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# Simulated and real world tests to compare drivers performance in dynamic wireless technology perspective

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**Abstract.** The ongoing electrification of road vehicles needs to be supported by proper growth of charging infrastructure. In this context, dynamic wireless charging can provide a number of advantages, main being the possibility to extend vehicle range without increasing on board battery capacity, potentially reducing cost, mass, and tank-to-wheel energy consumption. The development of such solutions however poses various questions, including the acceptance and the capability of users in driving according to infrastructure characteristics; in particular, the misalignment reduction while a driver follows a straight path positively influence the charging efficiency in dynamic wireless technology. In this paper, authors describe a tests campaign to determine driving perfomances using both a simulator and a real world equipped vehicle. The research question of this paper is to assess and quantify differences between the two approaches. To reach this objective, in a first phase, data have been collected through a driving simulator (i.e. a full car body mounted on a parallel linked kinematics with a large screen, proposing a virtual city scenario), and in a second phase through a car equipped with a camera. As a post processing phase, statistical tools have been used to describe driving performance indexes and related impacts on wireless charging infrastructure by determining the secondary voltage on the vehicle. Data coming from the activity will be functional to be used by scenario analyst to develop characterization tests only with a simulative approach to decrease costs.

## 1. Introduction

In the past years the interest for environmental impact of vehicles has experienced a strong increase due to the approval of the directives of the Kyoto protocol, and the effects of pollution on human health have been seriously studied [1], making car industry to produce more and more efficient vehicles, according to EURO standards [2].

Pollution effects have been discovered acting both on human health and monuments and historical masterpieces causing premature corrosion effects [3], [4].

Several studies [5],[6],[7] have been conducted showing that the effects of pollution on human and mental health cannot be neglected. Considering that transportation sector is responsible of approximately 25% of the total Greenhouse Gases (GHG) emissions [8] and more than 75% of these are attributable to ICE (Internal Combustion Engine) vehicles and the vast majority of the NOx, sulfides and particulate matter [9], it is obvious why a more eco-friendly mobility model should be preferred to the classical one. These problems especially affect many large European cities; their historical city centres often have centuries-old mobility infrastructure that cause traffic congestions and local pollution increases. One important example is the city of Firenze (Italy) [10], [11] where 5 km² of the city centre was declared UNESCO site; it hosts a large number of historical buildings together with a high population density. Nowadays, significant percentage of the urban population in the EU is exposed to pollutant concentrations higher than limit/target values stated by EU air quality legislation [11],[12]. Moreover, the high concentration of tourists led to the need of mobility, where the economy is highly dependent on the tourism [13].

Vehicle ownership is high for developed countries and tends to increase in developing ones [14].

In order to reduce the number of vehicles on the road and, consequently, pollution, several vehicle – sharing systems have been developed, but these have had little effect on new vehicle registrations, reducing them by only a few percentage points [15].

This work is aimed to deal with "old" environmental and mobility problems and new European Union plans, known as "Fit for 55" [16] package which goal is to reduce greenhouse gas emissions up to 55 % (related to 2021 goals) by 2030 and to achieve carbon neutrality by 2050. Climate change is a multidimensional matter and have to be treated as a real emergency, so that every sector has been considered in Fit for 55: from energy production up to vehicles and aircrafts [17].

According to data available, cars and van are responsible, as mentioned before, for about 75% of GHG release in the past few years, increasing every year due to higher number of vehicles on the road [18]. The European Green Deal poses various ambitious goals in front of us, considering that, as stated previously, emissions are to be zero by 2050, several questions must be analysed:

- How to develop new environmental strategies?
- How to develop less pollutant fuels in the next years?
- How to design and built new charging infrastructures?

Focusing on the latest question, "sustainable and Smart Mobility Strategy" and "TEN-T" network have to be considered: this programs are aimed to install up to 600 kW each 60 km of highway path by 2035. To achieve long-terms benefits from new environmental strategies, new methods have to be followed: smart cities are, now, really needed [19], [20].

The main drivers for developing electric vehicles (EVs) are, then, clearly outlined: environmental issues, energy crisis and decarbonization [21]. Considering that by 2035 no more internal combustion vehicles can be sold, it is legitimate to ask how existing charging infrastructures can be modified and integrated to make them more usable, facing with vehicle-grid integration (VGI) issues (see [22], [23], [24]). Nowadays electric vehicles (EV) are charged using static methods: the driver has to stop and "refill" the car according to charging power and rest time. Typically, EVs are charged during the night and this can lead to grid characteristics deterioration, congestion and stress on the charging infrastructure [25].

Charging power is one of the most important values that have to be considered while developing infrastructures: it is self-evident that facilities have to co-evolve with the EV sale rate [26], even because electric vehicles users are often experiencing "range anxiety" [27], due to short mileage of their vehicle. The trend to build and upgrade new infrastructure may lead to expensive grid expansion and high power demand [28].

With a view to reducing charging times, developing more efficient electric vehicles and reducing energy density in parking slots [29], dynamic wireless charging technology has been investigated; the application of such technology needs the solution of various challenging engineering and management problems, one of these being the acceptability from drivers and their capability to use it. In this work, authors prove that a misalignment reduction while a driver follows a straight path positively influence the charging efficiency. This technology has previously been developed in the earlier 90's and used by several researchers in the world, building prototypes and simplified models [30].

Lane keeping ability is strictly connected to dynamic wireless charging systems. Average drivers tend not to assume a good lane keeping behaviour, as stated in [31], various possible reasons can be effective on poor lane keeping conditions in a traffic flow such as road surface deformations, uneducated drivers, invisible lane markings, etc. It is expected that the continuous improvements of driver assistance systems (i.e. Advanced Driver Assistance Systems, ADAS) and automated driving technologies will progressively mitigate or avoid the issues related to imprecise lane keeping [32–34]; however most circulating vehicles are still not equipped with such devices. In addition, ADAS devices are mandatory since July 2022 worldwide but can anyway be disabled for a number of reasons, not far investigated in this paper. All these elements suggests that an investigation on unassisted driver's capability is necessary.

The aim of this paper is to carry out simulated and real-world tests, can be difficult to manage and costly to conduct [35], to compare drivers performance in dynamic wireless technology perspective.

## 2. Methods

In this section researching methods are presented: a tests campaign to determine driving performances using both a simulator and a real world equipped vehicle is described. In a first phase, data have been collected through a driving simulator (i.e. a full car body mounted on a parallel linked kinematics with a large screen, proposing a virtual city scenario), and in a second phase through a car equipped with a camera. Data coming from both simulation and real-world test have been used after adopting a physical model related to magnetic flux and its evaluation as offset flux and air gap flux. As a post processing phase, statistical tools have been used to describe driving performance indexes and related impacts on wireless charging infrastructure by determining the secondary voltage on the vehicle. The results coming from the activity will be functional to be used by scenario analyst to develop characterization tests only with a simulative approach to decrease costs and reduce vehicle batteries weight.

