:41	11:51	12:01	12:10	12:20	12:30	
Mercatorplein	09:32	09:42	09:52	10:02	10:12	10:22	10:32	10:42	10:52	11:02	11:12	11:22	11:32	11:42	11:52	12:02	12:12	12:22	12:32	12:42	
Fred. Hendrikplants.	09:41	09:51	10:01	10:11	10:21	10:31	10:41	10:51	11:01	11:11	11:21	11:31	11:41	11:51	12:01	12:11	12:21	12:31	12:41	12:51	
Centraal Station	09:51	10:01	10:11	10:21	10:31	10:41	10:51	11:01	11:11	11:21	11:31	11:41	11:51	12:01	12:11	12:21	12:31	12:41	12:51	13:01	
Louweshoek	12:36	12:46	12:56	13:06	13:16	13:26	13:36	13:46	13:56	14:06	14:16	14:26	14:36	14:46	14:56	15:06	15:16	15:26	15:36	15:46	
Cornelis Lelylaan	12:40	12:50	13:00	13:10	13:20	13:30	13:40	13:50	14:00	14:10	14:20	14:30	14:40	14:50	15:00	15:10	15:20	15:30	15:40	15:50	
Mercatorplein	12:52	13:02	13:12	13:22	13:32	13:42	13:52	14:02	14:12	14:22	14:32	14:42	14:52	15:02	15:12	15:22	15:32	15:42	15:52	16:02	
Fred. Hendrikplants.	13:01	13:11	13:21	13:31	13:41	13:51	14:01	14:11	14:21	14:31	14:41	14:51	15:01	15:11	15:21	15:31	15:41	15:51	16:01	16:11	
Centraal Station	13:11	13:21	13:31	13:41	13:51	14:01	14:11	14:21	14:31	14:41	14:51	15:01	15:11	15:21	15:31	15:41	15:51	16:01	16:11	16:21	
Louweshoek	15:56	16:06	16:16	16:26	16:36	16:46	16:56	17:06	17:16	17:26	17:36	17:46	17:56	18:07	18:17	18:27	18:37	18:47	18:57	19:07	
Cornelis Lelylaan	16:00	16:10	16:20	16:30	16:40	16:50	17:00	17:10	17:20	17:30	17:40	17:50	18:00	18:11	18:21	18:31	18:41	18:51	19:01	19:11	
Mercatorplein	16:12	16:22	16:32	16:42	16:52	17:02	17:12	17:22	17:32	17:42	17:52	18:02	18:12	18:22	18:32	18:42	18:52	19:02	19:12	19:22	
Fred. Hendrikplants.	16:21	16:31	16:41	16:51	17:01	17:11	17:21	17:31	17:41	17:51	18:01	18:11	18:21	18:31	18:41	18:51	19:01	19:11	19:21	19:31	
Centraal Station	16:31	16:41	16:51	17:01	17:11	17:21	17:31	17:41	17:51	18:01	18:11	18:21	18:31	18:41	18:51	19:01	19:11	19:21	19:31	19:41	

Fig 15: Stops for the Dutch line. Source: GVB.

3.4 Recharge options

As we have explained before, depending on the type of vehicle and the battery used, there are different options for the external recharge, summarised below.

3.4.1 No external recharge

As stated before, hybrid electrical vehicles (HEV) combine an electric engine (EM) with an internal combustion engine (ICE). In 2016, there were around 11 million hybrid electrical vehicles in the world, being the majority of them fabricated by Toyota Motor Corporation [url11].

Any vehicle has two different energy storage systems. The **primary energy storage** is the conventional tank filled with fuel, that can be gasoline, diesel, ethanol or even hydrogen or natural gas. The energy density in a fuel tank is around 3200 kWhs/litre, while the storage efficiency is 100%. A diesel engine pollutes much more than an OTTO engine (powered with gasoline), therefore they need special equipment in order to reduce the contamination of atmosphere. That makes them much more complicated than gasoline engines, so if there was an average diesel vehicle would be much more expensive to repair. Also, because of their complicated design, diesel vehicles tend to be more easily broken, specially when being used for city driving that implies continuous braking and accelerating. Because of all this, we will use always gasoline in our simulations for hybrid and plug-in hybrid vehicles. The primary energy converter, in this case the ICE, is unidirectional. The **secondary energy storage**, typically the batteries, is used to buffer energy converted by the primary energy converter or energy regenerated from braking. In hybrid electrical vehicles this is basically the electronically driven electrical machine [url12].

Hybrid electrical vehicles can be series or parallel, depending on the way the ICE is connected. In a series hybrid, the ICE and the wheels have no mechanical connection. The speed and the torque can be chosen freely, but there is a greater loss due to the energy conversions needed, which affects the efficiency in a negative way. The advantage with this type of hybrid is that the ICE can be mounted separately from the traction motor, which allows for example in buses to have a low floor. In contrast with the series, there is also a parallel model for hybrid vehicles. The main advantage is that the ICE is connected to the wheels via the gearbox, which reduces the energy conversions needed, increasing the efficiency. In our simulations, the later will be used.

3.4.2 External recharge

A plug-in electric hybrid vehicle (PHEV) is basically a hybrid vehicle with option of having its batteries recharged by being plugged into an external supply. It does also have an Internal Combustion Engine (ICE) and an Electrical Machine (EM) which alternated their use depending on the values allowed for the battery for minimal State of Charge and maximal Depth of Discharge. The Institute of Electrical and Electronics Engineers (IEEE) requires for a vehicle to be able to travel at least 16 km in exclusively electric mode without any fuel consumption to be called plug-in electric, namely, without the help of the ICE.

As in traditional hybrid vehicles, there are two basic plug-in hybrid configurations: Series and Parallel. Series plug-in hybrids are also called Extended Range Electric Vehicles (EREVs), in which the wheels are turned only by the electrical engine. They run with electricity until the battery needs to be recharged, and then the fuel is used to generate electricity. In Parallel Plug-in Hybrids the engine and electric motor are mechanically connected to the wheels and with each other. Both supply energy for the wheels to turn. Alone electrical operation usually happens at low speeds [url13].

One of the main problems for Plug-In Hybrids and for Full Electrics regards the external energy supply. A powerful and efficient supply is needed, so that charging the batteries does not take too long but still allows a minimal autonomy for the vehicle. Three possibilities for energy supply can be considered:

- Charging at night (conventional charging) and driving during the day.
- Having fast charging stations at strategic locations along the bus route.
- In addition to High Power Charging stations, also locate continuous charging sections along the route.

If a continuous charging road was to be installed all over a bus route, no batteries would be needed, but the cost of an Electric Road System is very expensive at the moment. Therefore, a possible solution is to alternate charging sections with external charging stations, or have bigger batteries which need charging less often. While obtaining energy from a road, the voltage is considered to be around 600V in our program.

Currently, there are three basic possibilities for charging the batteries of the vehicle in an external station, as explained by the electrical company Endesa [url6]:

Conventional charging: Usually uses a power level that takes about 8 hours to recharge fully a battery. It uses the same current and voltage as we have in our home (16A of AC and 230V), which implies the power provided is about 3,68 kW. This is normally used for charging private cars at home, preferably during the night when the energy demand is lower and therefore the prices of electricity are cheaper.

Semi-quick charging: The level of power used here implies about 4 hours to fully recharge a battery. It applies the same principle as traditional charging but uses a current of 32A with a voltage of 230V, so the power supplied is around 7,36 kW.

Quick charging: The main difference between this type of recharge and the two previous ones is the increase in the electrical current used, and the fact that the energy is delivered as continuous current (CC) instead of alternate current (AC). This adds up to a power level of 50kW, which can recharge 65% of a battery in only 15 minutes. This option is the easiest one for the traditional driver, used to filling his car's tank with fuel in less than 20 minutes, but it requires high levels of energy. The power delivered, for example, is comparable to the power required by a building of 15 apartments. This means that if this type of charging is spreaded, the whole grid would have to be modified to be able to accept it.

Over the past few years, superchargers have been developed and are still expecting great advances in the future. The company Tesla, for example, has created a supercharger consisting on multiple regular chargers working in parallel than can deliver up to 120 kW of DC directly to the battery.

Recent research in this area reveals that we are about to see the first wireless plug-in hybrid in the market. The company Mercedes-Benz has announced that in the ending of the year 2017 their S500e model will be released, with a wireless system that has an efficiency of around 90% and can charge with a speed of up to 3,6 kW [url14].

For the recharging possibilities in our case, we consider the conventional methods only suitable for charging the battery during the night, when the bus is not working, since then there is time enough for it to be fully recharged and it is cheaper than the quicker methods. By this method is how we assume the initial states of charge of the battery of always being between 90-95%. A conventional charger will be located in the first stop of the bus line. No simulations regarding this type of recharge will be therefore needed, but it will be taken later into consideration for the financial analysis. Our interest is directed towards the recharge needed during the day, while the bus is running and there is little time for it to be stopped since the cycle has to continue effectively. In the following sections we will perform an exhaustive analysis for Plug-In Hybrid and Full Electric vehicles and different charging scenarios in order to decide which option is more suitable for everyone of our three countries.

3.5 Conclusion

In summary, the methodology of this project is quite simple. The data is updated in the Matlab and Simulink programs, and different data is obtained for the different scenarios considered. The data is collected and compared, and a conclusion about the most convenient type of vehicle and recharge for every country is taken. For this model chosen, a financial analysis is performed in order to know the investment necessary to implement it.

The three cycles for each country have been shown and explained. As we can see, they do not have exactly the same length, which will affect the fuel consumption and SoC of the battery. In order to keep the analysis as homogeneous as possible, in the analysis of the results this will be taken into consideration. The different options for recharge have also been explained in detail. The combination of the cycles and recharge will give several cases of study, with a different simulation for every option. The results of this simulations are presented in the following chapter.

Chapter 4

Driving simulations

4.1 Introduction

In this chapter, the results of the simulations when running our Matlab cycle through the Simulink model are presented in tables. The most relevant parameters that have been changed from case to case are specified.

4.2 Hybrid Vehicle

With a hybrid electrical vehicle there is no external source for charging. The battery is recharged by the part of the ICE that is not being used to power the vehicle and by regenerating the braking power instead of losing it as heat [url12]. The sixth column in our data matrix, which represents the external plug-in is therefore always 0. For the battery parameters, we set a reference value of around 80-90% (the value the program tries to stay close to), a starting value of 85-95% (battery almost fully charged) and a minimum value of 75-85% charge (moment in which the ICE turns on), with the purpose of only allowing a small DoD and increasing the battery life. Several battery sizes and DoD allowed will be simulated for every country, seeking for a battery that lasts at least for three years without needing to be changed and that is not excessively big. The results are summarised below.



Fig 16. Hybrid Electrical Bus, model 7700 by Volvo, taken in Gothenburg, Sweden.

Source: Bus-Bild.de

4.2.1 Swedish Hybrid Vehicle

The speed across time and distance travelled obtained from the Matlab cycle are presented in the graph below.

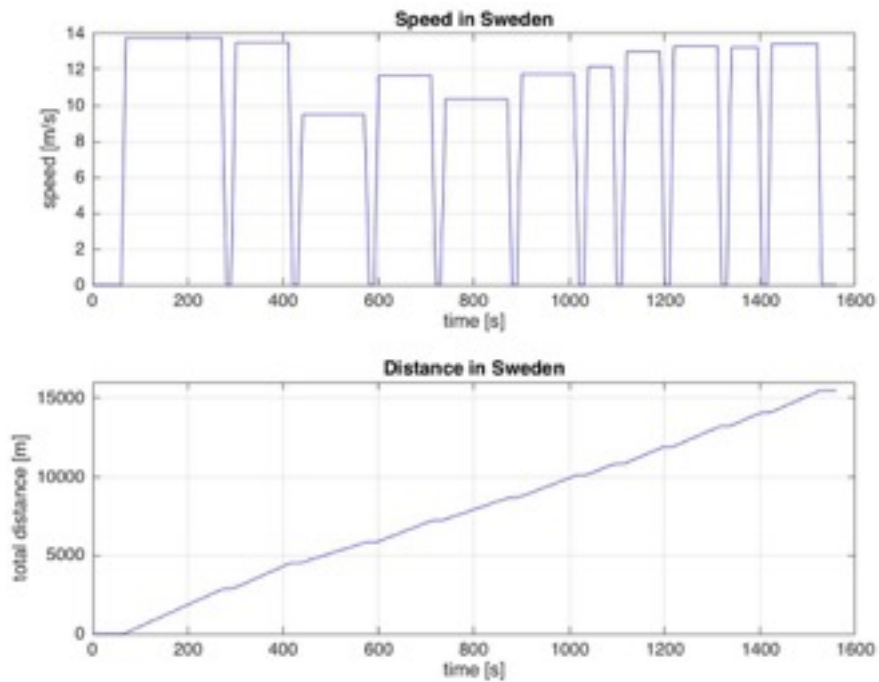


Fig 17. Graphs obtained by running the Hybrid Swedish Matlab cycle

The results obtained when driving our hybrid bus through the Swedish cycle are summarised in the table below.

