MODEL AND SIMULATION OF A PURE ELECTRIC BUS

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HITACHI AND AMT OF GENOA

- Due to the **climate changes**, a **change of paradigm** in the road transport sector is rapidly growing: the change **from fossil fuels to electrical solutions**.

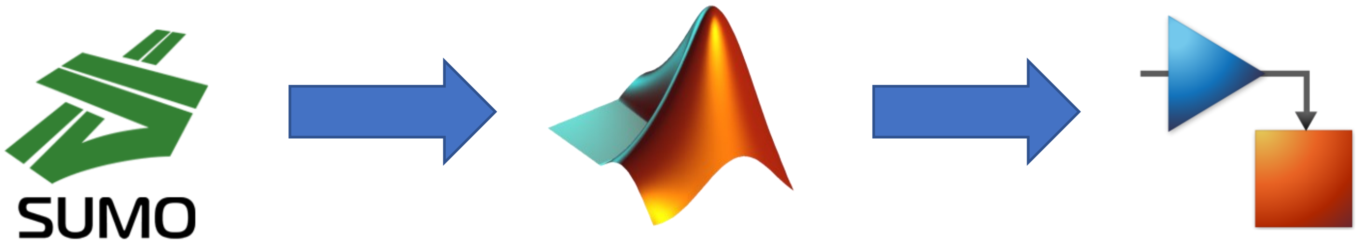
- **Hitachi** and **AMT of Genoa** are working together in this revolution, using **Irizar pure electric buses** in the city environment, aiming to **a significant emissions reduction**.

MAIN QUESTIONS:

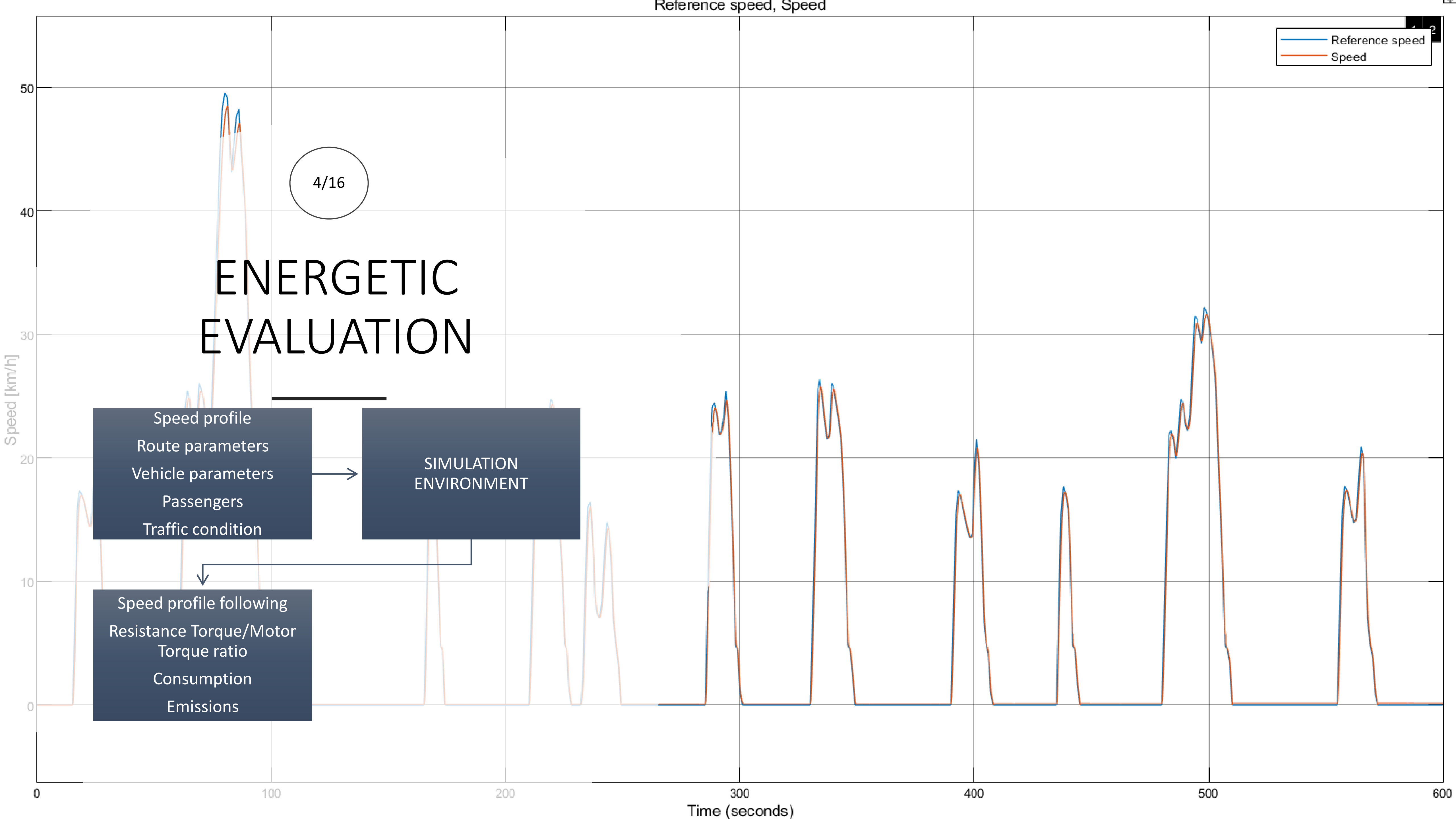
- **Electric buses are sized for specific trips** they are assigned for. If a bus is used in different routes, is it still idoneous?
- Given a certain route, is it possible to **forecast the bus consumption** for planning pourposes?
- Which are the **most important factors** in the electric bus consumption inside cities? Is it possible to **smooth them out**?

SOLUTION PROPOSED:

- **Predictive microscopic energetic and kinematic model**



ENERGETIC EVALUATION



Speed profile
Route parameters
Vehicle parameters
Passengers
Traffic condition

→ SIMULATION ENVIRONMENT

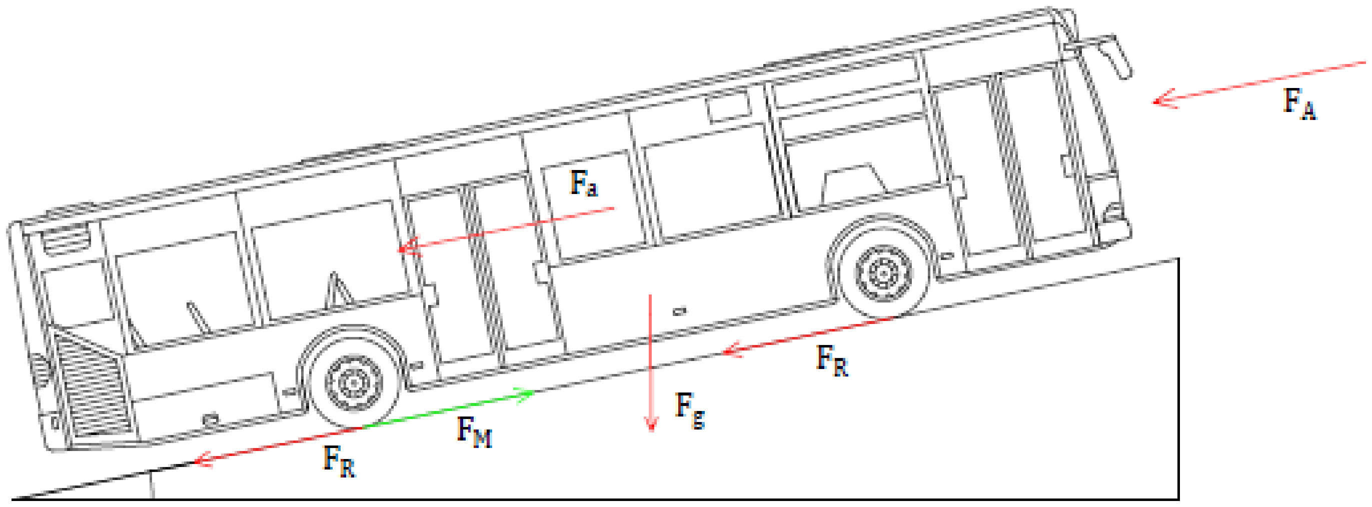
→ Speed profile following
Resistance Torque/Motor Torque ratio
Consumption
Emissions

RESISTANCE MODEL

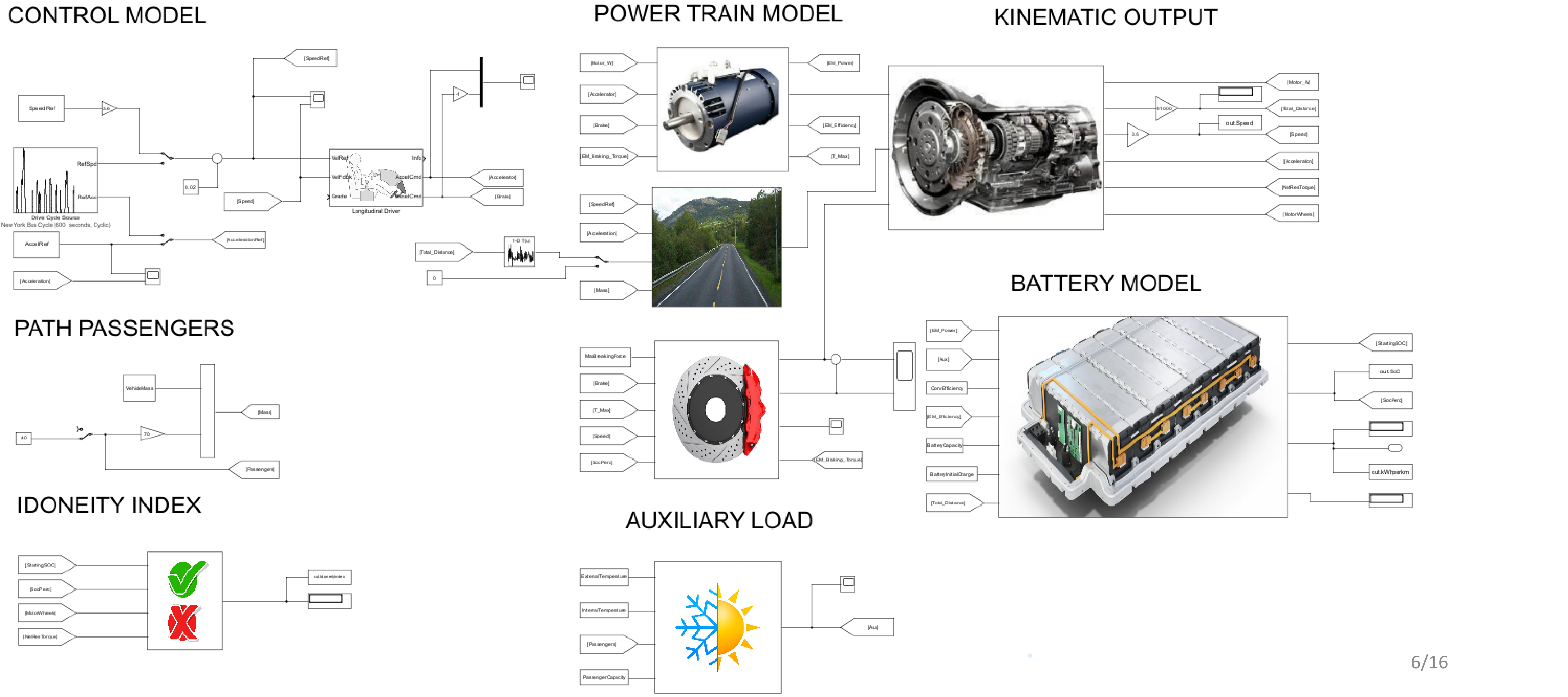
For the total resistance force the longitudinal 1-D model has been chosen, composed by:

- $F_{load} = F_a + F_A + F_r + F_{sl}$

- Inertial
- Aerodynamic
- Tire rolling
- Gradient



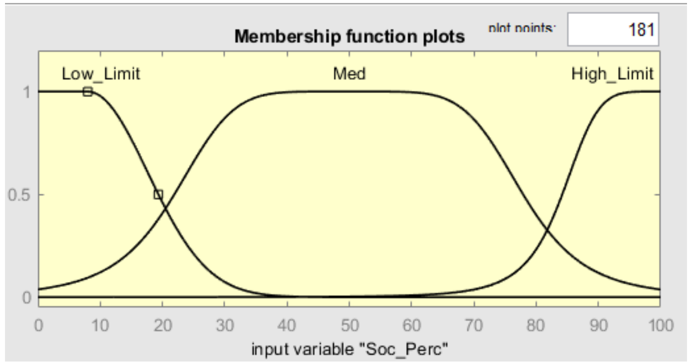
SIMULINK MODEL

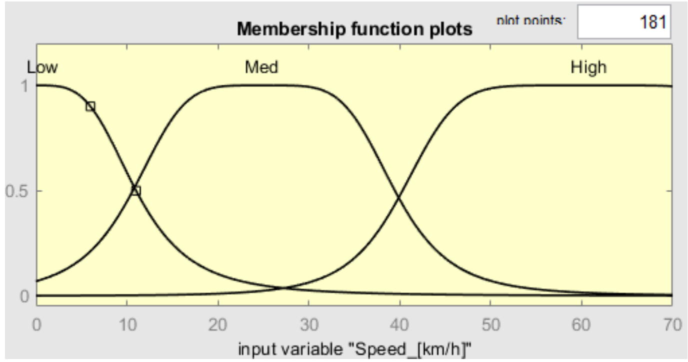


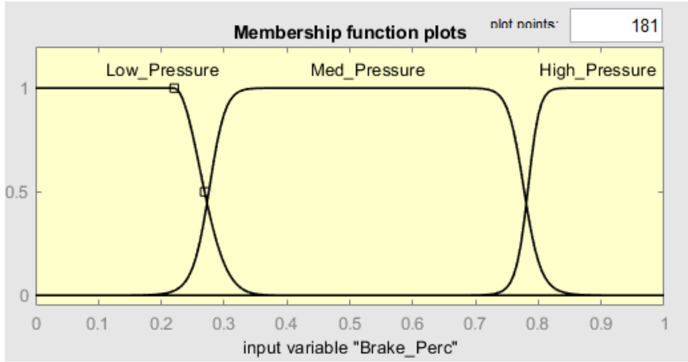
REGENERATIVE BRAKE INPUT

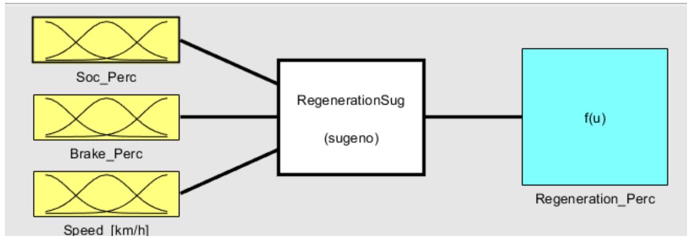
For respecting the safety limits and the battery life, regenerative brake ratio is not constant. The split between regenerative brake (saturated to the Max motor torque) and mechanical brake has been made by using the Fuzzy Logic Matlab Toolbox where the inputs in each step are:

- Speed [km/h];
- Brake pedal pressure [%];
- Current SOC [%].