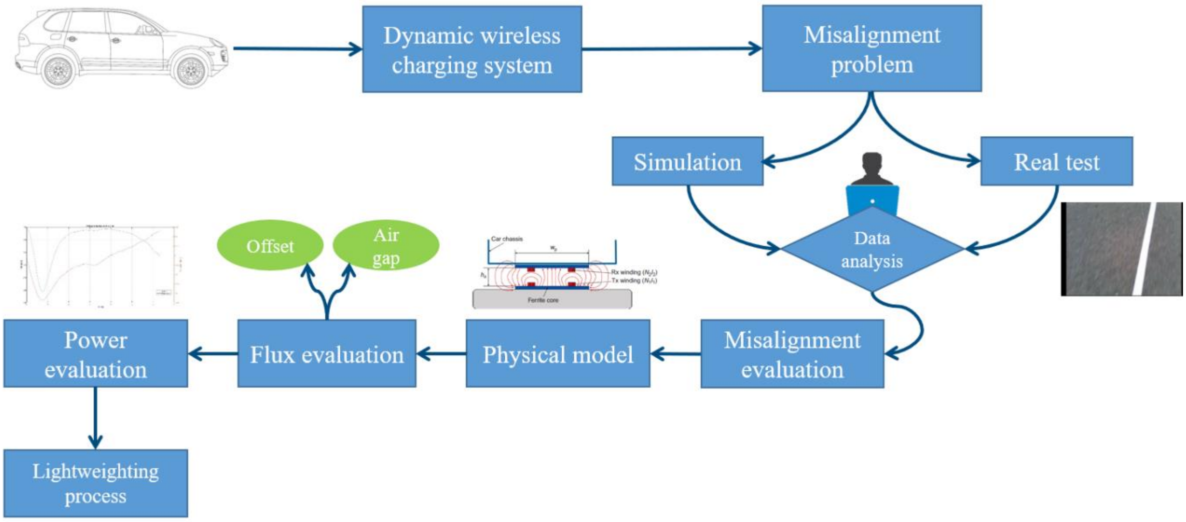
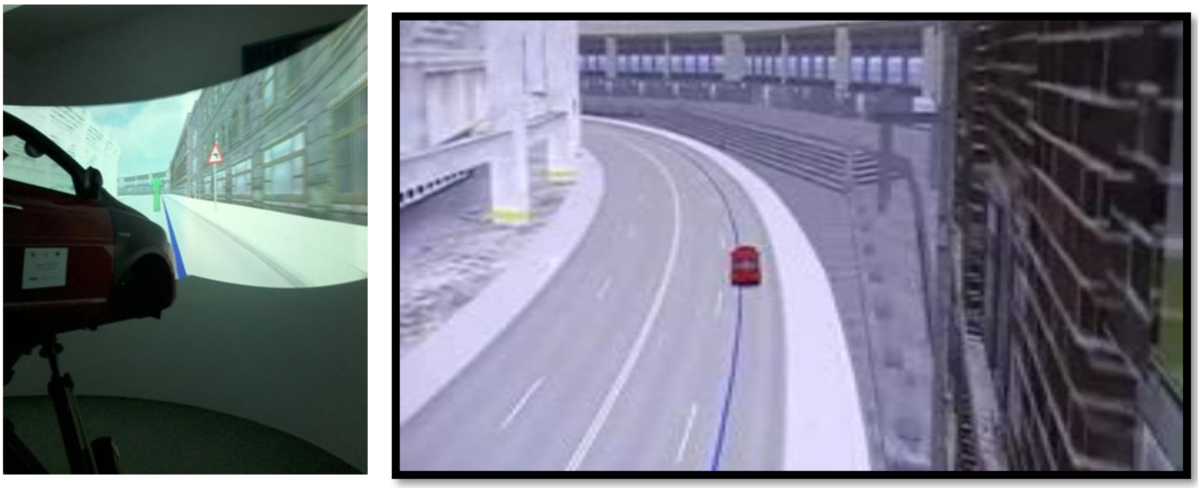


**Figure 1**. Method using to evaluate misalignment problem using both real and simulated tests.

### 2.1. Simulator test

Simulator tests have been conducted in LaSiS laboratory of University of Florence (Italy): a full car body has been mounted on a parallel linked kinematics (Figure 2, a) with a large screen, proposing a virtual city scenario (Figure 2, b) [36].



a) b)

**Figure 2**. a) LaSiS simulator b) A view of simulated urban path.

The participants were recruited on a voluntary basis among the students and teachers of the University of Florence. Twenty-eight subjects participated in the research, as can be noticed in Table 1. None of the subjects had previous experience with a driving simulator. The simulation has been carried out by uploading a city scenario with both straight path and corners, to evaluate performances in various driving conditions.

**Table 1**. Statistic sample for simulator test.

| Gender | | Age | | Driving licence years | | Driving frequency | Average speed (km/h) | Path type |
|---|---|---|---|---|---|---|---|---|
| M | F | min | max | min | max | | | |
| 19 | 9 | 22 | 45 | 4 | 20 | 1-5 | 20-60 | Straight and corner |

The studies about gender, age and the link to risk perception have been conducted in the past (see [37], [38]). The driving frequency score was discretised on a scale of 1 to 5, with the former being a value relating to sporadic driving and the latter to very frequent driving.

The scenography, showed in Figure 3, includes traffic lights and parked cars, in order to achieve a more realistic driving experience.