Case	Battery Capacity (kWh)	Fuel Consumption (litre/mil)	Minimum Battery Mass (kg)	SOCref (%)	SOCmin (%)	SOCinitial (%)
S.A	15	1.182	100	90	80	95
S.B	18	1.104	112.5	85	85	95
S.C	20	1.069	112.5	85	80	90
S.D	16	1.434	100	90	80	90
S.E	18	0,794	112.5	90	70	90
S.F	18	1.329	112.5	95	80	90
S.G	10	1.116	100	95	70	90

Table 4. Summary of Swedish results.

4.2.2 Spanish Hybrid Vehicle

The speed across time and distance travelled obtained from the Matlab cycle are presented in the graph below.

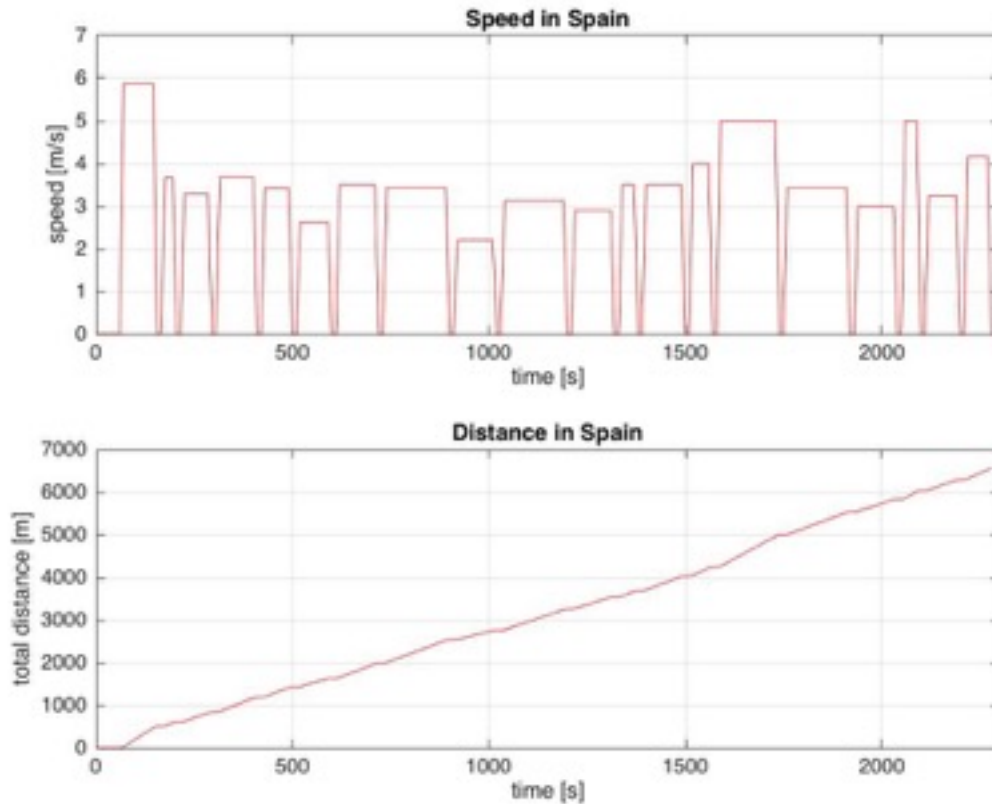


Fig 18. Graphs obtained by running the Matlab cycle

The results obtained by driving our bus through the Spanish cycle are shown in the table below.

Case	Battery Capacity (kWh)	Fuel Consumption (litre/mil)	Minimum Battery Mass (kg)	SOCref (%)	SOCmin (%)	SOCinitial (%)
E.A	15	1.117	93.75	95	80	90
E.B	16	1.256	100	90	80	95
E.C	16	0,221	100	90	70	90
E.D	12	1.611	80	90	80	90
E.E	14	1.142	80	85	80	90
E.F	10	0,716	80	85	70	90
E.G	12	0,707	80	85	80	95

4.2.3 Dutch Hybrid Vehicle

The speed across time and distance travelled obtained from the Matlab cycle are presented here.

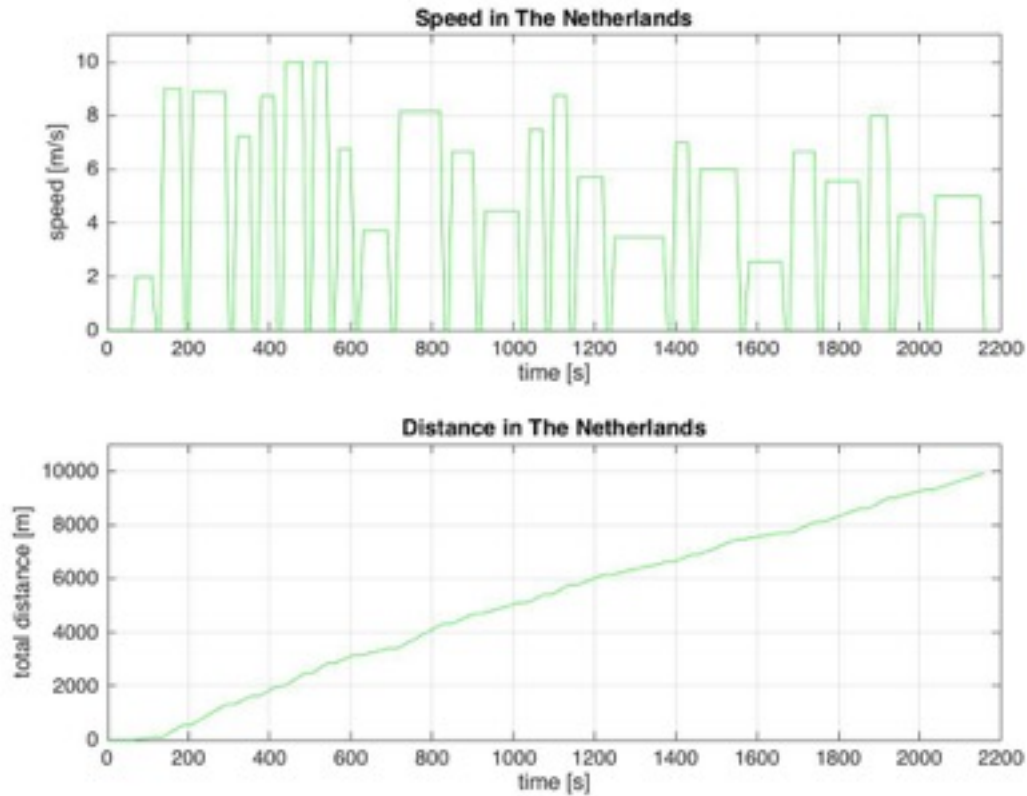


Fig 19. Graphs obtained by running the Dutch Hybrid Matlab cycle

The results obtained when driving our bus through the Dutch cycle are shown in the table below.

Case	Battery Capacity (kWh)	Fuel Consumption (litre/mil)	Minimum Battery Mass (kg)	SOCref (%)	SOCmin (%)	SOCinitial (%)
N.A	12	0,846	80	85	80	95
N.B	12	0,624	80	85	70	95
N.C	15	0,735	93.75	85	80	95
N.D	16	0,776	100	90	75	95
N.E	12	1.111	80	90	80	95
N.F	10	1.103	80	85	70	90
N.G	14	1.022	87.5	85	80	90

Table 6. Summary of Dutch results.

4.3 Plug-In Vehicle

We first considered the case in which we could perform a stop of 10 minutes in the middle of the cycle to allow the battery to be recharged in a quick-charging station. By looking at the SoC of the battery, we realise that ten minutes are not necessary, since a recharging time of four minutes will bring up the battery of a Plug-In to around 90%. We will then perform the simulations in this section for a recharge station on the middle of the line for a 4 minute stop around the middle of the line. In all these cases, as stated before, we will also consider that there is a charging station both at the beginning and the end of the line, so that the battery can always start fully charged. It is not necessary to consider this now in the simulations, since we are only counting one cycle, but it will be considered later on in the financial analysis. All of the graphs showing SoC and FC will not be included here for practical reasons.

4.3.1 Short recharge station in Sweden.

The speed across time and distance travelled obtained from the Matlab cycle for a recharge time during four minutes around the middle of the cycle are presented in the graph below.

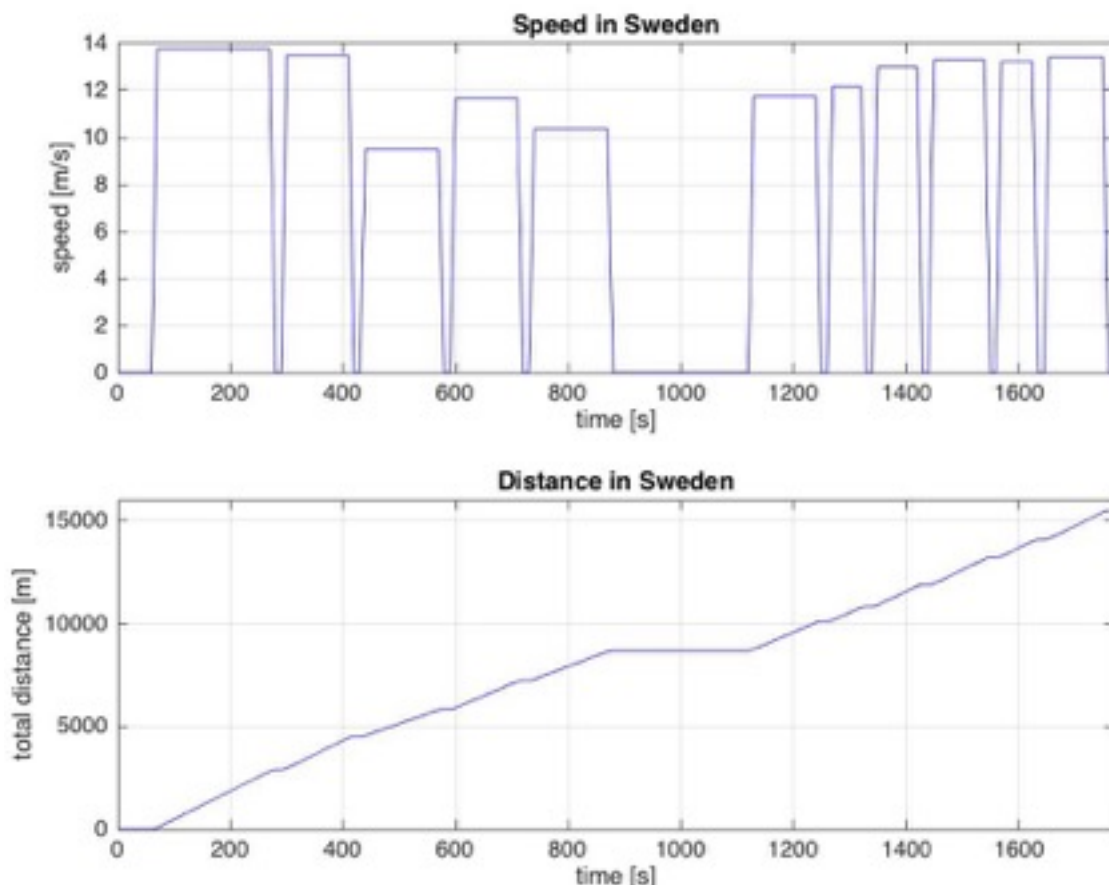


Fig 20. Graphs obtained by running the Matlab cycle

The results obtained when driving our bus through the Swedish cycle for a recharge time of four minutes are summarised in the table below.