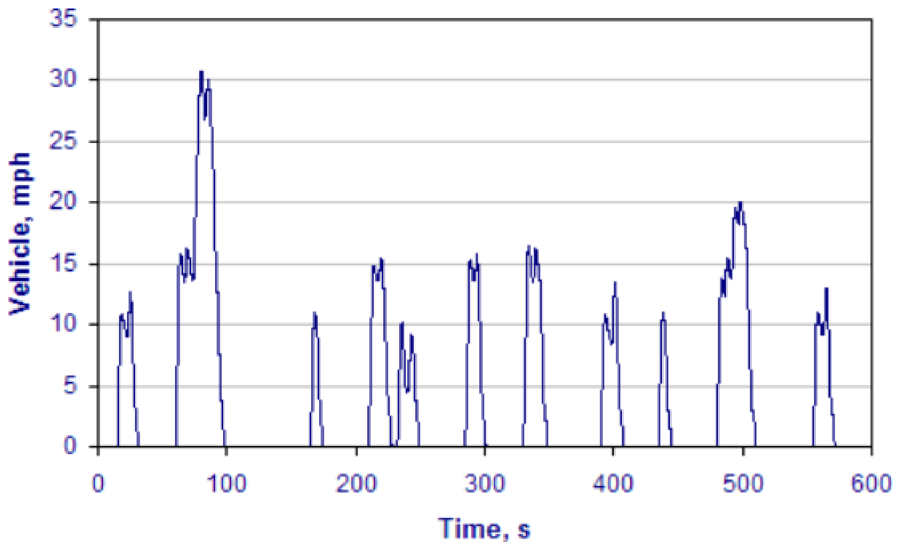


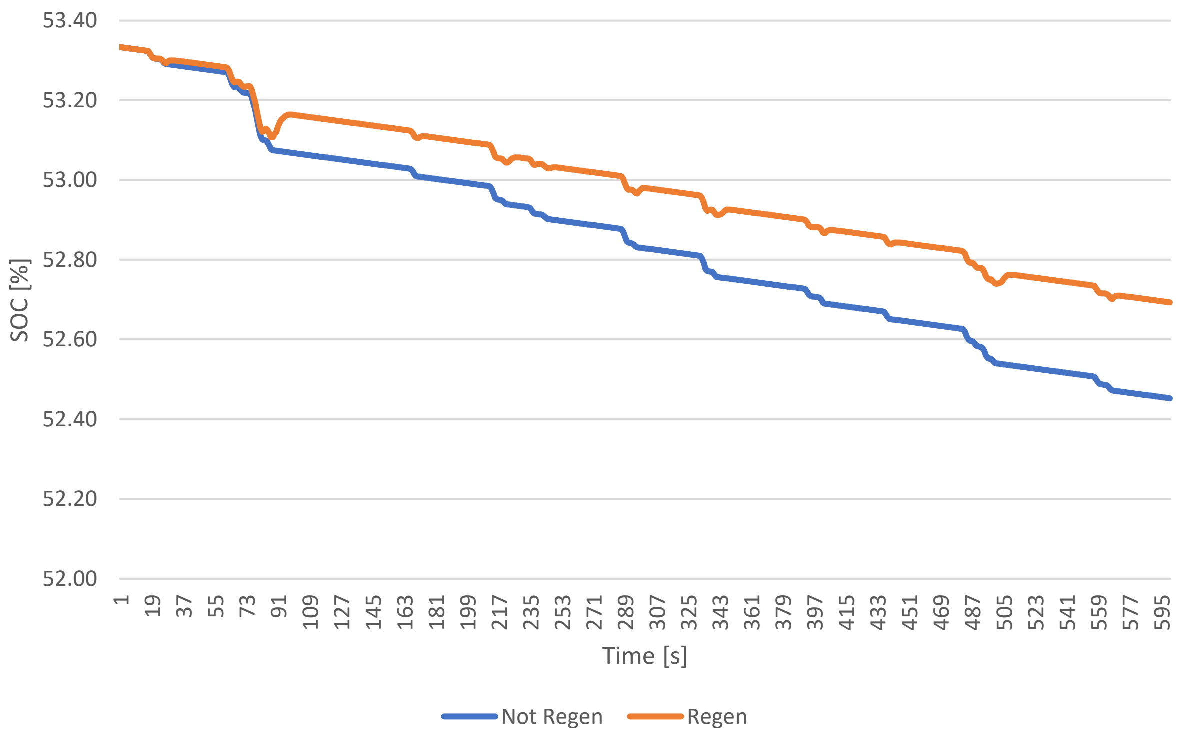






REGENERATIVE BRAKE EFFECT IN NEW YORK BUS CYCLE

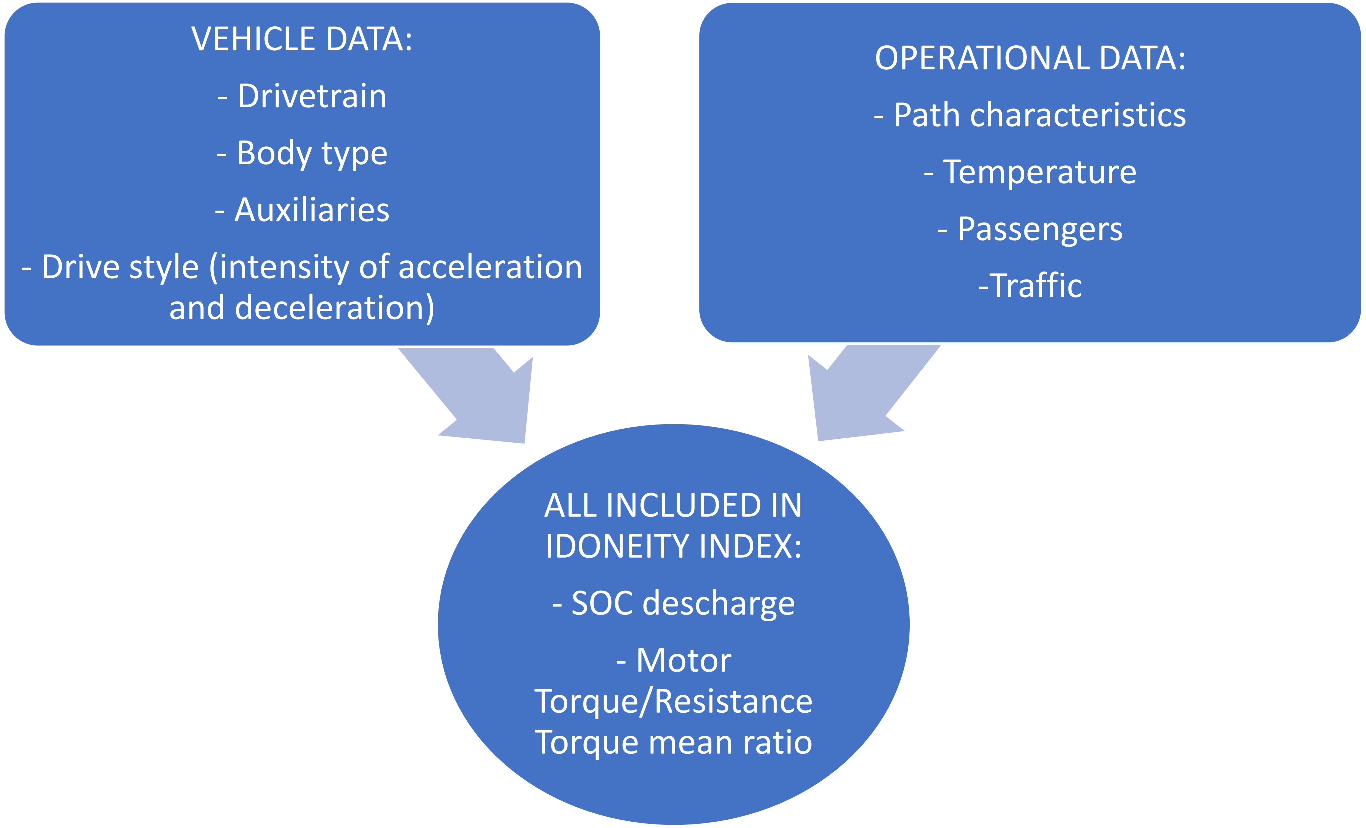




	Regen		Not Regen	
Parameter	Value	Unit	Value	Unit
Kwh/km	2.43		3.37	
Autonomy	77.74	km	56	km
SOC Descharge	0.64	%	0.88	%
Energy Used	2.304	kWh	3.17	kWh

Using the regenerative brake saves **more than 29% of energy**. Regenerative brake is a fundamental part for optimizing the energy consumption.

KPI AGGREGATION AND IDONEITY INDEX



$$I_{dx} = \left(1 - \frac{SOC_{initial} - SOC_{final}}{SOC_{initial}}\right) \cdot \frac{\int 2 - \frac{Res_{trq,t}}{Mot_{trq,t}} dt}{T_{trip}}$$

It quantifies the idoneity of a vehicle for a specific trip with a number comprised between 0 and 2:

- **0 - 0.8 Index**: the vehicle is not appropriate for the route and simulation is not reliable;
- **0.8 - 1.2 Index**: suitable for the route, but the simulation could contain uncertainties;
- **1.2 - 2 Index**: oversized for the route, errors in simulation can be neglected.

SUMO

Simulink speed profile can be determined by using SUMO (Simulation of Urban Mobility): a microscopic and continuous traffic simulator.

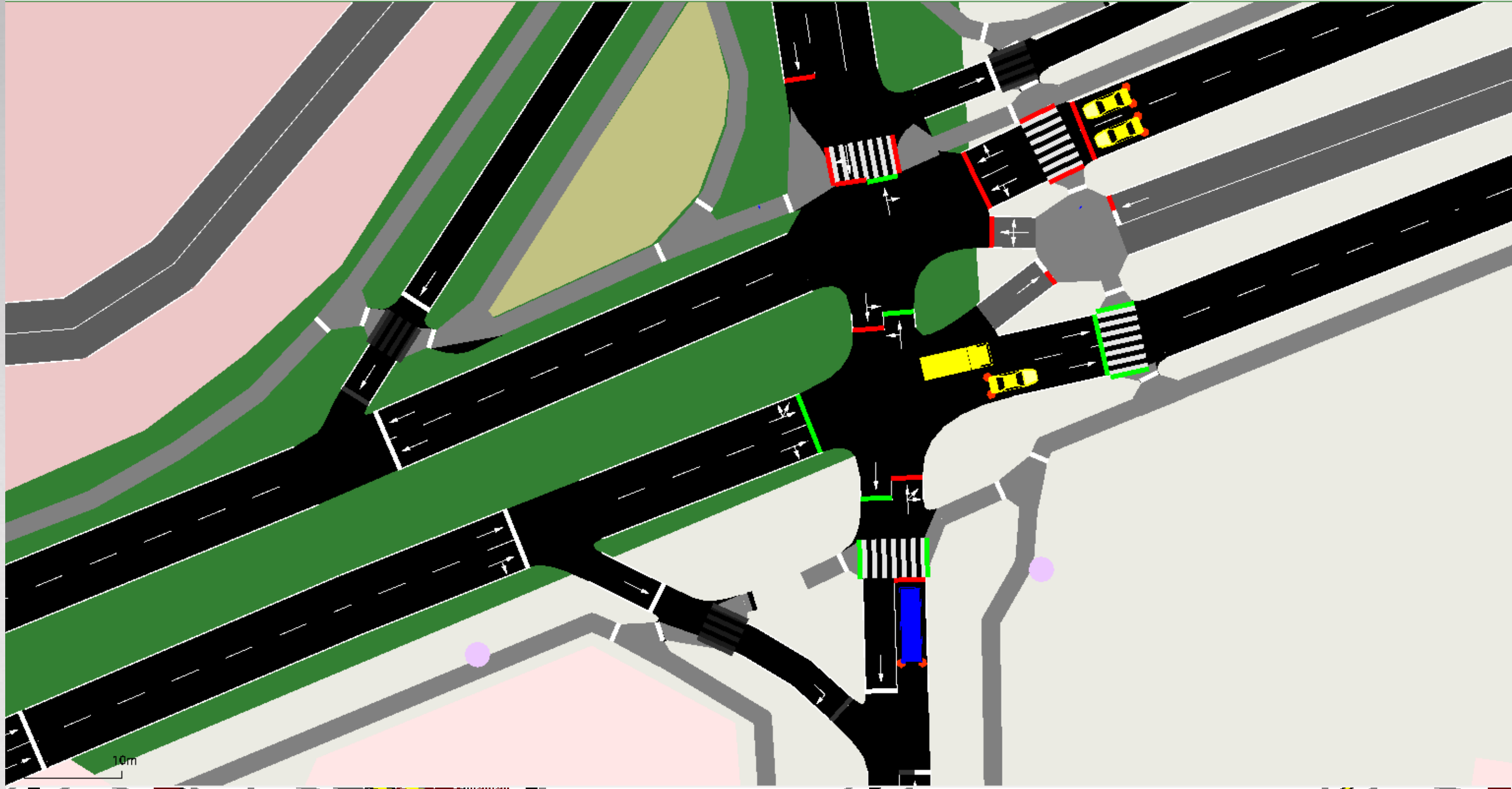
Input:

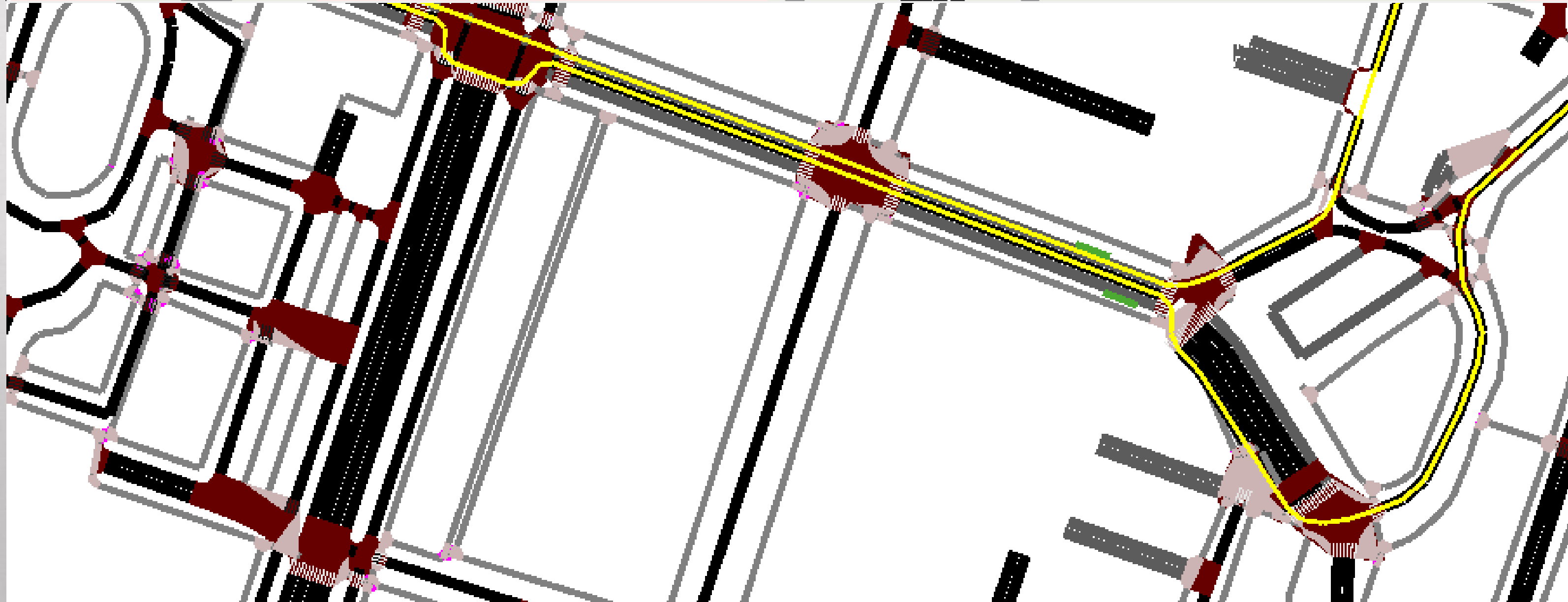
- Route map, stops, idle time;
- Traffic lights, drive style, traffic;
- Bus parameters.

Output:

- Speed profile;
- Time passed;
- Emissions.

Emissions	GWP
CO_2	1
NO_x	25-110
CO	1.6-1.8



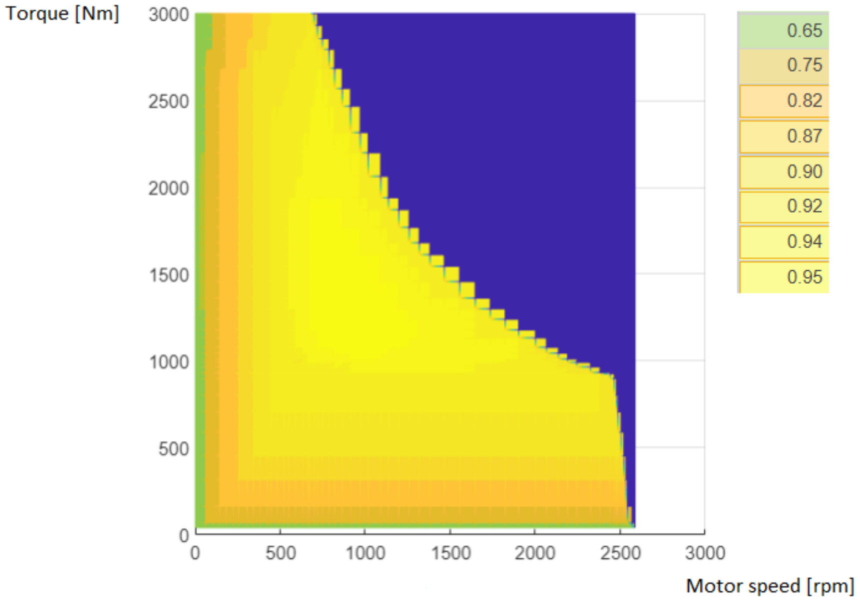


IRIZAR BUS IN GENOA

The bus line 44 (Borgoratti – Piazza Rotonda) has 21 stops and travels from Dante/De Ferrari to Rotonda/Capolinea. It is totally provided by Irizar ebus. Their autonomy is around 220 km.

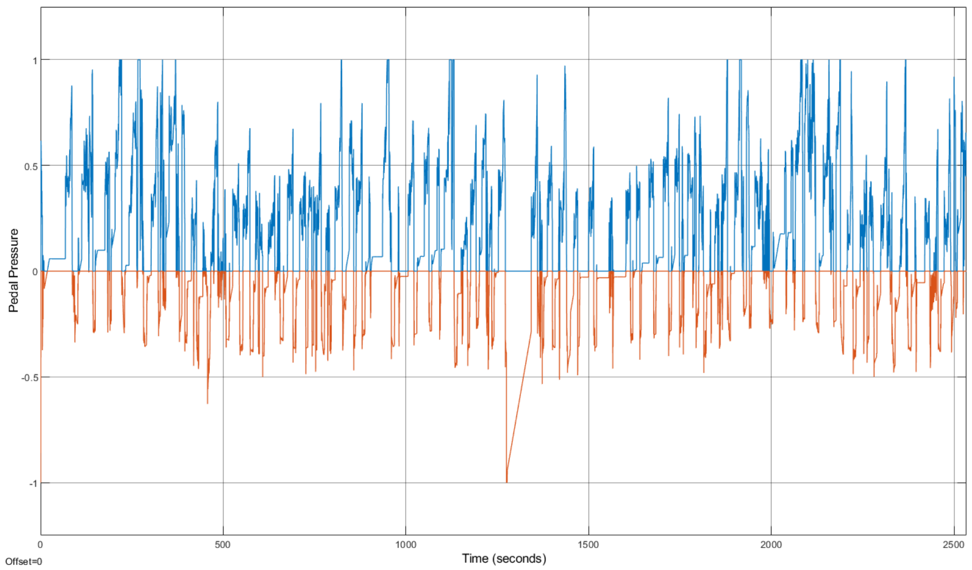
Genoa map provided by Google Earth with the bus line 44 roundtrip route.