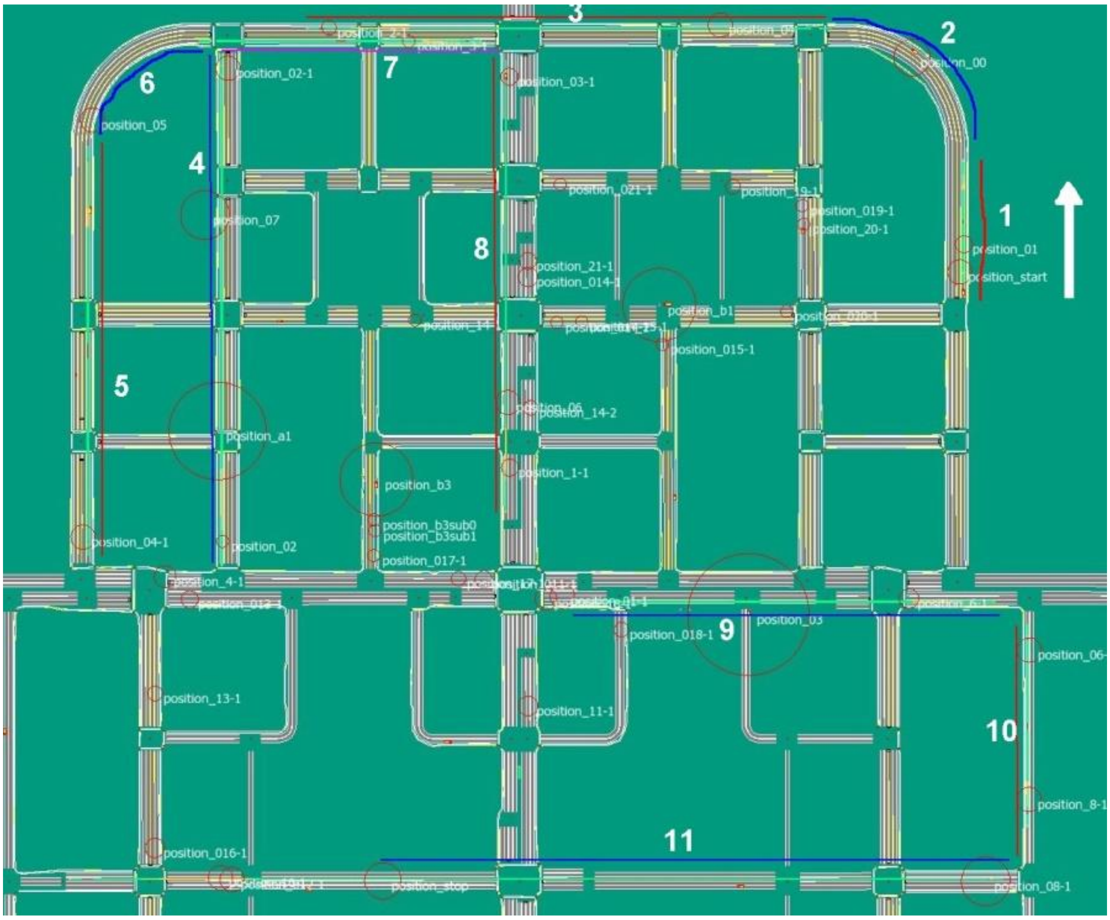


**Figure 3.** City scenario used during the simulated test. It includes both straight path and corners.

### 2.2. *Real-world test*

As for the real-world tests, they were carried out in a closed road in a safe zone, referring to Figure 4, Segment 'A' is about 50 metres long while the curved line 'B' is about 20 metres long, with a white path painted on the ground (Figure 5, a): the chosen road has all the characteristics of a normal road and in addition there were several cars parked in a fish-bone pattern during the test. The test car was equipped with a camera mounted on a specific support anchored to the vehicle bonnet (Figure 5, b). Additionally, the vehicle was not fitted with ADAS, such as lane keeping aid and adaptive cruise control [39], that are becoming more and more important in four and two-wheels vehicles [40], as the main goal of the experiment was to identify human influence in following a line while driving. Experimental sessions have been conducted in a speed range between 20 and 60 km/h . The regenerative braking systems and aspects related to performance and perception [41] are not included in this study, as a traditional ICE vehicle has been used.

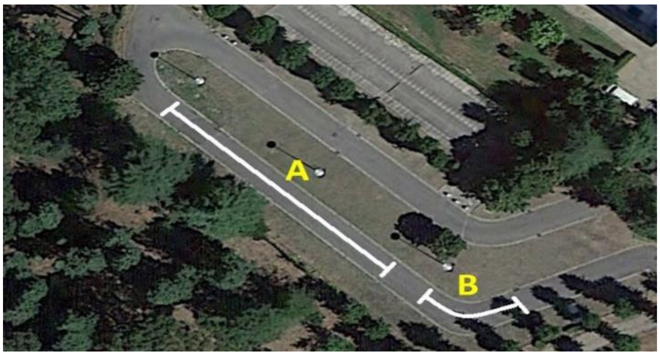


**Figure 4.** Test site in Florence.

a) b)

**Figure 5.** a) The line represents the electrified charging path. At the end of the longitudinal line there is a perpendicular one, used during image processing phase. b) Equipped test vehicle.

To carry out the test, each driver was asked to drive the route three times:

- on the first lap no support was given to the driver;
- at the beginning of the second lap simple indications were given regarding the side where the most misalignment persisted;
- on the third lap continuous indications were given to help the driver align the car.

In this way, it was possible to understand whether simple information and/or driving training could help the driver to improve his driving performance, this is a method often used during simulator tests (see [42], [43]). By means of a template, it was ascertained that the position of the camera allowed a field of view on the asphalt of 0,62 m and in case the same experiment be repeated in the future, the position of the camera could be reconstructed.

## 3. Post processing

In this section authors will describe how the information about misalignment have been extrapolated by footages. As a first step, frames recorder while the driver was out of the test field shown in Figure 4, where there was no white line painted, have been excluded.

Considering camera position in reference to vehicle centre of gravity, it is possible to understand how it must follow a larger path while driving along corners (see Figure 6 and Figure 7). Nevertheless, this error has not been considered during data analysis.

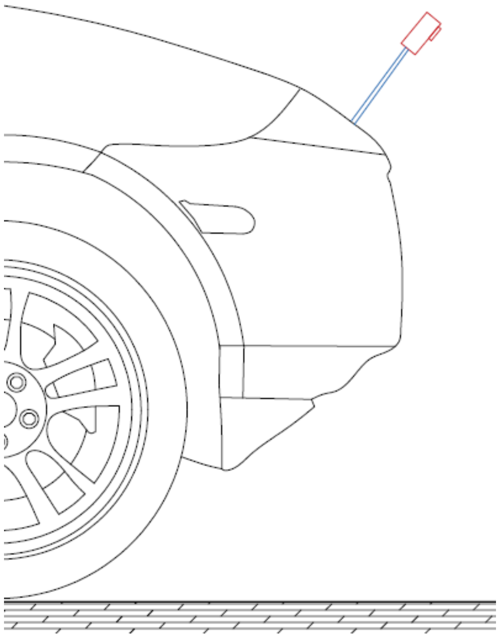


**Figure 6.** Lateral view of camera (in red) mounted on the vehicle using a rod (in blue).

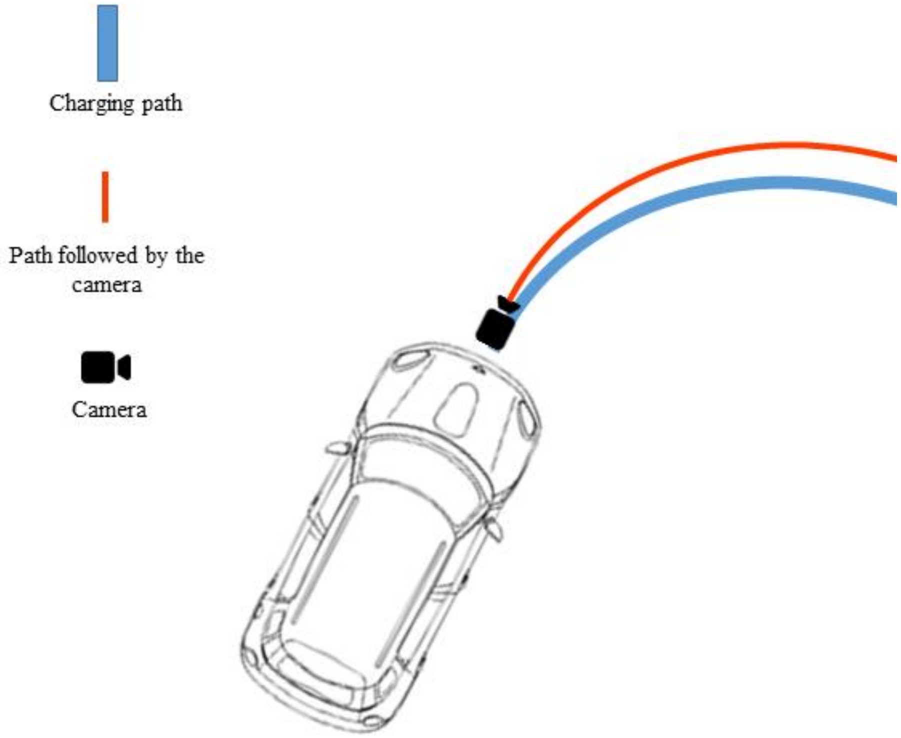


**Figure 7.** A schematic illustration of the path followed by the camera.

### *3.1. Simulink tool for footage analysis*

In order to evaluate misalignment, cut videos have been analysed in Matlab-Simulink environment (see Figure 8).