Case	Battery Capacity (kWh)	Fuel Consumption (litre/mil)	Minimum Battery Mass (kg)	SOCref (%)	SOCmin (%)	SOCinitial (%)
S.H	20	2.062	153.846	90	75	90
S.I	15	2.887	115.384	90	80	90
S.J	25	2.581	192.307	90	80	90
S.K	40	1.868	280	90	80	90
S.L	40	0	280	90	75	95
S.M	30	0,732	230.7	90	75	95
S.N	30	2.691	230.7	90	80	95

Table 7. Summary of Swedish results.

4.3.2 Short recharge station in Spain.

The speed across time and distance travelled obtained from the Matlab cycle for a recharge time of also four minutes in the middle of the route as in the previous case are presented in the graph below.

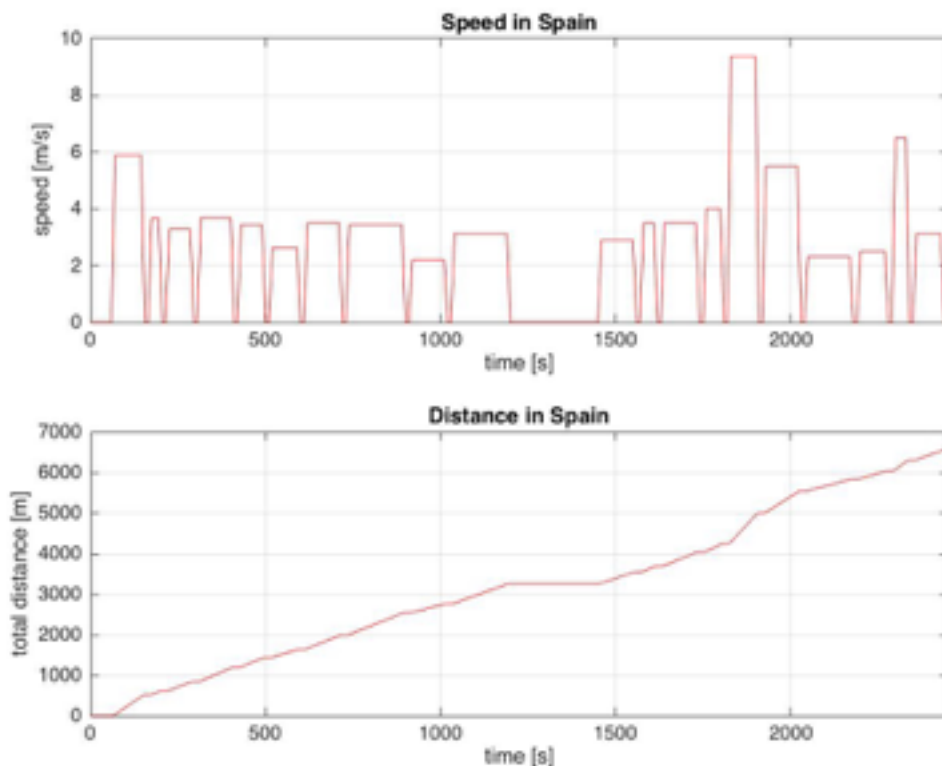


Fig 21. Graphs obtained by running the Matlab cycle

The results obtained when driving our bus through the Spanish cycle for a recharge time of 4 minutes are summarised in the table below.

Case	Battery Capacity (kWh)	Fuel Consumption (litre/mil)	Minimum Battery Mass (kg)	SOCref (%)	SOCmin (%)	SOCinitial (%)
E.H	30	1.299	230.7	90	75	95
E.I	30	2.864	230.7	90	80	95
E.J	40	2.098	280	90	80	95
E.K	40	0	280	90	75	95
E..L	30	1.299	230.7	90	75	95
E.M	35	2.876	260.23	90	75	90
E.N	20	2.563	192.307	90	75	95

Table 8. Summary of Spanish results.

4.3.3 Short recharge station in The Netherlands.

The speed across time and distance travelled obtained from the Matlab cycle for a recharge time of four minutes are presented in the graph below.

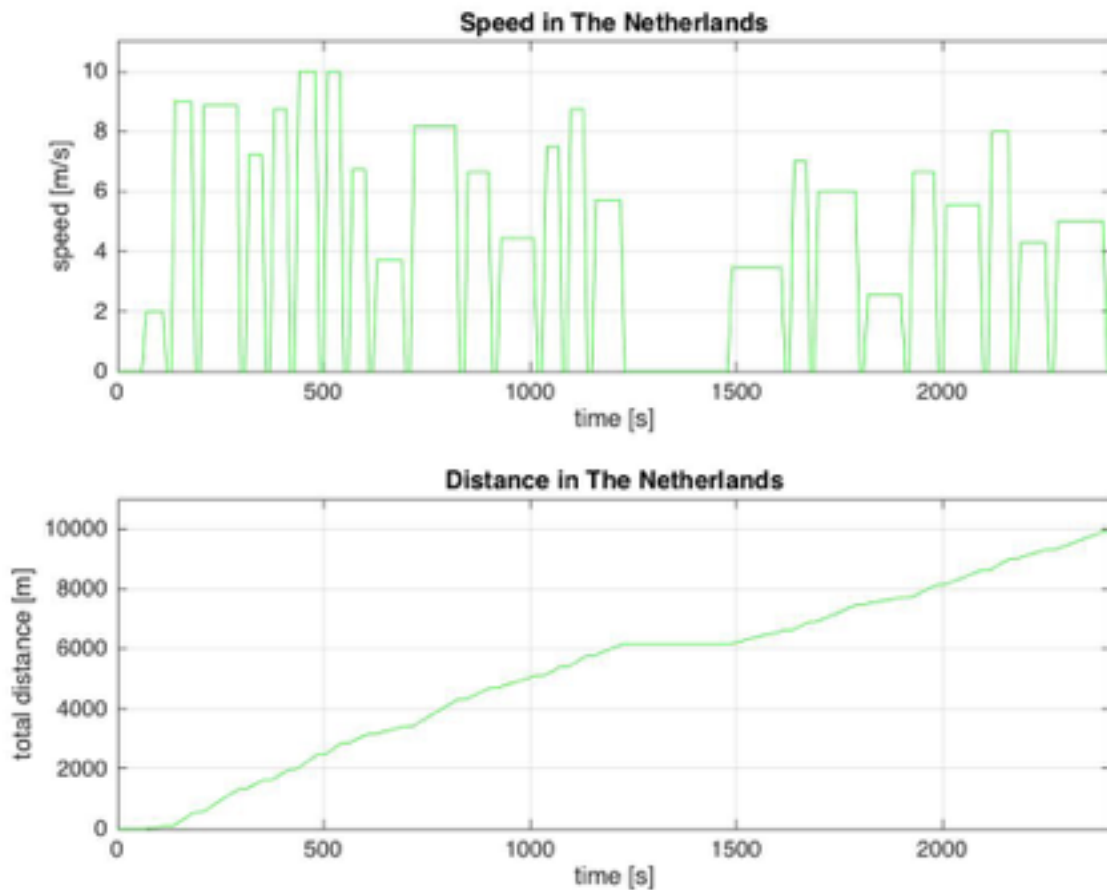


Fig 22. Graphs obtained by running the Matlab cycle

The results obtained when driving our vehicle through the Dutch cycle for a four minutes recharge time of a plug-in hybrid bus are summarised here.

Case	Battery Capacity (kWh)	Fuel Consumption (litre/mil)	Minimum Battery Mass (kg)	SOCref (%)	SOCmin (%)	SOCinitial (%)
N.H	30	2.190	230.7	90	75	95
N.I	35	2.382	260.23	95	75	95
N.J	40	3.013	280	90	80	95
N.K	35	2.442	269.23	90	75	95
N.L	25	2.079	192.307	90	70	95
N.M	30	2.11	230.7	90	70	95
N.N	40	0	280	90	70	95

Table 9. Summary of Dutch results.

4.4 Full electric vehicle

Special attention has to be paid in this case to the fuel consumption, which has to be zero at all cases. There are, therefore, some combinations of sizes and SoC of the battery that are not possible. All of the cases below have been taken into consideration only if they have zero fuel consumption, but a large number of simulations not reflected here were performed and discarded for showing some fuel consumption necessary. We will consider three different cases, two with a recharge station around the middle of the line as in the previous case but with different stopping times and one last case in which we will include the possibility of an electrical road. In this case the analysis of the graphs is particularly important because they are our main source of information for choosing a battery in absence of fuel consumption. From them we obtain the life of the battery according to the number of cycles and we can therefore know when we will need a new one and we can perform a more precise financial analysis.

As in the plug-in case, we first considered a four minute recharge in the middle of the line. The figures showing the speed and distance across time would be therefore the same as in section 4.2. However, after some simulations, we can observe that for a full electric this is not enough and very low DoD have to be allowed in order to guarantee zero fuel consumption even with large battery capacities. For example, with a very big battery of 100 kW, the maximum DoD that can be allowed is hardly 75%, which would bring a short life for such a big and expensive battery. This option is, therefore, discarded as a feasible and efficient way of recharge for an electric vehicle.

4.4.1 Two short time recharge stations

We will then consider the option of introducing two four minutes stops in the line, so that the battery can be rapidly recovered and does not reach a low DoD. It is not easy to determine the best location for this stations, so several simulations were performed trying to optimise the time between stops so that we can allow a high DoD and still have no fuel consumption.

4.4.1.1 Two short time recharge stations in Sweden

In this case, we place two quick-charging stations in which the bus is stopped for around four minutes each. Concretely, this stations are located in the stops called Ingarudd and Broderudd*. The figure that shows the speed and distance across time and the table containing the summary of the results are presented below.

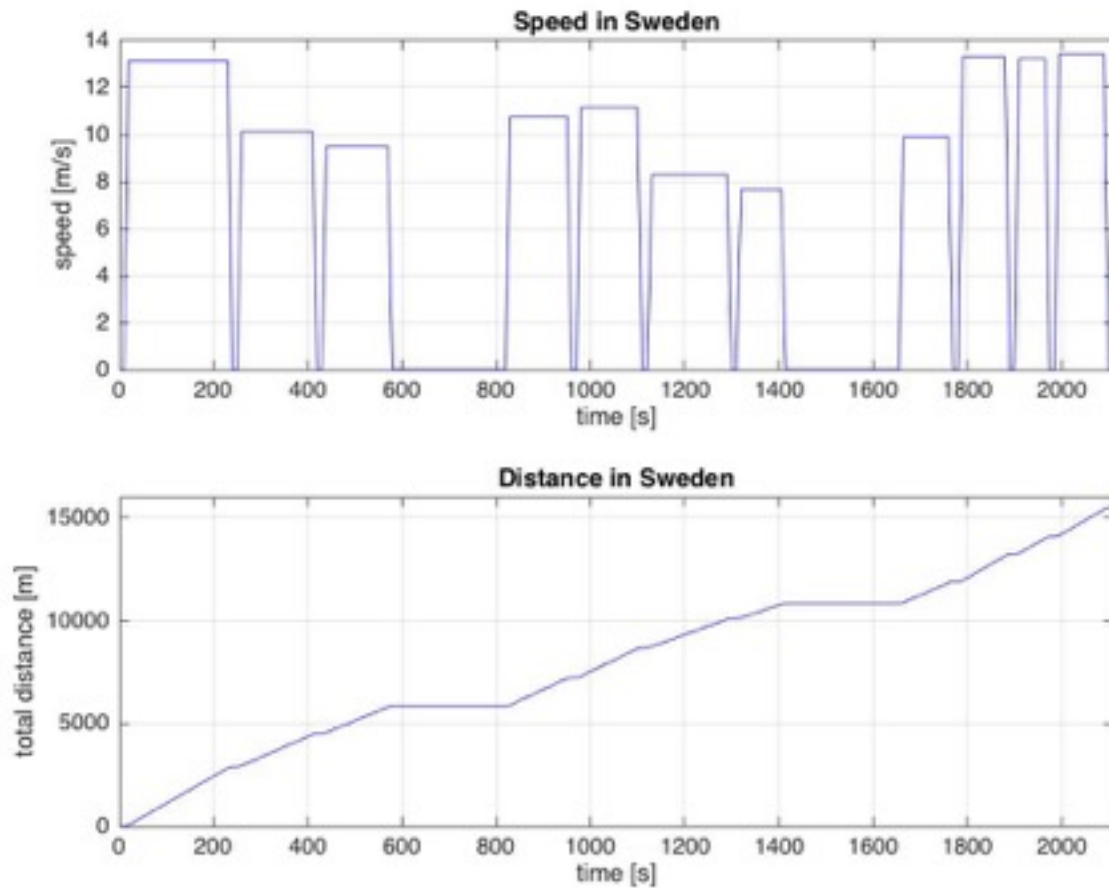


Fig 23. Graphs obtained by running the Matlab cycle

Case	Battery Capacity (kWh)	Fuel Consumption (litre/mil)	Minimum Battery Mass (kg)	SOCref (%)	SOCmin (%)	SOCinitial (%)
S.O	100	-	625	90	80	90
S.P	80	-	500	90	75	90
S.Q	75	-	437.5	95	75	90
S.R	90	-	562.5	95	75	90

Table 10. Summary of Swedish results for two charging stations . As it can be seen, if the DoD is allowed to be only up to 80%, which increases the battery life, this comes with a substantial increase on the battery capacity needed.