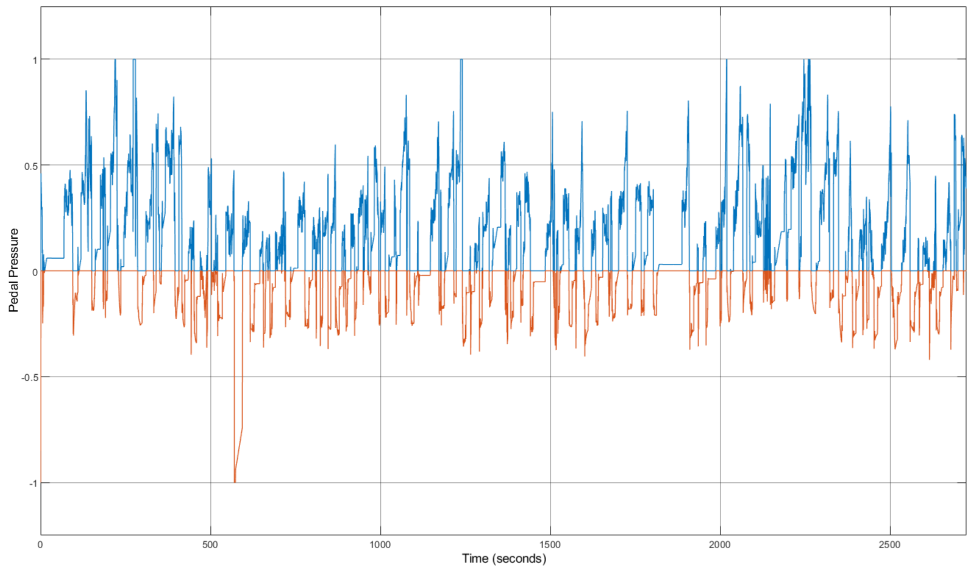
CONTROL ACTION



	Aggressive drive	Moderate drive	Unit
Max Acceleration	1	0.7	m/s^2
Max Deceleration	1.5	1	m/s^2

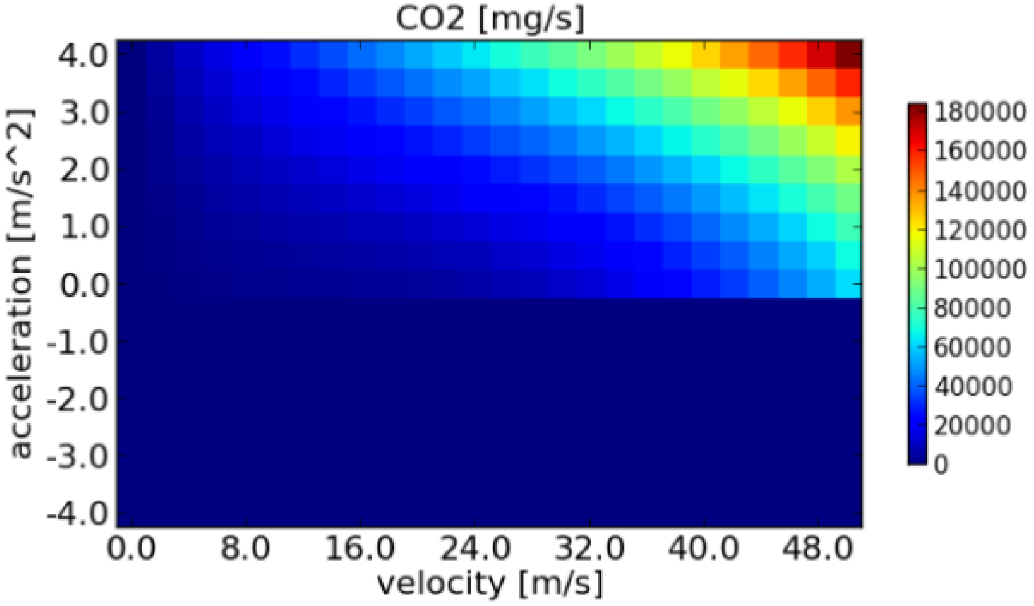
- With **lower pedal pressure** the motor operates in **more efficient** working points and the **regeneration ratio is higher**.
- **Mild drive style** (figure at the bottom) requires **significantly lower pedal actions**.

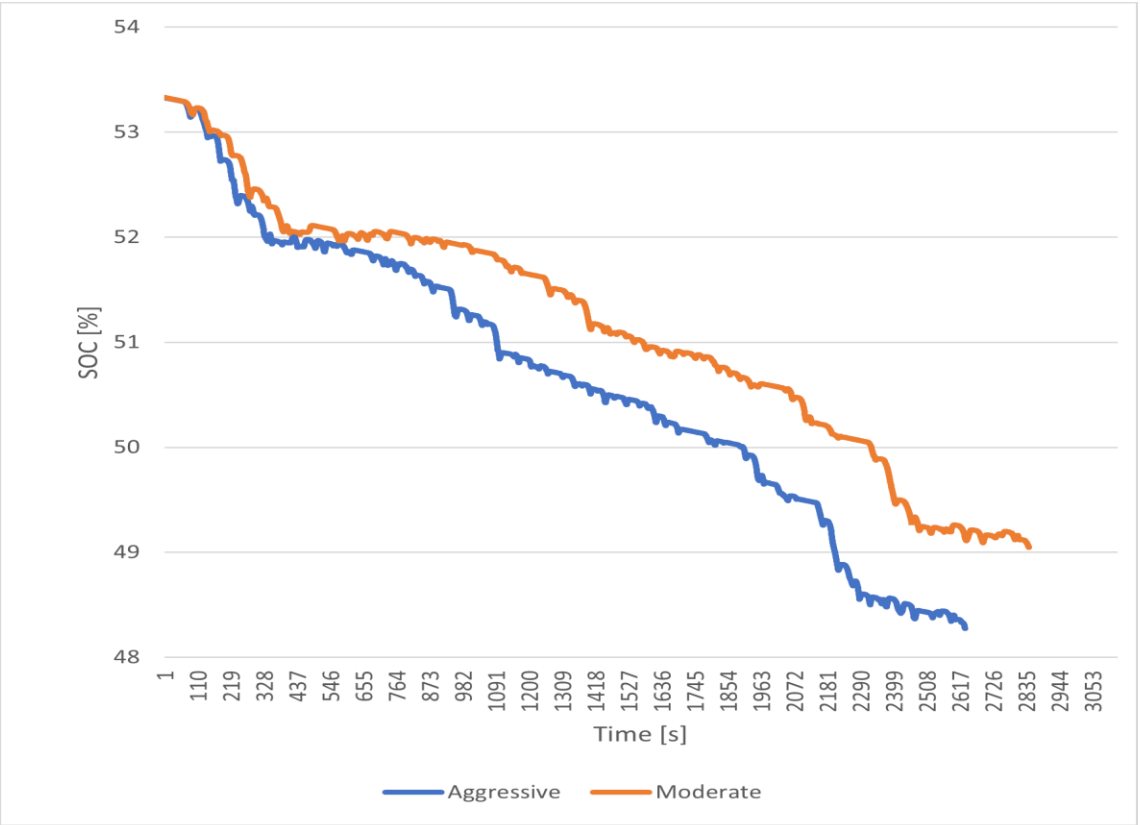




DRIVE STYLE EFFECT IN LINEA 44 IN GENOA

	Aggressive		Mild	
Parameter	Value	Unit	Value	Unit
Idoneity	1.614		1.677	
Duration	2633	s	2843	s
Kwh/km	1.592		1.3468	
Autonomy (full charge)	126.63	km	140.33	km
Energy Used	9.56	kWh	8.10	kWh
Fuel Used	5.21	l	4.87	l
Emissions engine	76.10	kgCO2eq	71.38	kgCO2eq
Emissions electric	5.7	kgCO2eq	4.83	kgCO2eq
Emissions avoided	92.5	%	93.23	%