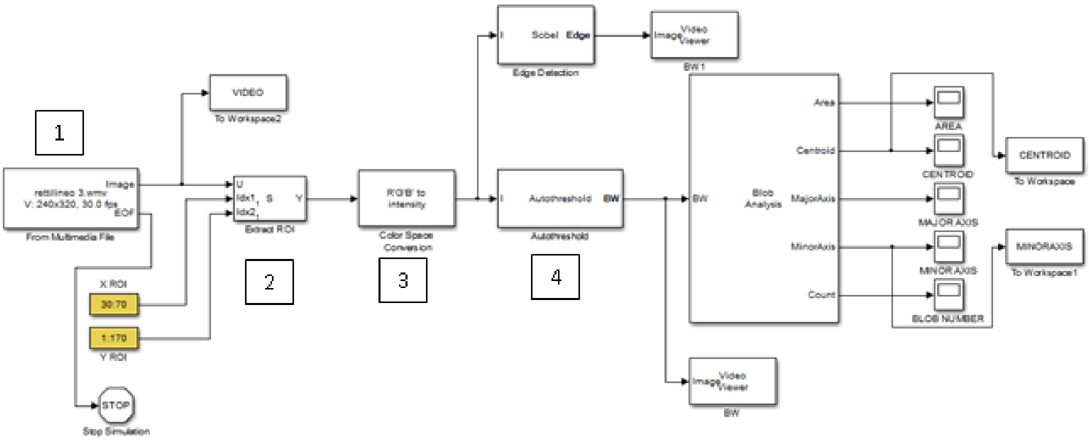


**Figure 8.** Matlab-Simulink code for footage analysis.

Main functions provided by the code are summarized in Table 2. This algorithm is based on “Blob analysis” function [44].

**Table 2**. Function involved in code and main operation provided

| Execution order | Operation |
|---|---|
| 1 | Coloured video upload |
| 2 | Footage downsizing |
| 3 | Gray-scale transformation |
| 4 | From grey-scale to black and white |
| 5 | Blob analysis |
| 6 | Output |

This process is repeated for each frame and gives a vectorial output with misalignment and time. A convention has been adopted whereby positive deviations are to the left of the main line and negative deviations are to the opposite part. Analysing data coming from real simulation, it is emerged a positive misalignment trend for every driver, this could be attributable to parallax error [45] as reported in Figure 9.

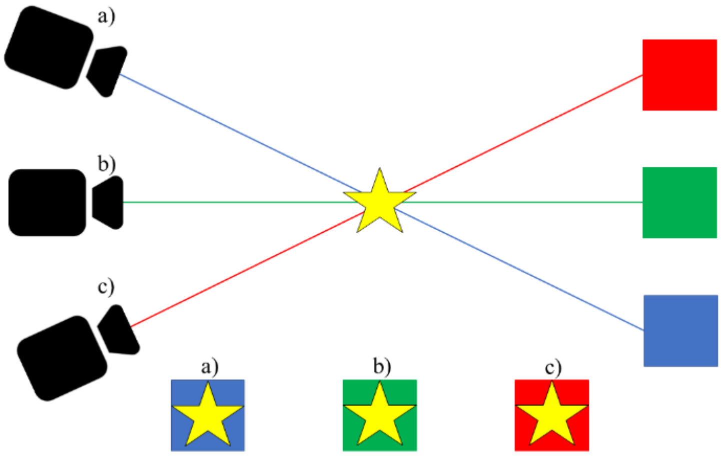


**Figure 9.** Parallax error.

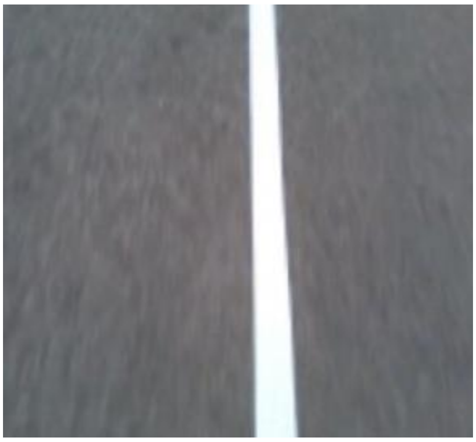


**Figure 10.** A screenshot taken during real world tests.

The analysis of the films (see Figure 10) carried out with the aforementioned code also revealed some erroneous findings due to spots on the road or external elements, such as manholes and pedestrian crossings. Outliers, highlighted in red circles (see Figure 11), emerged during the analysis have not been considered, because they were not taken into account as physical data.

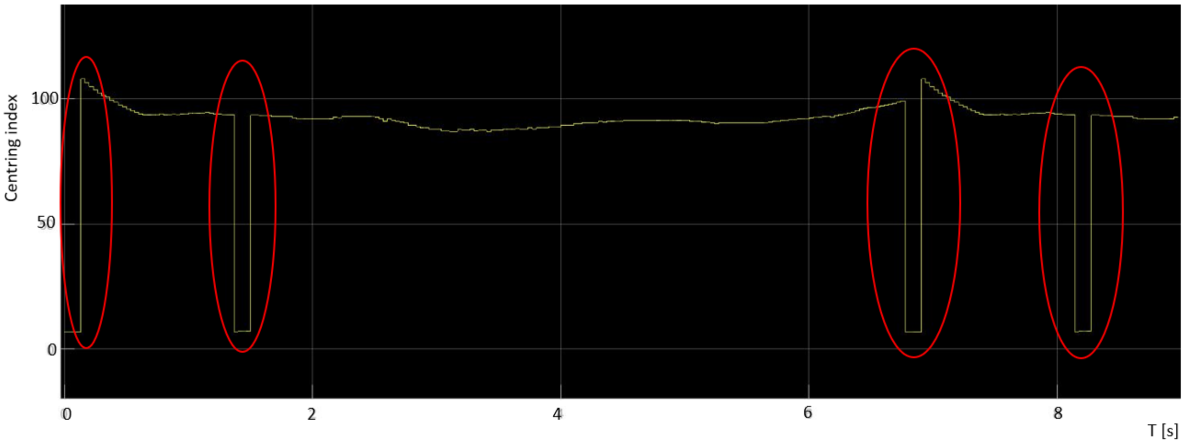


**Figure 11.** Centring index obtained by footage analysis vs time measured in seconds.

Centring index, provided by *blob analysis* block has been calibrated in order to link it to a physical value. Average duration of driving test analysed is between six and ten seconds.