4.4.1.2 Two short time recharge stations in Spain

In the Spanish case, we place two quick-charging stations in which the bus is stopped during four minutes in the stops called Fuencarral - Glorieta de Quevedo and General Moscardó - General Perón. The figure that shows the speed and distance across time and the table containing the summary of the results are presented below.

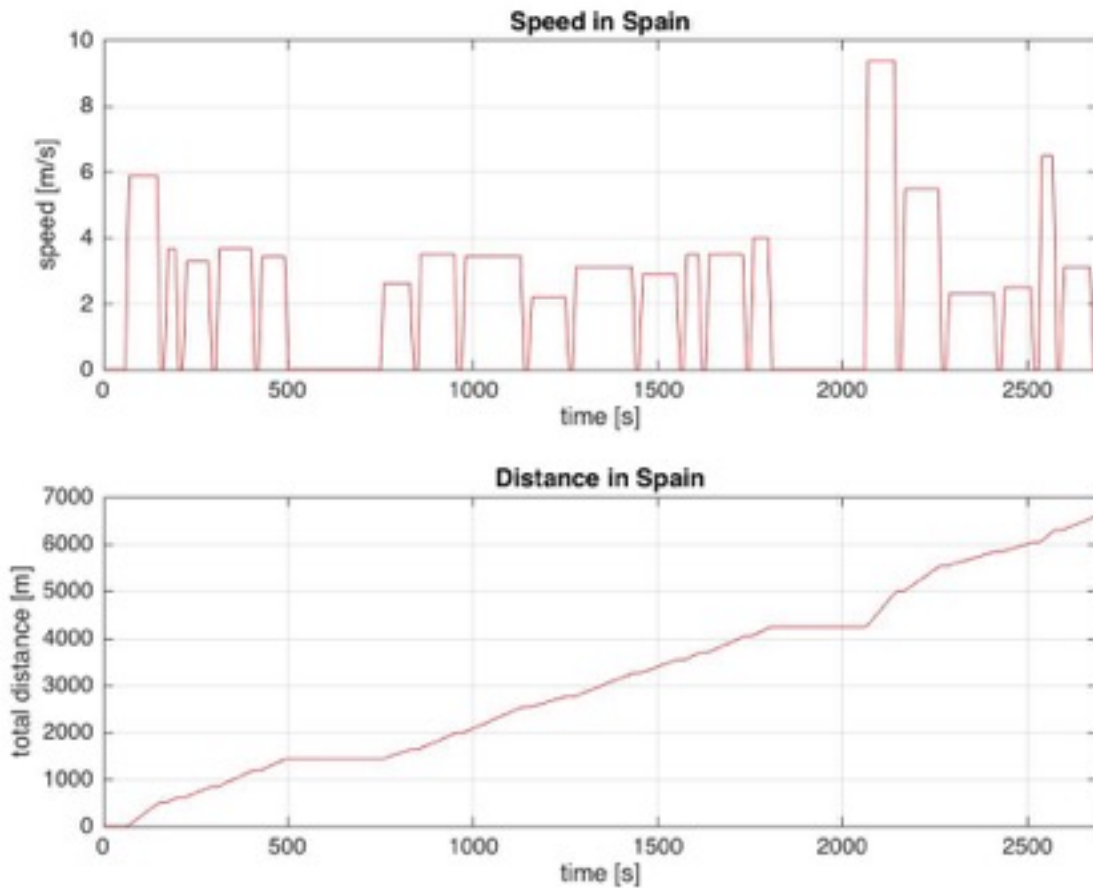


Fig 24. Graphs obtained by running the Matlab cycle

Case	Battery Capacity (kWh)	Fuel Consumption (litre/mil)	Minimum Battery Mass (kg)	SOCref (%)	SOCmin (%)	SOCinitial (%)
E.O	90	-	562.5	95	75	90
E.P	70	-	437.5	90	75	95
E.Q	80	-	500	90	80	95
E.R	100	-	625	90	75	90

Table 11. Summary of Spanish results for two charging stations, with a very similar outcome than Sweden.

4.4.1.3 Two short time recharge stations in The Netherlands

Finally, in the Dutch case we place two quick-charging stations in which the bus is stopped during four minutes in the stops called Robert Fruinlaan and Marco Polo Street. The figure that shows the speed and distance across time and the table containing the summary of the results are presented below.

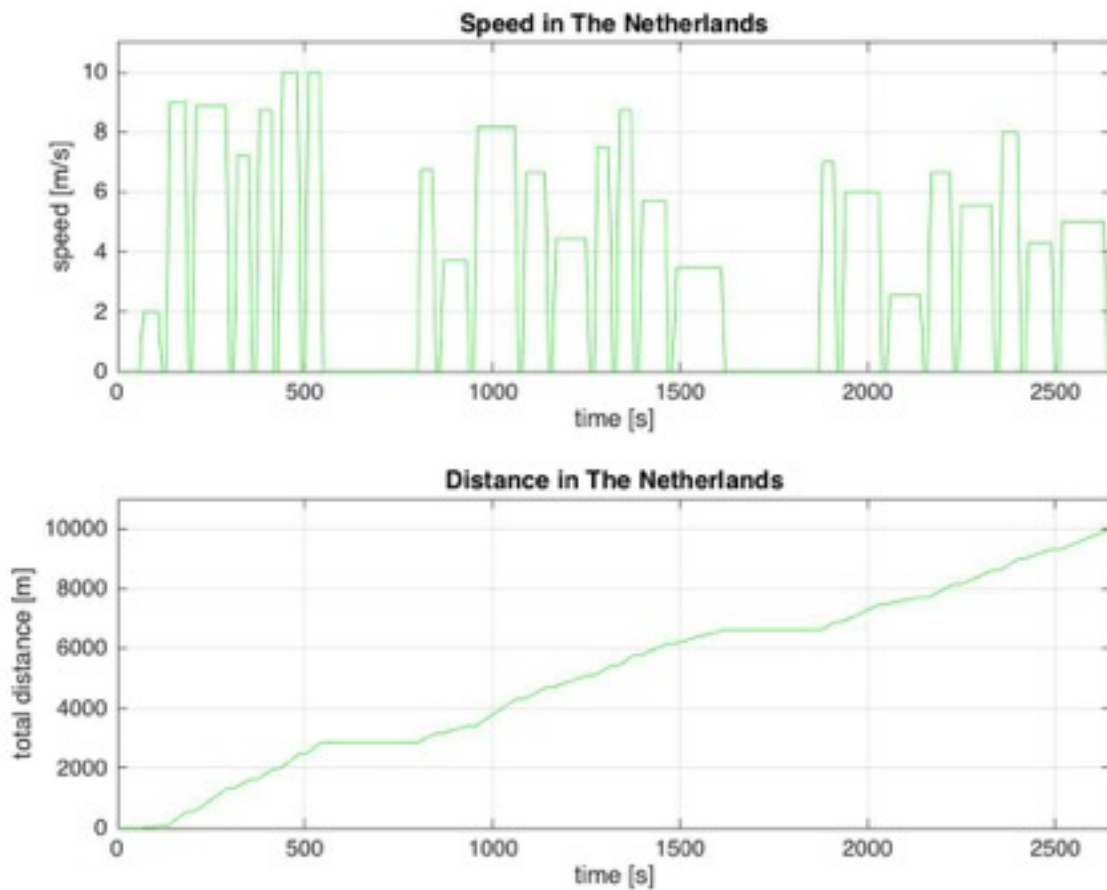


Fig 25. Graphs obtained by running the Matlab cycle

Case	Battery Capacity (kWh)	Fuel Consumption (litre/mil)	Minimum Battery Mass (kg)	SOCref (%)	SOCmin (%)	SOCinitial (%)
N.O	100	-	625	95	75	95
N.P	80	-	500	95	75	95
N.Q	80	-	500	90	75	90
N.R	95	-	593.75	95	80	95

Table 12. Summary of the Dutch results for two charging stations in the line, with a similar outcome than Sweden and Spain.

4.4.2 Electrical Road System (ERS)

As explained in the beginning of this chapter, there is also the option of installing electrical road along the way of our bus. If it was possible to cover the whole line, we would not even need batteries since the electricity would be obtained continuously directly from the road, so there would be no need to store it. However, with the current advances and prices an Electric Road System (ERS) is extremely expensive at the moment. Maybe in the future this will be an option, but for the moment it is out of scope. We will then consider a short space of ERS around the middle of the line that will recharge the batteries in our simulations. Since the bus does not need to stop any extra time compared to the initial schedule, the graphs showing distance and speed across time are the same ones as in the hybrid case and will not be displayed again in this section.

4.4.2.1 ERS in Sweden

In this case, we place the area of ERS in between the stops Ingarudd* and Broderudd*, which is a distance of 1330 metres.

Case	Battery Capacity (kWh)	Fuel Consumption (litre/mil)	Minimum Battery Mass (kg)	SOCref (%)	SOCmin (%)	SOCinitial (%)
S.S	80	-	500	95	75	95
S.T	90	-	562.5	90	75	95
S.U	60	-	400	95	75	95
S.V	70	-	437.5	95	75	90

Table 13. Summary of the Swedish results for a partially ERS in the line.

4.4.2.2 ERS in Spain

In this case, we place the area of ERS in between the stops named Santa Engracia nº 162 and General Moscardó - Hernani, which is a distance of 790 metres.

Case	Battery Capacity (kWh)	Fuel Consumption (litre/mil)	Minimum Battery Mass (kg)	SOCref (%)	SOCmin (%)	SOCinitial (%)
E.S	90	-	562.5	95	75	90
E.T	80	-	500	90	75	95
E.U	60	-	400	95	75	95
E.V	85	-	537.5	95	75	90

Table 14. Summary of the Spanish results for a partially ERS in the line.

4.4.2.3 ERS in The Netherlands

In this case, we place the area of ERS in between the stops named W. Schoutenstraat and Jan Evertsenstraat, which is a distance of 1050 metres.

Case	Battery Capacity (kWh)	Fuel Consumption (litre/mil)	Minimum Battery Mass (kg)	SOCref (%)	SOCmin (%)	SOCinitial (%)
N.S	60	-	400	95	75	95
N.T	100	-	625	90	80	90
N.U	80	-	500	90	75	90
N.V	70	-	593.75	90	75	95

Table 15. Summary of the Dutch results for a partially ERS in the line.

4.5 Conclusion

The results of the simulations when running our Matlab cycle through the Simulink model have been presented in tables. For every case, the capacity of the battery, the DoD allowed and the SoC parameters have been varied. The DoD has been kept between reasonable values so that is never higher than 25%. The mass of the battery has also been checked in every case, since a larger mass will influence negatively in the roll coefficient of the vehicle, increasing the fuel and electricity consumption. For every simulation the information has been collected and the graphs showing the SoC and the fuel consumption have also been stored but not all showed here for logistic reasons. However, they will be needed later on to obtain, for example, the lifetime of the battery, which is needed for calculating the cost of the total installation. In this chapter we have only stored the data from the simulations, and we will proceed to analyse it in the following two chapters, technically and economically.

Chapter 5

Technical analysis

5.1 Introduction

In this chapter we will have a look at all the results obtained from the simulations performed in Chapter 5 and we will make a sensible decision for the best choice of vehicle for Sweden, Spain and The Netherlands from the technical point of view. The procedure will then be to summarise the results and choose a model for every country. The first case will be fully explained, with every detail on how we reach a conclusion about the durability of the battery. Since the procedure is the same for every case, the rest will be summarised and presented in a table at the end of the first section.