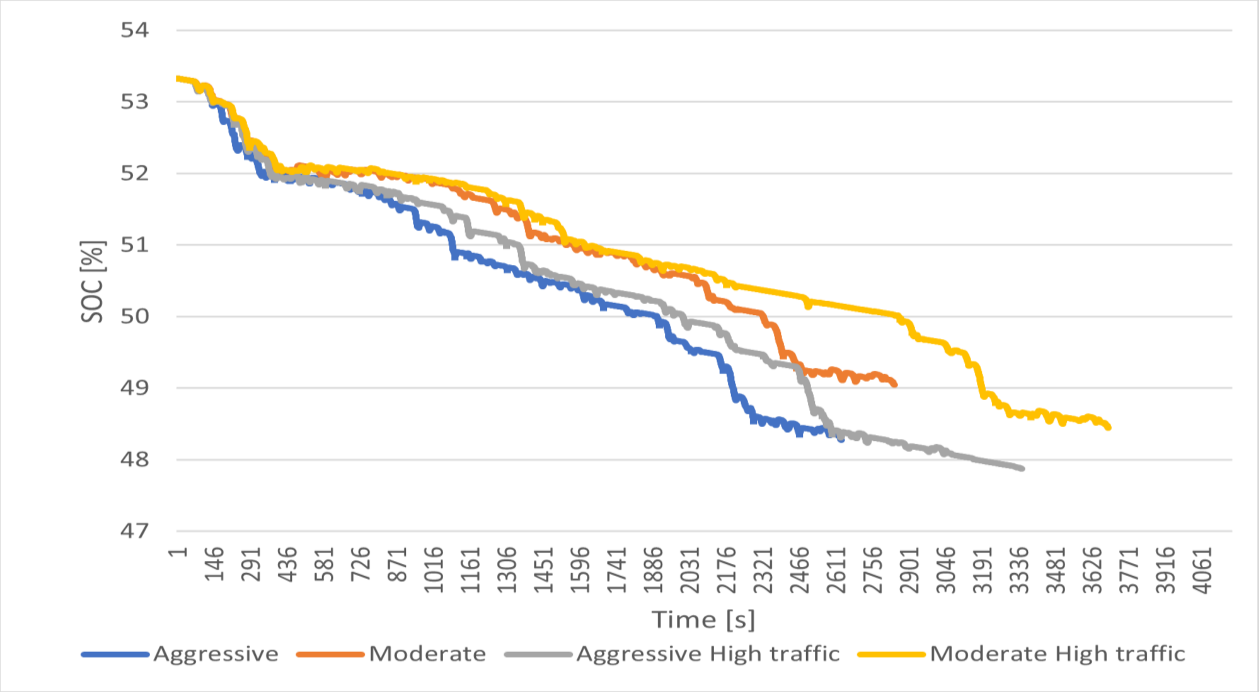


- **Mild drive style** leads to a **delay of 210 seconds** and an energy saving of **18.2%**.
- Due to the **lower acceleration**, passengers **comfort and security are improved**.

TRAFFIC AND DRIVE STYLE EFFECT

	Aggressive drive			
	Low traffic		High traffic	
Parameter	Value	Unit	Value	Unit
Idoneity	1.614		1.62	
Duration	2633	s	3350	s
kWh/km	1.592		1.717	
Autonomy (full charge)	226.13	km	209.67	km
Energy Used	18.20	kWh	19.64	kWh

	Mild drive			
	Low traffic		High traffic	
Parameter	Value	Unit	Value	Unit
Idoneity	1.677		1.686	
Duration	2843	s	3691	s
kWh/km	1.3668		1.537	
Autonomy (full charge)	267.3	km	234.48	km
Energy Used	15.43	kWh	17.6	kWh

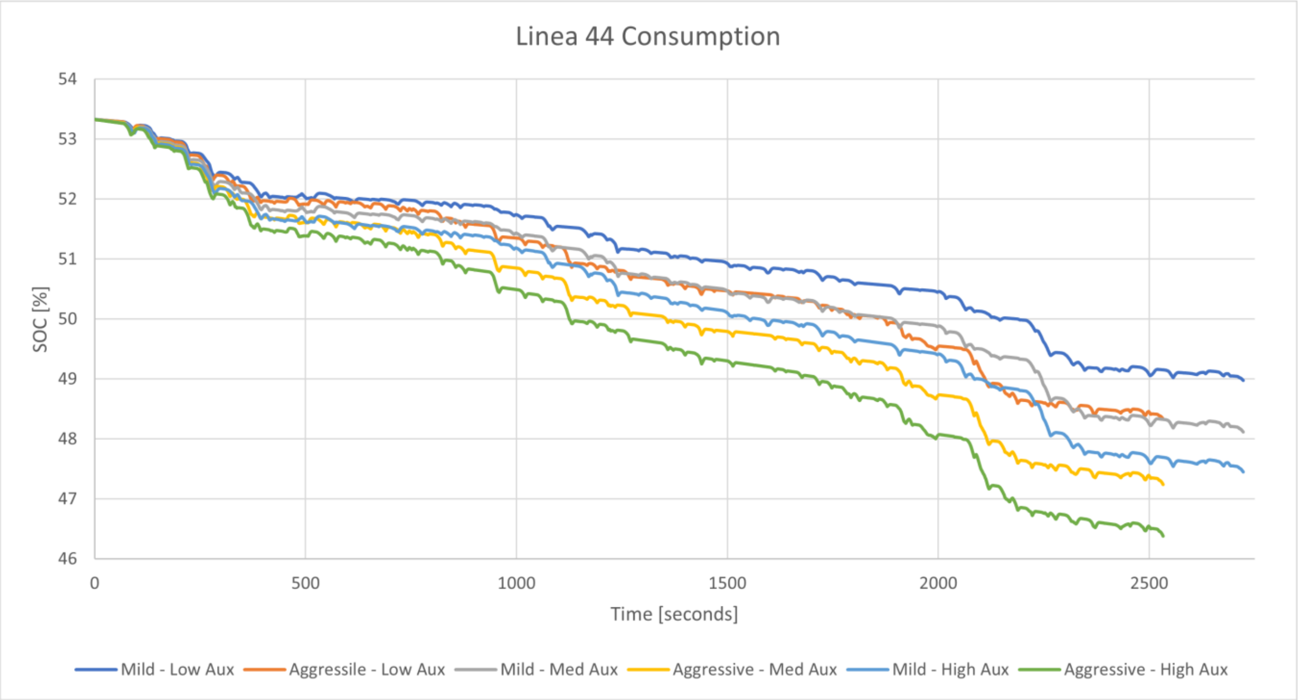


- **Poor traffic optimization** leads to an **energy waste** of **7.8% in aggressive drive** and **14% in mild drive**.
- **Drive styles** in the **high traffic situation** saves more than **11.7%** of energy with a **delay of 341 seconds**,
- **Drive styles** in the **low traffic** the energy saving is of **16.20%** with a **delay of 210 seconds**.
- **By comparing the best situation** (optimized traffic and mild drive style) **and the worst one** (aggressive drive style and poor traffic optimization) the **energy saving** is up to **27.5%.**