## 4. Data analysis

In this section, the tools used on the data obtained from the two tests will be analysed in order to assess their statistical consistency. Data coming from simulated and real-world tests have been processed according to the procedure shown in Figure 12.

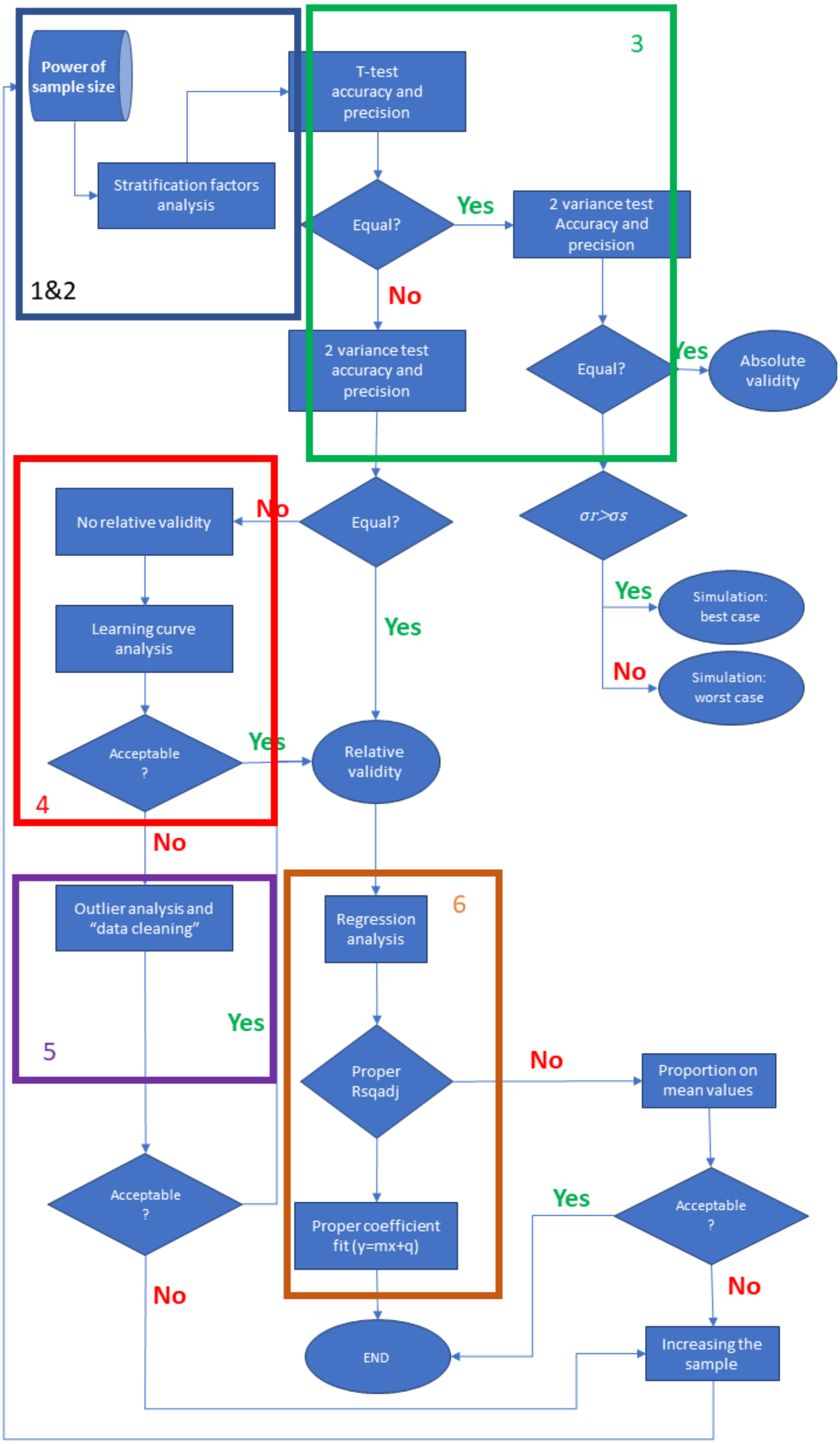
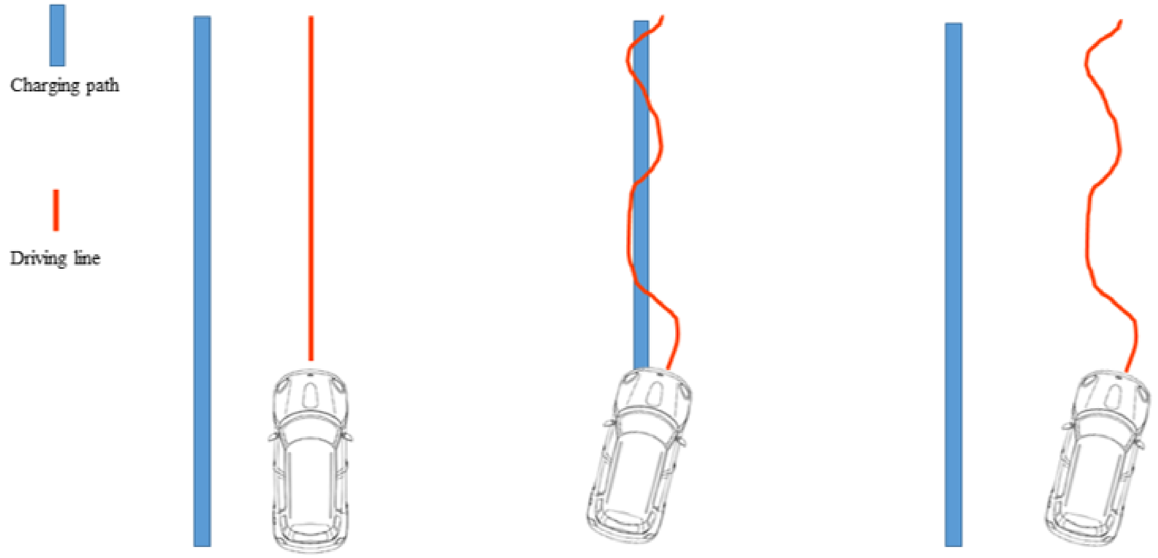


**Figure 12.** Flowchart used to evaluate data collected from real and simulated driving session.

The above flowchart describes the approach authors used to transform data in information: the aim of this work, in fact, is to define a model to investigate the problem of simulated vs real world tests, so it is needed to determine a repeatable procedure to compare different approaches.
Before further inspection of the statistical tools, it is necessary to distinguish between accuracy and precision in this specific test.



a) Precise but not accurate driving

b) Accurate but not precise driving

c) Neither precise nor accurate driving

**Figure 13.** Precision and accuracy during driving sessions.

As visualized in Figure 13, authors define the Precision as the driver ability to keep a "straight line" path without lateral deviations from the reference line and the Accuracy as the driver ability to keep the vehicle close to the electrified path identified by the painted line on the street-floor. These parameters are inferred from the data through the study of a variable, the electric captor barycentre distance from the reference line. From here, this parameter will be called "offset". Next step is to calculate both offset average and offset standard deviation to determine a continuous statistical curve that will be used as process model. In Figure 14 it is possible to visualize an "offset" distribution with average and standard deviation so Accuracy and Precision parameter:

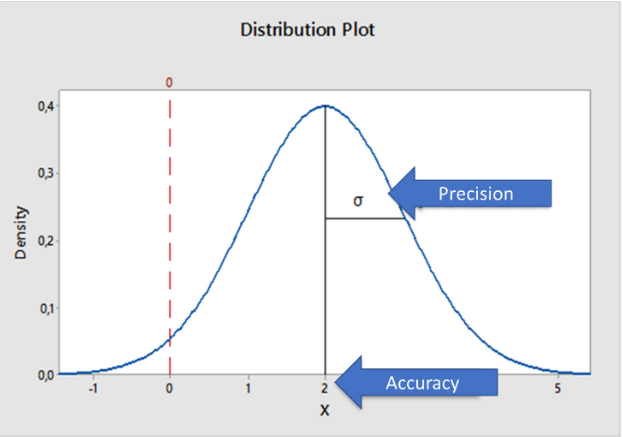


**Figure 14**. Precision and accuracy distribution.

Once the accuracy and precision are defined, it is possible to consider the Figure 12 algorithm. In fact, authors set up a method to infer real world behaviour starting from the simulator results, considering the actual test as a reference to compare future simulated case studies. The method main steps are described below, number of sub paragraphs are reported also in Figure 12:

1. Starting point is a Power of sample size analysis to determine if the variability in the data is adequately explained by the numerosity of the chosen sample. It is a preliminary analysis necessary to be confident of the sample significance before to start any other consideration.
2. Then it is important to choose the stratification factors. This activity will be important during the regression part that will be analysed here below. Stratification factors are factors that can be used to determine sub-population in the data to make differentiations in the sample and family analysis.
3. 2Sample t-tests and 2 variance tests: these tests compare the population average and standard deviations of the offset, respectively. The method is applied for both Accuracy and Precision. If the compared results are equal then the “absolute validity” is reached; if any of the two test average or standard deviations are different, “relative validity” is reached. “Absolute” and “relative” validity are two parameters that authors implement in this study to discriminate between two possible cases: if tests say that no difference are revealed, absolute validity means that it is possible to use simulator results for real world behaviour directly. If relative validity is reached, further studies, described in next steps, have to be carried out.
4. It is possible that learning curves behaviour can distort the driver attitude in the simulator. It is a very easy-to-use tool and so it is very easy to learn how to drive. This characteristic brings to a visible difference from the first simulator test and the last one. Through the paired t-test, authors evaluate the learning curves in the simulator between the first and the last lap searching for improvement.
5. If the results are still not acceptable authors propose an outliers analysis and their causes and proceed to eliminate the discarded values if any outlier is found. Point 4 and 5 are an iterative process to be repeated until relative validity is reached.
6. Last step is the regression analysis to determine the influencing variables in driving performance; in fact, if relative validity is reached it will be possible to determine which are the factors distorting the results. The regression analysis is a statistical method to quantify this distortion and to determine the stratification factor statistical significance. Considering Rsq-adj the correct parameter to discriminate between an acceptable and a not acceptable model, a regression coefficient proportioning in simulated test with those of the real world reference test is made.

In this algorithm, all the possibilities to go from simulated test to real world behaviour are investigated.

### 4.1. *Physical model*

According to previous studies, magnetic flux in dynamic wireless can be considered as consisting of two components:

- Air gap flux
- Displacement air flux

With regard to the first contribution, it is strictly connected with vehicle receptors’ height respect to the street. In earlier applications of this charging systems (see [46],[47]), the air gap was minimized using complex mechanical systems. KAIST applied wireless charging system to an electric bus (see [48], [49]) using an average air gap of 0,25 m: this value can be retained acceptable.
The authors assumed as valid the empirical flux variation law, presented in [46] and reported in Figure 15, derived from previous experimentation.

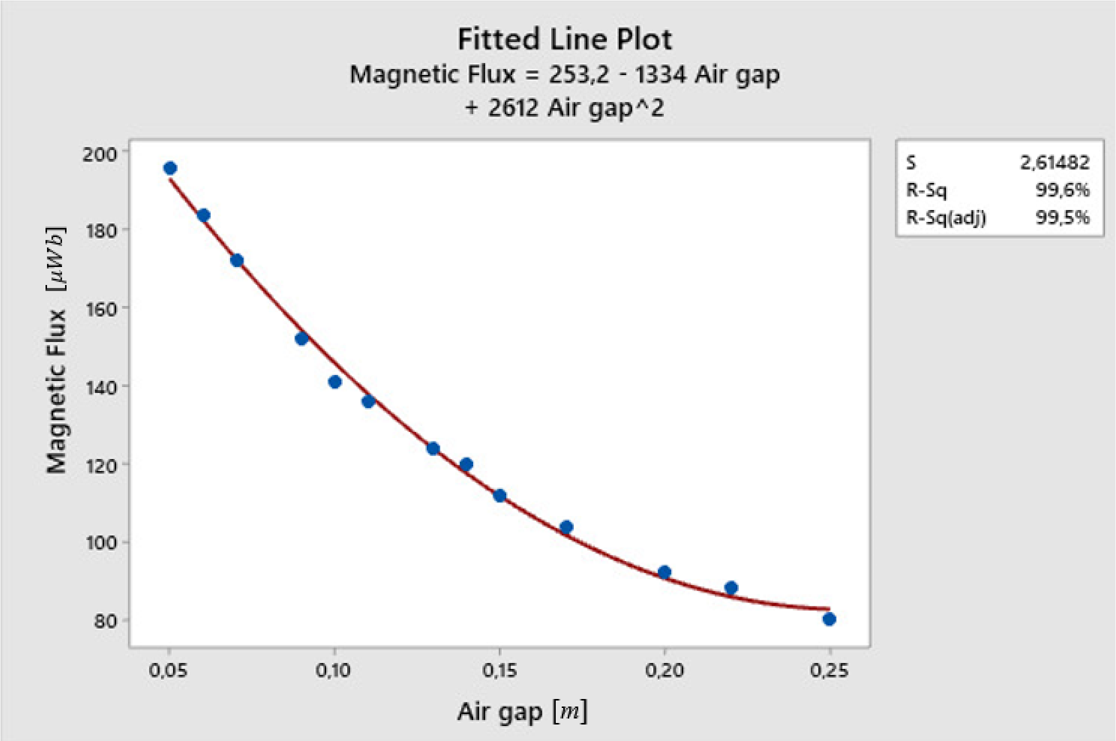


**Figure 15.** Magnetic flux variation vs air gap measured in m.

To assess the actual influence of this parameter, it is necessary to make a complete vehicle model, evaluating suspension displacement and tyre reaction model, developed both for automotive and motorcycle applications (see [50], [51]).

In this case, air gap, shown in Figure 16 has been considered constant during the test, assuming a smooth driving (constant speed) with no emergency brakes. Pitch angle sensible variation may affect magnetic flux and charging dynamics, in case of regenerative suspensions are considered [52].