5.2 Hybrid Vehicles

5.2.1 Swedish Hybrid Vehicle

In Table 4 we can observe that case S.E, with a battery of 18 kWh has the lowest fuel consumption, so it would seem as the most desirable one. However, this low consumption comes at the price of setting the minimum SoC to 70%, which is very low. This would substantially decrease the life of the battery. We will instead decide to choose a battery of 15 kWh and 93.75 kg and we set the parameters corresponding to case S.A. This produces a fuel consumption of 1.182 litre/mil, which is within the average of results obtained. By looking at the graph that shows the SoC, we estimate that one way takes about three full cycles in the battery. If the bus takes around one hour to go back and forth, and the daily schedule of the company establishes that this is done twelve times a day (from 7 a.m. to 7 p.m), this adds up to 72 cycles a day. With the help of figure 6 in chapter 2, and allowing a DoD of the 15%, we see that our battery will provide 80.000 cycles before it needs to be replaced. This implies that we can use it for three years, which is enough for us, since the battery technology is evolving so quickly that we trust that in this time there will be much cheaper and powerful batteries so it is pointless to buy more durable batteries right now. However, when possible, it is of course preferable to have a battery that lasts as long as possible.

5.2.2 Spanish Hybrid Vehicle

In the case with lowest fuel consumption, case E.C in table 5, the DoD is again 20%, which provides a total of 50.000 cycles. The number of cycles is 3 in one way, which adds up to 72 cycles a day. The lifetime of the battery, which will weigh 100 kg is then two years, which is maybe too short. The following option is chosen then, which is the 15 kWh battery in case E.A that will last for three years.

5.2.3 Dutch Hybrid Vehicle

In case N.D of table 6, the DoD is 20%, which provides a total of 50.000 cycles. The number of cycles is 2 in one way, which adds up to 48 cycles a day. The lifetime of the battery, which will weigh 100 kg is then five years.

5.3 Plug-In hybrid Vehicle

5.3.1 Swedish plug-in hybrid vehicle

In case S.M in table 7, the DoD is 15%, which provides a total of 80.000 cycles. The number of cycles is 2 in one way, which adds up to 48 cycles a day. The lifetime of the 30 kWh battery, which will weigh 230.7 kg is five years.

5.3.2 Spanish plug-in hybrid vehicle

In case E.L in table 8, the DoD is also 15%, which provides a total of 80.000 cycles. The number of cycles is again 2 in one way, which adds up to 48 cycles a day. The lifetime of the 30 kWh battery, which will weigh 230.7 kg is five years, very similarly to the previous case.

5.3.3 Dutch plug-in hybrid vehicle

In case N.N in table 9, we have managed to find a combination for which the vehicle can run the whole cycle in electrical mode, being the fuel consumption zero. The DoD is 25%, which apparently reduces the lifetime considerably, but we still have only one cycle per way which is equivalent to a total life of the battery of three years and a half. The 40 kWh battery, which will weigh 280 kg is considered to be worth it even if it is a little bigger than expected for a plug-in vehicle.

5.4 Full Electric Vehicle

5.4.1 Two recharge stations

5.4.1.1 Two recharge stations in Sweden

In this case, the only battery providing less than 3 cycles per way is the one studied in case S.O in table 10, which has a capacity of 100 kW, quite big, so quite expensive. However, since the DoD is only the 10% we have up to 110.000 cycles available, which implies a 6 year lifetime. The next option would be the 80 kWh battery, which would have a lifetime of almost 2 years, maybe too short, so we will still choose the 100 kWh battery.

5.4.1.2 Two recharge stations in Spain

In this case, all the scenarios have three cycles in one way, so we will choose the option with lower DoD in order to optimise the lifetime. This is case E.Q in table 11, with a 15% DoD will provide a lifetime of three years.

5.4.1.3 Two recharge stations in The Netherlands

We will choose here the case with less DoD, corresponding to 15% in case N.R in table 12. The lifetime of this 95 kWh battery will be three years, since it also has three cycles in one way as the previous case.

5.4.2 Electrical Road System

5.4.2.1 ERS in Sweden

The best considerable option here would be case S.S in table 13, since it has only one cycle per way and 20% DoD, which allows a lifetime of five years and a half. The size of the battery is then 80 kWh with a weigh of 500 kg.

5.4.2.2 ERS in Spain

The best scenario would here be case S.T from table 14, since it has only one cycle per way and 20% DoD, which allows a lifetime of five years and a half, exactly as in the previous case.

5.4.2.3 ERS in The Netherlands

In this case we simulated a smaller battery to check the impact, and we can see that the lifetime would be indeed too short, about a year, in case N.S from table 15, so it is not suitable. We will then rather choose, as in the two previous cases, the 80 kWh battery that provides a lifetime of around three years and a half.

		<i>SWEDEN</i>	<i>SPAIN</i>	<i>THE NETHERLANDS</i>	
No external recharge	Hybrid	15kWh	15 kWh	16 kWh	
		3 years	3 years	5 years	
		fc = 1.182	fc = 1.517	fc = 0.776	
External Recharge	Plug-In (4 minute recharge)	30 kWh	30 kWh	40 kWh	
		5 years	5 years	3.5 years	
		fc = 0.732	fc = 1.299	fc = 0	
	Full Electric (fc = 0)	Two recharge stations	100 kWh	80 kWh	95 kWh
			6 years	3 years	3 years
		ERS	80 kWh	80 kWh	80 kWh
			5.5 years	5.5 years	3.5 years

Table 16. Summary of the analysis of scenarios.

5.5 Conclusions

We have analysed the results from the simulations in Chapter 4 and a sensible decision for the best choice of vehicle for Sweden, Spain and The Netherlands has been made. Seeking clarity, the results were summarised in tables 15 and 16. We can observe how the size of the battery, as expected, increases from the hybrid vehicle, with sizes around 15 kWh up to the full electric, with big batteries of around 90 kWh. At the same time, the fuel consumption decreases equivalently from higher values in the hybrid case to zero in the full electric. The cost of the chosen installation will be now performed in the following chapter, since we look for only one option for every country.

Chapter 6

Economic analysis

6.1 Introduction

In order to perform a financial analysis, we need to consider several parameters, like the price of the batteries, the cost of electricity, the price of an external recharging station or a section of ERS... The difference between fuel and electricity prices between the three countries will be taken into account as expressed below, as huge differences can be appreciated between Sweden and Spain, being electricity per kilowatt hour more than twice as expensive in Spain than in Sweden.

6.2 Prices

The data that will be considered regarding the physical infrastructure has been provided by Lund University and will be taken as sufficiently homogeneous in Europe, since the companies providing this kind of products are mostly international.

The prices for the **infrastructure** are then [6]:

- Battery System Cost: 452 €/kWh
- External DC Charging Station: 226 €/kWh
- Electrical Road System: 452 k€/km

The prices in **Sweden** are:

- Electricity: 0.048 €/kWh [url17]
- Fossil Fuel average: 1.333 €/L [url18]

The prices in **Spain** are:

- Electricity: 0,109 €/kWh [url19]
- Fossil Fuel average: 1.198 €/L [url20]

The prices in **The Netherlands** are:

- Electricity: 0.088 €/kWh [url21]
- Fossil Fuel average: 1.469€/L [url22]

6.3 Calculations

As done before, in order to present the data in a clear structure, two cases case will be explained fully and the rest will me summarised in a table but obtained similarly. The investment regarding fuel and number of batteries needed will be performed for a time of five years, since a longer time will be pointless since the fuel and electricity prices vary a lot from year to year and specially now great advances in the efficiency of energy storage are being developed.

For the case of a hybrid bus in Sweden, we have chosen a battery of 15 kWh that will have a price of 6780€ and will last for 3 years. We will then need to replace it before five years and the total price will be 13560€. We need no external station or ERS in this

case. The way for the Swedish case is 15.47 km and the bus will do it, as established, 12 times a day back and forth, which is a total of 371.28 km per day. This adds up to an average of 677586 km per year, with a fuel consumption of 1.182 litre/mil. One mil is equivalent to 10 km, so the total price for fuel is 106521 €/year, so 532603€ for the five years. Finally, since the hybrid vehicle does not use external electricity recharge, there is no need to add any extra cost for electricity from the grid. The total investment for five years time is then around 546163€.

In the case of full electric vehicle in Sweden with two external recharge stations, we have chosen a battery of 100 kWh that will have a price of 45200€ and will not need to be replaced during the five years time. The two stations will need to be able to recharge at least 15% of this battery (corresponding to the DoD plus a safety margin), which is 15 kWh each, and they will then have a price of 6780€ in total for both. There is no fuel consumption, but the electricity obtained from the grid has to be taken into account. As stated, considering a 10% DoD we can approximate that we recharge 20 kWh two times per cycle, which is 48 kWh per day, so 87.6 MWh in the five years, which will cost around 4250€. As we can see, the price for electricity is very cheap compared to fuel expenses. The total investment for infrastructure, electricity and fuel for five years in this case is then estimated to be about 105572€.

The rest of the cases are analysed in a similar way, coming up to the following. All the prices are in euros.

		<i>SWEDEN</i>	<i>SPAIN</i>	<i>THE NETHERLANDS</i>	
No external recharge	Hybrid	546163	395124	646150	
External Recharge	Plug-In (4 minute recharge)	251357	247669	93387	
	Full Electric (fc = 0)	Two recharge stations	105572	220074	227217
		ERS	599250	369750	514250

Table 17. Summary of the analysis of prices for the different scenarios, in euros.

Finally, to make this comparative fair, since all the lines do not have exactly the same length and this has quite an impact on fuel consumption, we will divide the results obtained from Table 17 by the distance of the corresponding cycle, so the final units are euros per metre travelled.

		<i>SWEDEN</i>	<i>SPAIN</i>	<i>THE NETHERLANDS</i>	
No external recharge	Hybrid	35304	60324	65070	
External Recharge	Plug-In (4 minute recharge)	16248	37812	9404	
	Full Electric (fc = 0)	Two recharge stations	6824	33600	22881
		ERS	38736	56450	51787

Table 18. Summary of the analysis of prices for the different scenarios, in euros per km.

6.4 Conclusion

With the help of Table 15 we can clearly see which option is cheaper for a consideration of five years time. The price represented there is obviously not the total price, since aspects like maintenance have not been taken into account, as well as extra components in the vehicle that need to be added, for example, a transformer for the DC current obtained from the external station if the motor is AC, etc. However, this extra cost will be more or less constant for the three countries, so it does not have a direct effect on the comparative for choosing the best and most economical option, signalled in bold letters.

In conclusion, the best option for Sweden and Spain would be to have two external points of recharge distributed along the cycle with a full electric vehicle, while in The Netherlands we can observe that the cheapest option seems to be a plug-in, but since the cycle in this case is done fully in electrical mode we could as well consider that full electric is the most suitable for the dutch line as well.

Chapter 7

Final conclusions

We started this document explaining that fuel fossil vehicles are the main source for contamination and that a deep change in the social behaviour regarding transportation needs to be done in order to reach a sustainable future. Otherwise, we face substantial problems regarding health and energy supply that can have awful consequences for the future generations. With this project our aim is to take a step towards this evolution to sustainability by contributing to a public transportation system that does not pollute as much as the current one does.

7.1 Model conclusions

The model presented has been run only through three specific bus lines, but any kind of cycle can be implemented by modifying the Matlab script. This means that a much bigger analysis of the transportation system can be performed with the use of our Simulink diagrams. We have kept the vehicle data more or less constant, only varying the battery parameters, but all the dimensions of the vehicle can also be modified, allowing to simulate also for cars, trucks or other types of vehicles. The program even includes the option of setting an extra parameter that is activated when sporty driving is expected, for example if running the cycle for a powerful sports car. The types of batteries used can also be changed, instead of only considering Li-Ion as we did, and even the fuel can be established not only as gasoline but also as diesel or ethanol by varying the density. All of this flexibility creates a solid Matlab/Simulink program that can predict fuel consumption and electricity usage for almost any kind of vehicle in any kind of road, which gives a clear idea of the possibilities that are offered for future continuation of this project.

7.2 Technical conclusions

Based on the results of the simulations performed, we have decided that the best option for all the three countries is to have a full electric vehicle and introduce two charging stations in the most convenient points along the route, so that it is possible to run the cycle with batteries within a reasonable size and allowed DoD and SoC. It is also important to consider that we also need to take into account the way the electricity is produced. If we only allow this stations to obtain electricity from renewable energies such as solar or wind energy, the positive impact on the environment will be much more effective. As we could expect from previous research coming from the MERGE project mentioned in Chapter 2, the behaviour is more or less homogeneous for the three areas studied and we could consider then that a unique model can be efficient for all of them.