AUXILIARY AND DRIVE STYLE EFFECT

	Aggressive drive style					
	Low		Med		High	
Parameter	Value	Unit	Value	Unit	Value	Unit
Idoneity	1.62		1.59		1.55	
kWh/km	1.652		1.837		2.194	
Auxiliaries contribution	18.2	%	20.1	%	22.23	%
Autonomy	217.92	km	195.97	km	169	km
Energy used	18.9	kWh	21	kWh	24.35	kWh

	Moderate drive style					
	Low		Med		High	
Parameter	Value	Unit	Value	Unit	Value	Unit
Idoneity	1.68		1.66		1.62	
kWh/km	1.416		1.567		1.82	
Auxiliaries contribution	22.53	%	25.3	%	28.37	%
Autonomy	254.24	km	229.74	km	197.8	km
Energy used	16.22	kWh	17.94	kWh	20.84	kWh



Three tests conducted for **each drive style** with **low traffic**:

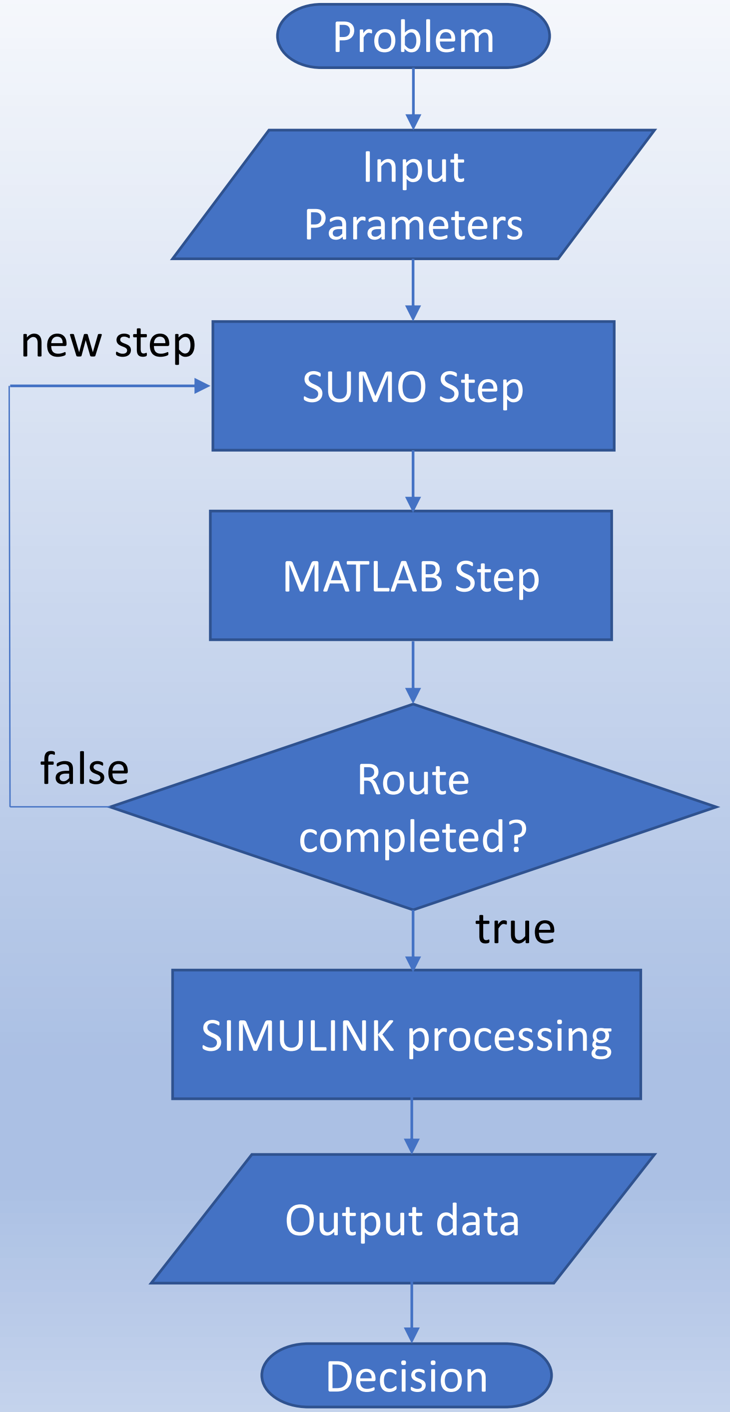
- **Low Aux:** ΔT = 5 °C, occupation at 30%, 32 passengers
- **Med Aux:** ΔT = 20 °C, occupation at 55%, 45 passengers
- **High Aux:** ΔT = 20 °C, occupation at 80%, 65 passengers

Energy saving among important cases:

- **Low/High Aux | Fixed aggressive drive**: **32.80%**;
- **Low/High Aux | Fixed mild drive**: **28.53%**;
- **Fixed High Aux | Aggressive/Mild drive**: **20.55%**

MY WORK IN SYNTHESIS

- Hitachi's **question**
- **Input** bus and route **parameters**
- SUMO MODEL for the **route simulation**
- MATLAB as a **bridge** between softwares
- SIMULINK for **energetic results**
- **Output results**
- **Best decision** for the **specific situation**



THESIS RESULTS

- **Prediction: with this work, predictions** regarding the bus consumption, route feasibility and travel time can be done **without tests on field with quantitative precision**
- **Drive style:** drive style can affect **driving speed** and the **powertrain efficiency**. Presence of **traffic lights** can alter the time of travel
- **Traffic:** traffic **increases the number** of brake, acceleration and idle **instances**, leading to **several delay**
- **Energy saving and schedule delays are deeply linked:** more time required for the trip inevitably increases the auxiliary consumption

FUTURE POSSIBILITIES

- **Optimization of resources**: selling **extra energy**, optimizing the **number of buses** and employing them with **strategy**, such as using partially descharged buses in high descendant routes
- **Inclusion of smart cities control** for **optimizing the traffic flows** and the traffic lights **coordination**
- **Using real traffic data** for simulating typical Genoa scenarios and already knowing **how to behave**
- **Inclusion of genetic or dynamic algorithms** for **speed optimization** and obtaining the **best compromise** between energy usage and time schedules

THANK YOU FOR YOUR ATTENTION