**Figure 16.** Air gap evaluation on the test vehicle. During the test it is assumed to be constant due to the test circuit morphology.

Adopted relationship between magnetic flux and offset is available in Figure 17. Offset is the main parameter analysed in this study, as it is strongly dependent from drivers ability.

Previous studies [53] have shown that this factor is important in determining the magnetic flux intensity, with this in mind, vehicles with 'anti-offset abilities' were developed [54] and research activities were oriented through charging pad design [55].

The offset evaluation, provided by Matlab code previously presented, is depicted in Figure 18.

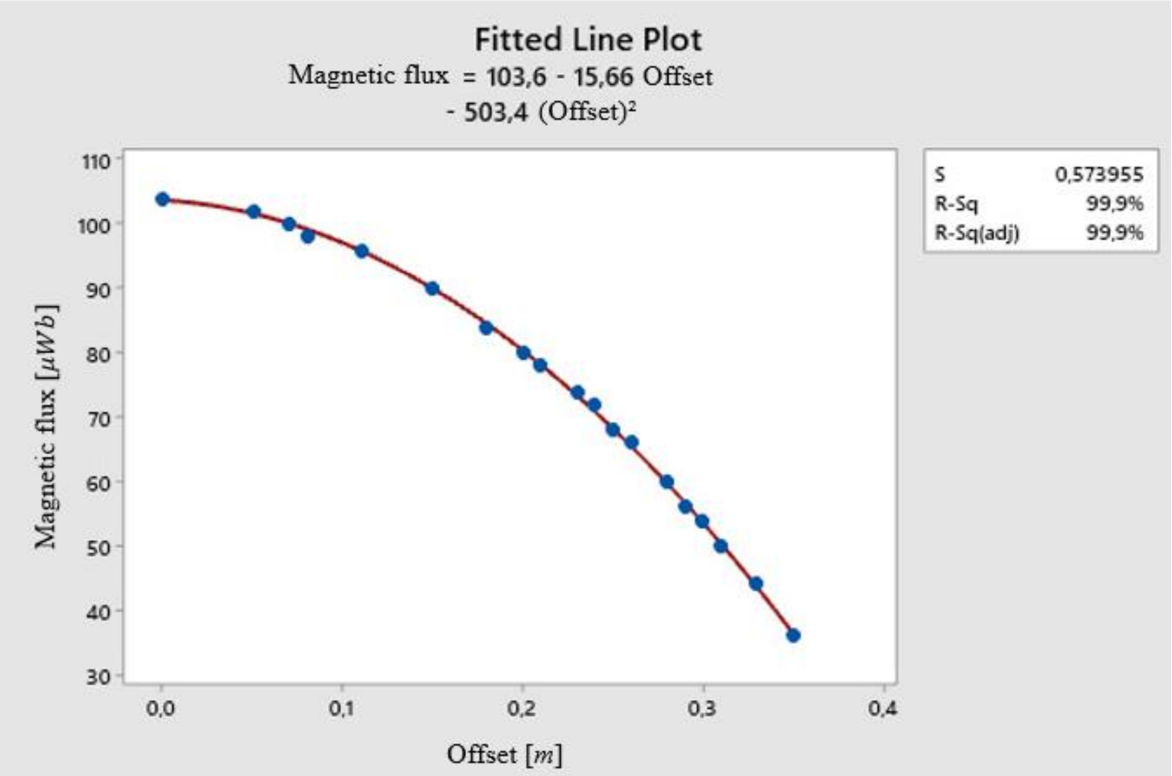


**Figure 17.** Magnetic flux variation vs offset measured in m.

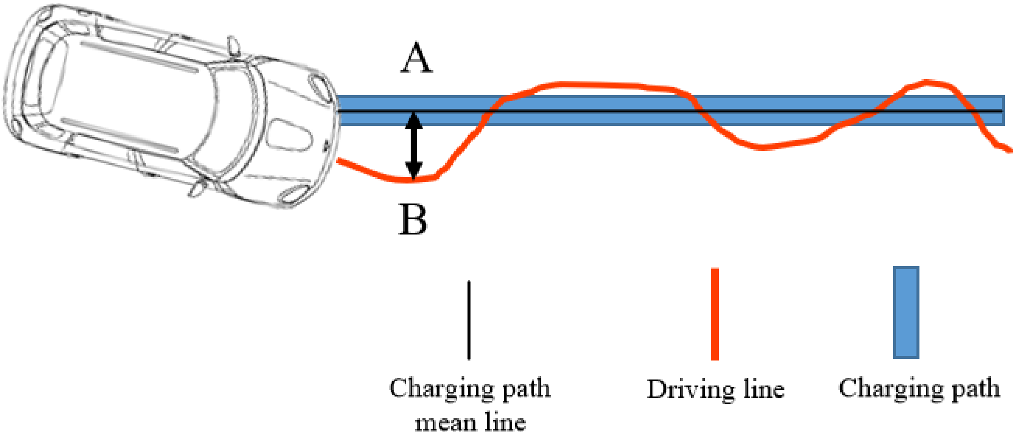


**Figure 18.** A schematic illustration of offset evaluation.

Authors adopted the simplified physical model presented in [53] and reported in equation (1), considering voltage on secondary coil as result of magnetic interaction between road circuit and vehicle one.

$$V = \frac{n\omega_0 \mu_0 I_s A_0}{2h_0} \cong n\omega_0 \phi_0 \qquad (1)$$

**Table 3.** Parameters involved in **Errore. L'origine riferimento non è stata trovata.**)

| Parameter | Significance | Unit | Adopted value |
|---|---|---|---|
| $\boldsymbol{V}$ | Pick up voltage | [V] | |
| $\boldsymbol{n}$ | Number of windings | | 45 |
| $\boldsymbol{\omega_0}$ | Electrical Angle | [rad/s] | |
| $\boldsymbol{\mu_0}$ | Vacuum magnetic permeability | | |
| $\boldsymbol{I_s}$ | Current on primary circuit | [A] | |
| $\boldsymbol{A_0}$ | Receptor's area | [m²] | |
| $\boldsymbol{h_0}$ | Air gap | [m] | |
| $\boldsymbol{\phi_0}$ | Magnetic flux | [Wb] | Depending on offset value |

In wireless charging applications, the pick up voltage is considered as a secondary parameter, but it can easily be linked to power transferred from the road charging path due to its direct proportionality with respect to power.