7.3 Economical conclusions

We have proved that indeed the price of fuel is higher the price of electricity in the mid and long term, and since our study is focused on a bus that has an average of kilometres per day much higher than a normal particular vehicle, the effect is observed

quicker. For a shorter term of one or two years it would probably be cheaper to invest in hybrid technology with no external charging, but the prices of electricity are much lower than the current fossil fuel prices so the initial investment is quickly recovered by choosing electrical vehicles, as they reduce the fuel consumption drastically. As expected, the price for just a section of the whole cycle having an Electrical Road System is still too expensive to be considered, plus the added difficulty of the process of building it on the middle of a busy city like Madrid or Amsterdam. However, we strongly believe that this could be the future of transportation.

In conclusion, the results obtained agree with the expected and even prove that the full electric, which is the most sustainable option, is also the most efficient in the long term. We are therefore positive that, with enough awareness and motivation towards the big companies and the government, that are responsible for the public transportation, we can attain a sustainable network that will not only pollute much less but also be cheaper than the current one.

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Annex I

Detail for the cycles

Stop	Time (h)	Time (s)	Distance (m)
Johannesberg	7:05	0	0
Johannesberg	7:06	60	0
Brodderud	7:09	280	2890
Ingarud	7:12	420	4510
Ingarud*	7:15	600	5840
Brodderud*	7:17	720	7240
Lövasen	7:20	900	8690
Torsentorp	7:22	1020	1010
Backen	7:23	1100	1083
Sörgården	7:25	1200	1187
Storegården	7:27	1400	1320
Berga Vägskäl	7:28	1410	1406
Hasslerörs skola	7:30	1530	1547

Table 1: Details for the Swedish line

Stop	Time (h)	Time (s)	Distance (m)
Barceló - Tribunal	7:24	0	0
Barceló - Tribunal	7:25	60	0
Fuencarral - Sandoval	7:26	120	500
Fuencarral - Alburquerque	7:27	180	610
Fuencarral - Gta Quevedo	7:28	240	840
Gral Álvarez de Castro - Eloy Gonzalo	7:31	420	1190
Gral Álvarez de Castro - Gª Paredes	7:32	480	1430
Gral Álvarez de Castro - José Abascal	7:34	600	1640
Sta. Engracia - Bretón de los Herreros	7:36	720	1990
Sta. Engracia - Mª Guzmán	7:39	900	2540
Sta. Engracia nº 162	7:41	1020	2760
Rmnd Fdez. Villaverde - Ponzano	7:44	1200	3260
Gral. Moscardó - Hernani	7:46	1320	3550
Gral. Moscardó - Basílica	7:47	1380	3690
Gral. Moscardó - Gral Peron	7:49	1500	4040
Gral Peron - Orense	7:50	1560	4240
Cp. Haya - Pedro Teixeira	7:53	1740	4990
Capitán Haya - Gral. Yague	7:56	1920	5540
Cp.Haya - Sor Aª de la Cruz	7:58	2040	5840
Cp. Haya - Rosario Pino	7:59	2100	6040
Cp. Haya - Inst. Estadística	8:01	2220	6300
Bravo Murillo - Pza. Castilla	8:02	2280	6550

Table 2: Details for the Spanish line

Stop	Time (h)	Time (s)	Distance (m)
Louwes Corner	6:55	0	0
Louwes Corner	6:56	60	0
Louwesweg	6:57	120	100
Johan Huizingalaan	6:58	180	550
Sierplein	7:00	300	1350
Cornelis Lelylaan	7:01	360	1640
Justus Lipsius Street	7:02	420	1990
Robert Fruinlaan	7:03	480	2490
Jan Tooropstraat	7:04	540	2890
Derkinderenstraat	7:05	600	3160
Nachtwachlaan	7:06	660	3420
Main road	7:09	840	4320
W. Schoutenstraat	7:10	900	4720
Mercatorplein	7:12	1020	5120
Marco Polo Street	7:13	1080	5420
Jan Evertsenstraat	7:14	1140	5770
Jan v.Galenstraat	7:15	1200	6170
Markthallen	7:18	1380	6620
G. v.Ledenberchstraat	7:19	1440	6900
Fred. Henry Plants.	7:21	1560	7500
Marnixplein	7:23	1680	7730
Nw. Willemsstraat	7:24	1740	8130
Haarlemmerplein	7:26	1860	8630
Outside Oranjestraat	7:27	1920	9030
Out Brouwersstraat	7:28	1980	9330
Central Station	7:31	2160	9930

Table 3: Details for the Dutch line

Annex II

Matlab Code

The following scripts are the ones used to update the variables and create the cycles:

```
%Choice of country
% -----
% Set Drive_cycle = 1 if you want to choose Sweden;
% Set Drive_cycle = 2 if you want to choose The Netherlands;
% Set Drive_cycle = 3 if you want to choose Spain;
```

```
Drive_cycle = 3;
```

```
% Choice of hybridisation
% -----
% Set Typeofvehicle = 1 if you want a hybrid vehicle;
% Set Typeofvehicle = 2 if you want a plug-in vehicle;
% Set Typeofvehicle = 3 if you want a full electric vehicle;
```

```
Typeofvehicle = 1;
```

```
% Choice of vehicle
% -----
% Set Vehicle = 1 if you want an average car
% Set Vehicle = 2 if you want a city bus
```

```
Vehicle = 2;
```

```
% Choice of fuel type
% -----
% Set Fuel = 1 if you want to choose gasoline
% Set Fuel = 2 if you want to use diesel
% Set Fuel = 3 if you want to use ethanol
```

```
Fuel = 1;
```

```
% -----
% -----
% -----
```

```
clear cycle
switch Drive_cycle
    case 1 % SWEDEN
        load Swedish;
        cycle = data;
    case 2 % NETHERLANDS
        load Dutch;
        cycle = data;
    case 3 % SPAIN
        load Spanish;
        cycle = data;
end
```

```
switch Typeofvehicle
    case 1 % hybrid
        % Percentage of electric in the total power
        EMvsTotal = 0.20;
        % Power of the battery, in kWatts
        Wbatt=15*3.6e6;

    case 2 % plugin
```

```

% Percentage of electric in the total power
EMvsTotal = 0.80;
% Power of the battery, in kWatts
Wbatt=15*3.6e6;

case 3 % fullelectric
% Percentage of electric in the total power
EMvsTotal = 0.9999999999;
% Power of the battery, in Watts
Wbatt=90*3.6e6;

end

switch Vehicle
case 1 % Car
Mv = 1600; % Vehicle weight
rw = 0.30;
Cd = 0.26;
Cr = 0.008;
Av = 2.55;
vmax=172/3.6;
Pmax=100000;
Number_of_gears = 6;
MinShiftTime = 0.5;
Paux = 1000;

case 2 % City Bus
Mv = 5990;
rw = 0.506;
Cd = 0.79;
Cr = 0.00576;
Av = 2.550*2.924;
vmax=130/3.6;
Pmax = 250000;
Number_of_gears = 6;
MinShiftTime = 2;
Paux = 2000;

end

rho_air = 1.2; % Air density
grav = 9.81;

if Fuel==1, % Gasoline
load EtaICE_OTTO;
EtaICE = EtaICE_OTTO;
wice_max = 6000*2*pi/60;
elseif Fuel==2&Vehicle==1, % Car Diesel
load EtaICE_DIESEL;
EtaICE = EtaICE_DIESEL;
wice_max = 4500*2*pi/60;
elseif Fuel==2&Vehicle>1, % Truck Diesel
load EtaICE_HeavyDIESEL;
EtaICE = EtaICE_HeavyDIESEL;
wice_max = 2500*2*pi/60;
else
'Erroneous fuel choice'
end

[value,row]=max(max(EtaICE'));

```

```

Pice_max = Pmax*(1-EMvsTotal);
wice_min = 700*2*pi/60; % 800 rpm
Tice_max = Pice_max/(wice_max*row/(length(EtaICE)-1));
%
[PtoT,Tice,Wice,Tlim_ice,FuelConsICE]=CreateICEmap(Pice_max,wice_max,Tice_max,EtaICE);

% Transmission settings

utvx_max = wice_max/((vmax/20)/rw);
utvx_min = wice_max/(1.2*vmax/rw);
DCT=1;
Utvx_vect = zeros(1,Number_of_gears+1);
Utvx_vect(1,1) = utvx_min;
Utvx_vect(1,length(Utvx_vect(1,:))) = inf;

for i=2:Number_of_gears,
    Utvx_vect(1,i) = Utvx_vect(1,i-1)*(utvx_max/utvx_min)^(1/(Number_of_gears-1));
end

EtaGEAR = 0.97;
% Fuel energy density in [Ws/liter]
% Fuels=cellstr(['Gasoline';'Diesel  '; 'E85      ']);

switch Fuel
    case 1 % Gasoline
        Density = 31.4e6;
    case 2, % Diesel, 0.808 kg/liter
        Density = 35.8e6;
    case 3, % Ethanol (E85)
        Density = (85*19.6e6 + 15*32e6)/100;
end

% Electric machine parameters
Pem_max = Pmax*EMvsTotal; % Peak continuous power
Tem_max = Pem_max/(wice_max/4); % Peak continuous torque with 1:4 as field weakening ratio
wem_max = wice_max; % EM mounted on cranc shaft
% [Pemloss,EtaEM,Tem,Wem] = CreateEMmap(Pem_max,wem_max,Tem_max);
% [PtoTem,EtaEM,Tem,Wem,Tem_lim,EnergyConsEM] = CreateEMmap(Pem_max,wem_max,Tem_max);

% Power Electronics efficiency (preset)
EtaPE = 0.97;

% Battery parameters
% Wbatt = 100*3600*Mbatt; % 100 Wh/kg, 3600 sec/h, Mbatt kg
% [EtaBATT,Pbatt,Mbatt,Pbatt_max_new,Wbatt_new]=CreateBATTmap(Pem_max,Wbatt);

SOC_batt_ref_value = 95;
SOC_batt_start_value = 95;
SOC_tract_max = 99;
SOC_tract_min = 75;

% Controller parameters
Tau_charge = 1;
ksoc = max(Wbatt)/400/Tau_charge;
ksoc_vect = ksoc*tan(pi/2.05*[-1:1/15:1])*2;
%ksoc = max(Wbatt)/400/Tau_charge;

```

```

%% SWEDEN

% This script will fill in the Drive Cycle, which will be a matrix of six
% columns and the number of rows corresponding to the time in seconds.

% create the empty matrix (data)

data=zeros(1560,6);

% Filling the TIME COLUMN

for i=1:1560
    data(i,1)=i;
end

% Calculate the maximum speed needed (providing that the space travelled is
% the area under the graphic that represents time vs speed).
time = [0 60 180 190 300 310 600 610 720 730 900 910 1020 1030 1080 1090 1200
1210 1320 1330 1380 1390 1500 1560];
space = [0 0 2890 2890 4510 4510 5840 5840 7240 7240 8690 8690 10100 10100 10830
10830 11870 11870 13200 13200 14060 14060 15470 15470];
speedmax = zeros (1,length(space));

for j=1:23
    if (time(j+1)-time(j)-10) == 0
        speedmax(1,j) = 0;
    else
        speedmax(1,j) = (space (j+1)-space(j))/(time(j+1)-time(j)-10);
    end
end

% We can observe that, if we estimate the acceleration/deceleration time in 10s,
we need
% maximum speeds up to 21,5 m/s (75 km/h) to reach the stop at the time
% established, providing stops of 10s each (with longer stops, maximum speeds
increases too much).

% FILLING THE SPEED COLUMN

%% JOHANNESBERG-BRODDERUD
for m=1:10
    data(m+time(2),2)=(speedmax(2)*data(m,1))/10;
end
for n=time(2)+10:time(3)-10
    data (n,2) = speedmax(2);
end
for p=1:10
    data(p+time(3)-10,2)= speedmax(2)-p*(speedmax(2)/10);
end
clear m;
clear n;
clear p;

%% BRODDERUD-INGARUD
for m=1:10
    data(m+time(4),2)=(speedmax(4)*data(m,1))/10;
end

```

```

for n=time(4)+10:time(5)-10
    data (n,2) = speedmax(4);
end
for p=1:10
    data(p+time(5)-10,2)= speedmax(4)-p*(speedmax(4)/10);
end
clear m;
clear n;
clear p;

% % INGARUD-INGARUD*
for m=1:10
    data(m+time(6),2)=(speedmax(6)*data(m,1))/10;
end
for n=time(6)+10:time(7)-10
    data (n,2) = speedmax(6);
end
for p=1:10
    data(p+time(7)-10,2)= speedmax(6)-p*(speedmax(6)/10);
end
clear m;
clear n;
clear p;

% % INGARUD*-BRODDERUD*
for m=1:10
    data(m+time(8),2)=(speedmax(8)*data(m,1))/10;
end
for n=time(8)+10:time(9)-10
    data (n,2) = speedmax(8);
end
for p=1:10
    data(p+time(9)-10,2)= speedmax(8)-p*(speedmax(8)/10);
end
clear m;
clear n;
clear p;

% % BRODDERUD*-LOVASEN
for m=1:10
    data(m+time(10),2)=(speedmax(10)*data(m,1))/10;
end
for n=time(10)+10:time(11)-10
    data (n,2) = speedmax(10);
end
for p=1:10
    data(p+time(11)-10,2)= speedmax(10)-p*(speedmax(10)/10);
end
clear m;
clear n;
clear p;

% % LOVASEN-TORSTENTORP
for m=1:10
    data(m+time(12),2)=(speedmax(12)*data(m,1))/10;
end
for n=time(12)+10:time(13)-10
    data (n,2) = speedmax(12);
end
for p=1:10

```

```

    data(p+time(13)-10,2)= speedmax(12)-p*(speedmax(12)/10);
end
clear m;
clear n;
clear p;

% % TORSTENTORP-BACKEN
for m=1:10
    data(m+time(14),2)=(speedmax(14)*data(m,1))/10;
end
for n=time(14)+10:time(15)-10
    data (n,2) = speedmax(14);
end
for p=1:10
    data(p+time(15)-10,2)= speedmax(14)-p*(speedmax(14)/10);
end
clear m;
clear n;
clear p;

% % BACKEN-SORGARDEN
for m=1:10
    data(m+time(16),2)=(speedmax(16)*data(m,1))/10;
end
for n=time(16)+10:time(17)-10
    data (n,2) = speedmax(16);
end
for p=1:10
    data(p+time(17)-10,2)= speedmax(16)-p*(speedmax(16)/10);
end
clear m;
clear n;
clear p;

% % SORGARDEN-STOREGARDEN
for m=1:10
    data(m+time(18),2)=(speedmax(18)*data(m,1))/10;
end
for n=time(18)+10:time(19)-10
    data (n,2) = speedmax(18);
end
for p=1:10
    data(p+time(19)-10,2)= speedmax(18)-p*(speedmax(18)/10);
end
clear m;
clear n;
clear p;

% % STOREGARDEN-BERGA VAGSKAL
for m=1:10
    data(m+time(20),2)=(speedmax(20)*data(m,1))/10;
end
for n=time(20)+10:time(21)-10
    data (n,2) = speedmax(20);
end
for p=1:10
    data(p+time(21)-10,2)= speedmax(20)-p*(speedmax(20)/10);
end
clear m;
clear n;

```

```

clear p;

% % BERGA VAGSKAL-HASSLERORS SKOLA
for m=1:10
    data(m+time(22),2)=(speedmax(22)*data(m,1))/10;
end
for n=time(22)+10:time(23)-10
    data (n,2) = speedmax(22);
end
for p=1:10
    data(p+time(23)-10,2)= speedmax(22)-p*(speedmax(22)/10);
end
clear m;
clear n;
clear p;

% % FILLING THE SPACE COLUMN
% (The space is the area under the speed graph).

clear f;
for f=1:1560
    data (f,3) = trapz (data(1:f,2));
end
clear f;

% -----
% -----
figure (2)
plot (data (:,1),data(:,2),'m');
xlabel ('time [s]');
ylabel ('speed [m/s]');

figure (3)
plot (data (:,1),data(:,3),'b');
xlabel ('time [s]');
ylabel ('total distance [m]');

% -----
% -----
% % The fourth and fifth columns are attached to the slope and altitude,
% % and will be considered 0 at all times.
% % The sixth column in our matrix is the slide-in, and will receive a 0 % %
when the bus is not being charged
% % and a 1 when it is.
% -----

endtime = length (data(:,1));
cycle = data;
save Swedish;

```

```

%% SPAIN

% This script will fill in the Drive Cycle, which will be a matrix of six
% columns and the number of rows corresponding to the time in seconds.

% create the empty matrix (data)

data=zeros(2280,6);

% Filling the TIME COLUMN

for i=1:2280
    data(i,1)=i;
end

% Calculate the maximum speed needed (providing that the space travelled is
% the area under the graphic that represents time vs speed).
time = [0 60 120 130 180 190 240 250 420 430 480 490 600 610 720 730 900 910
1020 1030 1200 1210 1320 1330 1380 1390 1500 1510 1560 1570 1740 1750 1920 1930
2040 2050 2100 2110 2220 2230 2280 2340];
space = [0 0 500 500 610 610 840 840 1190 1190 1430 1430 1640 1640 1990 1990
2540 2540 2760 2760 3260 3260 3550 3550 3690 3690 4040 4040 4240 4240 4990 4990
5540 5540 5840 5840 6040 6040 6300 6300 6550 6550];
speedmax = zeros (1,length(space));

for j=1:length(space)-1
    if (time(j+1)-time(j)-10) == 0
        speedmax(1,j) = 0;
    else
        speedmax(1,j) = (space (j+1)-space(j))/(time(j+1)-time(j)-10);
    end
end

% FILLING THE SPEED COLUMN

%% Barcel?/Tribunal - Fuencarral/Sandoval
for m=1:10
    data(m+time(2),2)=(speedmax(2)*data(m,1))/10;
end
for n=time(2)+10:time(3)-10
    data (n,2) = speedmax(2);
end
for p=1:10
    data(p+time(3)-10,2) = speedmax(2)-speedmax(2)*p/10;
end
clear m;
clear n;
clear p;

%% Fuencarral/Sandoval - Fuencarral/Alburquerque
for m=1:10
    data(m+time(4),2)=(speedmax(4)*data(m,1))/10;
end
for n=time(4)+10:time(5)-10
    data (n,2) = speedmax(4);
end
for p=1:10
    data(p+time(5)-10,2)= speedmax(4)-p*(speedmax(4)/10);
end
clear m;

```



```

clear n;
clear p;

% % Fuencarral/Albuquerque - Fuencarral/Quevedo
for m=1:10
    data(m+time(6),2)=(speedmax(6)*data(m,1))/10;
end
for n=time(6)+10:time(7)-10
    data (n,2) = speedmax(6);
end
for p=1:10
    data(p+time(7)-10,2)= speedmax(6)-p*(speedmax(6)/10);
end
clear m;
clear n;
clear p;

% % Fuencarral/Quevedo - Eloy Gonzalo
for m=1:10
    data(m+time(8),2)=(speedmax(8)*data(m,1))/10;
end
for n=time(8)+10:time(9)-10
    data (n,2) = speedmax(8);
end
for p=1:10
    data(p+time(9)-10,2)= speedmax(8)-p*(speedmax(8)/10);
end
clear m;
clear n;
clear p;

% % Eloy Gonzalo - Alvarez de Castro
for m=1:10
    data(m+time(10),2)=(speedmax(10)*data(m,1))/10;
end
for n=time(10)+10:time(11)-10
    data (n,2) = speedmax(10);
end
for p=1:10
    data(p+time(11)-10,2)= speedmax(10)-p*(speedmax(10)/10);
end
clear m;
clear n;
clear p;

% % Alvarez de Castro - Jos? Abascal
for m=1:10
    data(m+time(12),2)=(speedmax(12)*data(m,1))/10;
end
for n=time(12)+10:time(13)-10
    data (n,2) = speedmax(12);
end
for p=1:10
    data(p+time(13)-10,2)= speedmax(12)-p*(speedmax(12)/10);
end
clear m;
clear n;
clear p;

% % Jos? Abascal - Sta.Engracia/Bret?n de los Herreros

```

```

for m=1:10
    data(m+time(14),2)=(speedmax(14)*data(m,1))/10;
end
for n=time(14)+10:time(15)-10
    data (n,2) = speedmax(14);
end
for p=1:10
    data(p+time(15)-10,2)= speedmax(14)-p*(speedmax(14)/10);
end
clear m;
clear n;
clear p;

% % Sta.Engracia/Bret?n de los Herreros - Sta.Engracia/M.Guzm?n
for m=1:10
    data(m+time(16),2)=(speedmax(16)*data(m,1))/10;
end
for n=time(16)+10:time(17)-10
    data (n,2) = speedmax(16);
end
for p=1:10
    data(p+time(17)-10,2)= speedmax(16)-p*(speedmax(16)/10);
end

clear m;
clear n;
clear p;

% % Sta.Engracia/M.Guzm?n - Sta.Engracial62
for m=1:10
    data(m+time(18),2)=(speedmax(18)*data(m,1))/10;
end
for n=time(18)+10:time(19)-10
    data (n,2) = speedmax(18);
end
for p=1:10
    data(p+time(19)-10,2)= speedmax(18)-p*(speedmax(18)/10);
end

clear m;
clear n;
clear p;

% % Sta.Engracial62 - RaimundofdezVillaverde/Ponzano
for m=1:10
    data(m+time(20),2)=(speedmax(20)*data(m,1))/10;
end
for n=time(20)+10:time(21)-10
    data (n,2) = speedmax(20);
end
for p=1:10
    data(p+time(21)-10,2)= speedmax(20)-p*(speedmax(20)/10);
end

% % RaimundofdezVillaverde/Ponzano - Gral.Moscard?/Hernani
for m=1:10
    data(m+time(22),2)=(speedmax(22)*data(m,1))/10;
end
for n=time(22)+10:time(23)-10
    data (n,2) = speedmax(22);
end

```

```

end
for p=1:10
    data(p+time(23)-10,2)= speedmax(22)-p*(speedmax(22)/10);
end

% % Gral.Moscard?/Hernani - Gral.Moscard?/Basilica
for m=1:10
    data(m+time(24),2)=(speedmax(24)*data(m,1))/10;
end
for n=time(24)+10:time(25)-10
    data (n,2) = speedmax(24);
end
for p=1:10
    data(p+time(25)-10,2)= speedmax(24)-p*(speedmax(24)/10);
end

% % Gral.Moscard?/Basilica - Gral.Moscard?/Gral.Peron
for m=1:10
    data(m+time(26),2)=(speedmax(26)*data(m,1))/10;
end
for n=time(26)+10:time(27)-10
    data (n,2) = speedmax(26);
end
for p=1:10
    data(p+time(27)-10,2)= speedmax(26)-p*(speedmax(26)/10);
end

% % Gral.Peron - Orense
for m=1:10
    data(m+time(28),2)=(speedmax(28)*data(m,1))/10;
end
for n=time(28)+10:time(29)-10
    data (n,2) = speedmax(28);
end
for p=1:10
    data(p+time(29)-10,2)= speedmax(28)-p*(speedmax(28)/10);
end

% % Orense - PedroTeixeira
for m=1:10
    data(m+time(30),2)=(speedmax(30)*data(m,1))/10;
end
for n=time(30)+10:time(31)-10
    data (n,2) = speedmax(30);
end
for p=1:10
    data(p+time(31)-10,2)= speedmax(30)-p*(speedmax(30)/10);
end

% % PedroTeixeira - CapitanHaya/GralYague
for m=1:10
    data(m+time(32),2)=(speedmax(32)*data(m,1))/10;
end
for n=time(32)+10:time(33)-10
    data (n,2) = speedmax(32);
end
for p=1:10
    data(p+time(33)-10,2)= speedmax(32)-p*(speedmax(32)/10);
end

```

```

%% % CapitanHaya/GralYague - CpHaya/SorAngela
for m=1:10
    data(m+time(34),2)=(speedmax(34)*data(m,1))/10;
end
for n=time(34)+10:time(35)-10
    data (n,2) = speedmax(34);
end
for p=1:10
    data(p+time(35)-10,2)= speedmax(34)-p*(speedmax(34)/10);
end

%% % CpHaya/SorAngela - CpHaya/RosarioPino
for m=1:10
    data(m+time(36),2)=(speedmax(36)*data(m,1))/10;
end
for n=time(36)+10:time(37)-10
    data (n,2) = speedmax(36);
end
for p=1:10
    data(p+time(37)-10,2)= speedmax(36)-p*(speedmax(36)/10);
end

%% % CpHaya/RosarioPino - InstEstadística
for m=1:10
    data(m+time(38),2)=(speedmax(38)*data(m,1))/10;
end
for n=time(38)+10:time(39)-10
    data (n,2) = speedmax(38);
end
for p=1:10
    data(p+time(39)-10,2)= speedmax(38)-p*(speedmax(38)/10);
end

%% % InstEstadística - PzaCastilla
for m=1:10
    data(m+time(40),2)=(speedmax(40)*data(m,1))/10;
end
for n=time(40)+10:time(41)-10
    data (n,2) = speedmax(40);
end
for p=1:10
    data(p+time(41)-10,2)= speedmax(40)-p*(speedmax(40)/10);
end

%% % FILLING THE SPACE COLUMN
%% (The space is the area under the speed graph).

clear f;
for f=1:2280
    data (f,3) = trapz (data(1:f,2));
end
clear f;

% -----
% -----
figure (2)
plot (data (:,1),data(:,2), 'b');

```

```

xlabel ('time [s]');
ylabel ('speed [m/s]');

figure (3)
plot (data (:,1),data(:,3),'g');
xlabel ('time [s]');
ylabel ('total distance [m]');

% -----
% -----
% % The fourth and fifth columns are attached to the slope and altitude,
% % and will be considered 0 at all times.
% % The sixth column in our matrix is the slide-in, and will receive a 0 % %
% % when the bus is not being charged
% % and a 1 when it is.
% -----
% -----

endtime = length (data(:,1));
cycle = data;
save Spanish;

% % NETHERLANDS

% This script will fill in the Drive Cycle, which will be a matrix of six
% columns and the number of rows corresponding to the time in seconds.

% create the empty matrix (data)

data=zeros(2160,6);

% Filling the TIME COLUMN

for i=1:2160
    data(i,1)=i;
end

% Calculate the maximum speed needed (providing that the space travelled is
% the area under the graphic that represents time vs speed).
time = [0 60 120 130 180 190 300 310 360 370 420 430 480 490 540 550 600 610 660
670 840 850 900 910 1020 1030 1080 1090 1140 1150 1200 1210 1380 1390 1440 1450
1560 1570 1680 1690 1740 1750 1860 1870 1920 1930 1980 1990 2160 2220];
space = [0 0 100 100 550 550 1350 1350 1640 1640 1990 1990 2490 2490 2890 2890
3160 3160 3420 3420 4320 4320 4720 4720 5120 5120 5420 5420 5770 5770 6170 6170
6620 6620 6900 6900 7500 7500 7730 7730 8130 8130 8630 8630 9030 9030 9330 9330
9930 9930];
speedmax = zeros (1,length(space));

for j=1:length(space)-1
    if (time(j+1)-time(j)-10) == 0
        speedmax(1,j) = 0;
    else
        speedmax(1,j) = (space (j+1)-space(j))/(time(j+1)-time(j)-10);
    end
end

% FILLING THE SPEED COLUMN

% % Louwes Corner - Louwesweg
for m=1:10

```

```

    data(m+time(2),2)=(speedmax(2)*data(m,1))/10;
end
for n=time(2)+10:time(3)-10
    data (n,2) = speedmax(2);
end
for p=1:10
    data(p+time(3)-10,2) = speedmax(2)-speedmax(2)*p/10;
end
clear m;
clear n;
clear p;

% % Louwesweg - Johan Huizingalaan
for m=1:10
    data(m+time(4),2)=(speedmax(4)*data(m,1))/10;
end
for n=time(4)+10:time(5)-10
    data (n,2) = speedmax(4);
end
for p=1:10
    data(p+time(5)-10,2)= speedmax(4)-p*(speedmax(4)/10);
end
clear m;
clear n;
clear p;

% % Johan Huizingalaan - Sierplein
for m=1:10
    data(m+time(6),2)=(speedmax(6)*data(m,1))/10;
end
for n=time(6)+10:time(7)-10
    data (n,2) = speedmax(6);
end
for p=1:10
    data(p+time(7)-10,2)= speedmax(6)-p*(speedmax(6)/10);
end
clear m;
clear n;
clear p;

% % Sierplein - Cornelis Lelylaan
for m=1:10
    data(m+time(8),2)=(speedmax(8)*data(m,1))/10;
end
for n=time(8)+10:time(9)-10
    data (n,2) = speedmax(8);
end
for p=1:10
    data(p+time(9)-10,2)= speedmax(8)-p*(speedmax(8)/10);
end
clear m;
clear n;
clear p;

% % Cornelis Lelylaan - Justus Lipsius Street
for m=1:10
    data(m+time(10),2)=(speedmax(10)*data(m,1))/10;
end
for n=time(10)+10:time(11)-10
    data (n,2) = speedmax(10);

```

```

end
for p=1:10
    data(p+time(11)-10,2)= speedmax(10)-p*(speedmax(10)/10);
end
clear m;
clear n;
clear p;

% % Justus Lipsius Street - Robert Fruinlaan
for m=1:10
    data(m+time(12),2)=(speedmax(12)*data(m,1))/10;
end
for n=time(12)+10:time(13)-10
    data (n,2) = speedmax(12);
end
for p=1:10
    data(p+time(13)-10,2)= speedmax(12)-p*(speedmax(12)/10);
end
clear m;
clear n;
clear p;

% % Robert Fruinlaan - Jan Tooropstraat
for m=1:10
    data(m+time(14),2)=(speedmax(14)*data(m,1))/10;
end
for n=time(14)+10:time(15)-10
    data (n,2) = speedmax(14);
end
for p=1:10
    data(p+time(15)-10,2)= speedmax(14)-p*(speedmax(14)/10);
end
clear m;
clear n;
clear p;

% % Jan Tooropstraat - Derkinderenstraat
for m=1:10
    data(m+time(16),2)=(speedmax(16)*data(m,1))/10;
end
for n=time(16)+10:time(17)-10
    data (n,2) = speedmax(16);
end
for p=1:10
    data(p+time(17)-10,2)= speedmax(16)-p*(speedmax(16)/10);
end

clear m;
clear n;
clear p;

% % Derkinderenstraat - Nachtwachtlaan
for m=1:10
    data(m+time(18),2)=(speedmax(18)*data(m,1))/10;
end
for n=time(18)+10:time(19)-10
    data (n,2) = speedmax(18);
end
for p=1:10
    data(p+time(19)-10,2)= speedmax(18)-p*(speedmax(18)/10);

```

```

end

clear m;
clear n;
clear p;

% % Nachtwachtlaan - Main Road
for m=1:10
    data(m+time(20),2)=(speedmax(20)*data(m,1))/10;
end
for n=time(20)+10:time(21)-10
    data (n,2) = speedmax(20);
end
for p=1:10
    data(p+time(21)-10,2)= speedmax(20)-p*(speedmax(20)/10);
end

% % Main Road - W. Schoutenstraat
for m=1:10
    data(m+time(22),2)=(speedmax(22)*data(m,1))/10;
end
for n=time(22)+10:time(23)-10
    data (n,2) = speedmax(22);
end
for p=1:10
    data(p+time(23)-10,2)= speedmax(22)-p*(speedmax(22)/10);
end

% % W. Schoutenstraat - Mercatorplein
for m=1:10
    data(m+time(24),2)=(speedmax(24)*data(m,1))/10;
end
for n=time(24)+10:time(25)-10
    data (n,2) = speedmax(24);
end
for p=1:10
    data(p+time(25)-10,2)= speedmax(24)-p*(speedmax(24)/10);
end

% % Mercatorplein - Marco Polo Street
for m=1:10
    data(m+time(26),2)=(speedmax(26)*data(m,1))/10;
end
for n=time(26)+10:time(27)-10
    data (n,2) = speedmax(26);
end
for p=1:10
    data(p+time(27)-10,2)= speedmax(26)-p*(speedmax(26)/10);
end

% % Marco Polo Street - Jan Evertsenstraat
for m=1:10
    data(m+time(28),2)=(speedmax(28)*data(m,1))/10;
end
for n=time(28)+10:time(29)-10
    data (n,2) = speedmax(28);
end
for p=1:10
    data(p+time(29)-10,2)= speedmax(28)-p*(speedmax(28)/10);

```



```

end

% % Jan Evertsenstraat - Jan v.Galenstraat
for m=1:10
    data(m+time(30),2)=(speedmax(30)*data(m,1))/10;
end
for n=time(30)+10:time(31)-10
    data (n,2) = speedmax(30);
end
for p=1:10
    data(p+time(31)-10,2)= speedmax(30)-p*(speedmax(30)/10);
end

% % Jan v.Galenstraat - Markthallen
for m=1:10
    data(m+time(32),2)=(speedmax(32)*data(m,1))/10;
end
for n=time(32)+10:time(33)-10
    data (n,2) = speedmax(32);
end
for p=1:10
    data(p+time(33)-10,2)= speedmax(32)-p*(speedmax(32)/10);
end

% % Markthallen - G v.Ledenberschstraat
for m=1:10
    data(m+time(34),2)=(speedmax(34)*data(m,1))/10;
end
for n=time(34)+10:time(35)-10
    data (n,2) = speedmax(34);
end
for p=1:10
    data(p+time(35)-10,2)= speedmax(34)-p*(speedmax(34)/10);
end

% % G v.Ledenberschstraat - Fred. Henry Plants
for m=1:10
    data(m+time(36),2)=(speedmax(36)*data(m,1))/10;
end
for n=time(36)+10:time(37)-10
    data (n,2) = speedmax(36);
end
for p=1:10
    data(p+time(37)-10,2)= speedmax(36)-p*(speedmax(36)/10);
end

% % Fred. Henry Plants - Marnixplein
for m=1:10
    data(m+time(38),2)=(speedmax(38)*data(m,1))/10;
end
for n=time(38)+10:time(39)-10
    data (n,2) = speedmax(38);
end
for p=1:10
    data(p+time(39)-10,2)= speedmax(38)-p*(speedmax(38)/10);
end

% % Marnixplein - Nw. Willemstraat
for m=1:10
    data(m+time(40),2)=(speedmax(40)*data(m,1))/10;

```

```

end
for n=time(40)+10:time(41)-10
    data (n,2) = speedmax(40);
end
for p=1:10
    data(p+time(41)-10,2)= speedmax(40)-p*(speedmax(40)/10);
end

% % Nw. Willemstraat - Haarlemmerplein
for m=1:10
    data(m+time(42),2)=(speedmax(42)*data(m,1))/10;
end
for n=time(42)+10:time(43)-10
    data (n,2) = speedmax(42);
end
for p=1:10
    data(p+time(43)-10,2)= speedmax(42)-p*(speedmax(42)/10);
end

% % Haarlemmerplein - Outside Oranjestraat
for m=1:10
    data(m+time(44),2)=(speedmax(44)*data(m,1))/10;
end
for n=time(44)+10:time(45)-10
    data (n,2) = speedmax(44);
end
for p=1:10
    data(p+time(45)-10,2)= speedmax(44)-p*(speedmax(44)/10);
end

% % Outside Oranjestraat - Outside Brouwerstraat
for m=1:10
    data(m+time(46),2)=(speedmax(46)*data(m,1))/10;
end
for n=time(46)+10:time(47)-10
    data (n,2) = speedmax(46);
end
for p=1:10
    data(p+time(47)-10,2)= speedmax(46)-p*(speedmax(46)/10);
end

% % Outside Brouwerstraat - Amsterdam Centraal
for m=1:10
    data(m+time(48),2)=(speedmax(48)*data(m,1))/10;
end
for n=time(48)+10:time(49)-10
    data (n,2) = speedmax(48);
end
for p=1:10
    data(p+time(49)-10,2)= speedmax(48)-p*(speedmax(48)/10);
end

% % FILLING THE SPACE COLUMN
% (The space is the area under the speed graph).

clear f;
for f=1:2160
    data (f,3) = trapz (data(1:f,2));
end
clear f;

```

```

% -----
-----
figure (2)
plot (data (:,1),data(:,2),'b');
xlabel ('time [s]');
ylabel ('speed [m/s]');

figure (3)
plot (data (:,1),data(:,3),'g');
xlabel ('time [s]');
ylabel ('total distance [m]');

% -----
-----
% % The fourth and fifth columns are attached to the slope and altitude,
% % and will be considered 0 at all times.
% % The sixth column in our matrix is the slide-in, and will receive a 0 % %
when the bus is not being charged
% % and a 1 when it is.
% -----
-----

endtime = length (data(:,1));
cycle = data;
save Dutch;

```