In order to evaluate the battery State of Charge (SOC), model presented in [56] has been adopted and reported in equation (2), due to the complexity and multitude of factors involved in the model (and summarized in Table **4**, the authors will only mention the main quantities and proportionalities.

$$SOC_{k+1}(r) = \begin{cases} SOC_k(r) - \dfrac{ECR^{'}(r) d_k(r)}{BatCap(r)} + \dfrac{\eta_c \eta_{b,t} P\left(\frac{\tau}{60}\right)}{BatCap(r)} & if\ SOC_{k+1}(r) \leq SOC_{ub} \\ SOC_{ub}\ otherwise & \end{cases} \tag{2}$$

**Table 4.** Parameters involved in State of Charge formula

| Parameter | Significance | Unit |
|---|---|---|
| $\boldsymbol{k}$ | The count of charging stations ina particular bus encounters during a daily operation | |
| $\boldsymbol{r}$ | Ruote ID | |
| $\boldsymbol{SOC_k(r)}$ | State of charge (SOC) at stop k for each route r | |
| $\boldsymbol{ECR'(r)}$ | The adjusted energy consumption rate for each route r by considering the lightweighting effects | [kWh/mile] |
| $\boldsymbol{d_k(r)}$ | The distance between stop k and stop k + 1 for each route r | [miles] |
| $\boldsymbol{\eta_c}$ | The wireless charging efficiency (grid-to-battery) | |
| $\boldsymbol{\eta_{b,t}}$ | The battery round-trip efficiency at particular year t, which fades over time from 90% to 72% | |
| $\boldsymbol{P}$ | The charger power rate | [kW] |
| $\boldsymbol{\tau}$ | Dwell time at a particular stop | [min] |
| $\boldsymbol{BatCap(r)}$ | Vector of battery capacity for each route | [kWh] |
| $\boldsymbol{SOC_{ub}}$ | The maximum SOC threshold (upper bound) | |

Considering the aforementioned formula, direct proportionality between the state of charge and the dwell time, which, in turn, is inversely proportional to the speed of the vehicle, it’s self-evident.

## 5. Conclusion and final remarks

In this chapter, authors present conclusion and final remarks, applying physical model presented above and providing dynamic wireless charging SWOT analysis.

### *5.1. Driving test results*

As mentioned before, misalignment is an important factor in this kind of application. Authors considered several complex models presented in literature and decided to analyse voltage variation with respect to time [57].

In the next figure (from Figure 19 to Figure 21) three driving behavior have been studied:

- A low performance driving session
- A medium performance driving session
- A high-performance driving session

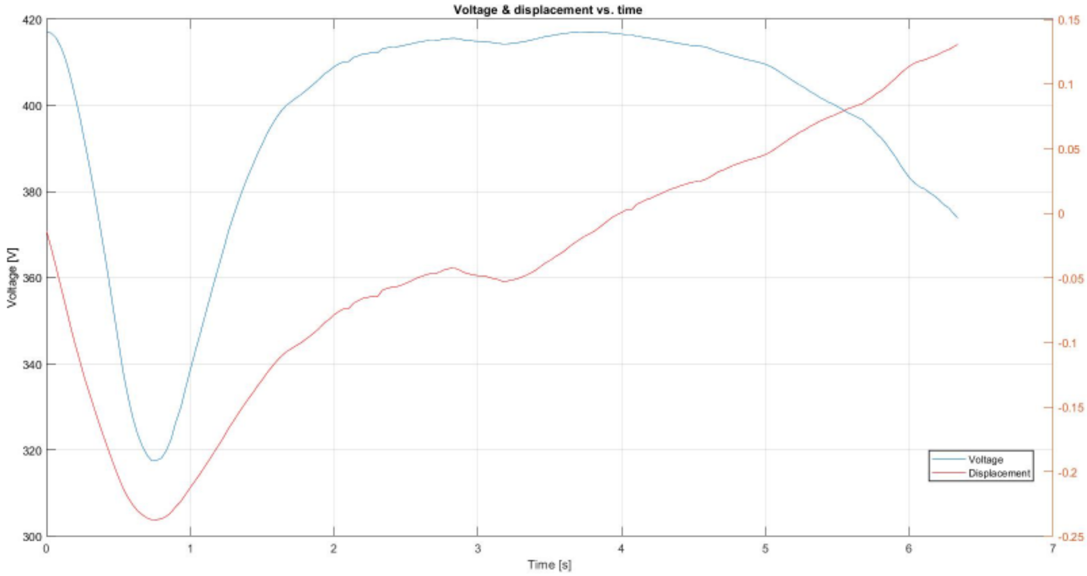


**Figure 19.** An example of bad driving behaviour.

In Figure 19 displacement curve, represented in red, highlights how the driver tends to derive towards positive offset after a first phase. This behaviour is reflected in the voltage which, after 2 s, drops considerably.

Considering longer driving sessions, this driving style is highly inefficient and is not suitable for a good battery charging cycle. The same considerations can also be made for driving in curved tracts, where maintaining a position consistent with that of the charging path could be challenging.

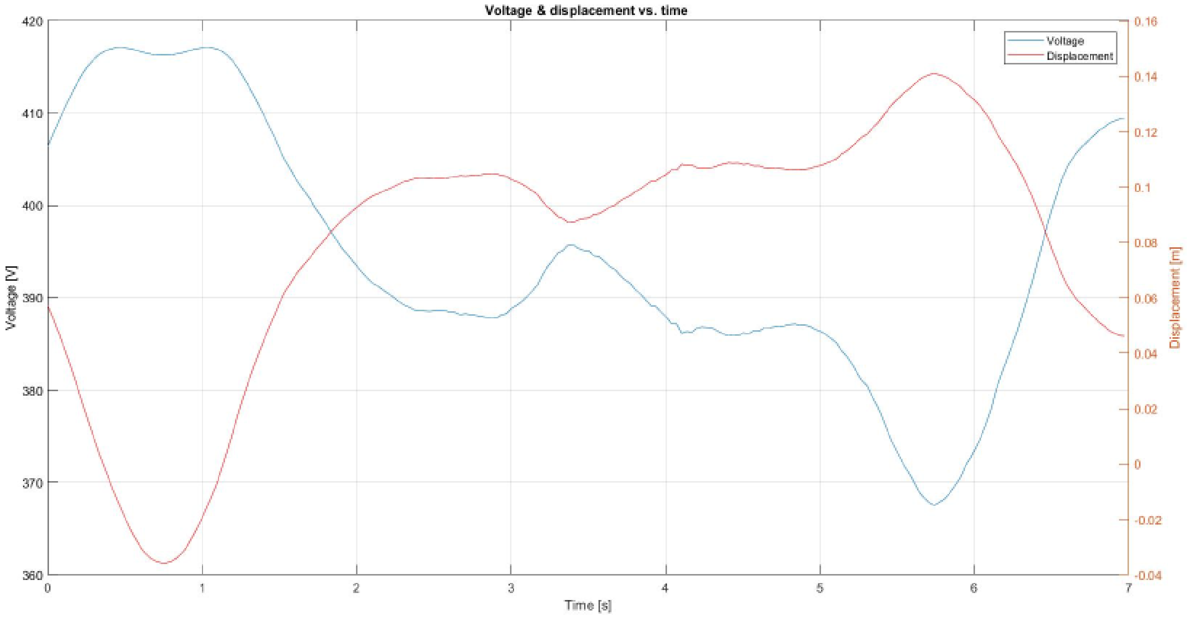


**Figure 20.** An example of average driving behaviour.

In Figure 20 the driver, between 2 and 5 seconds, tends to keep a constant offset, but still too far from the charging path. The average voltage value is better than the previous test-case presented.
It is important to show offset minimum and maximum: in these phases the driver tends to correct the trajectory.

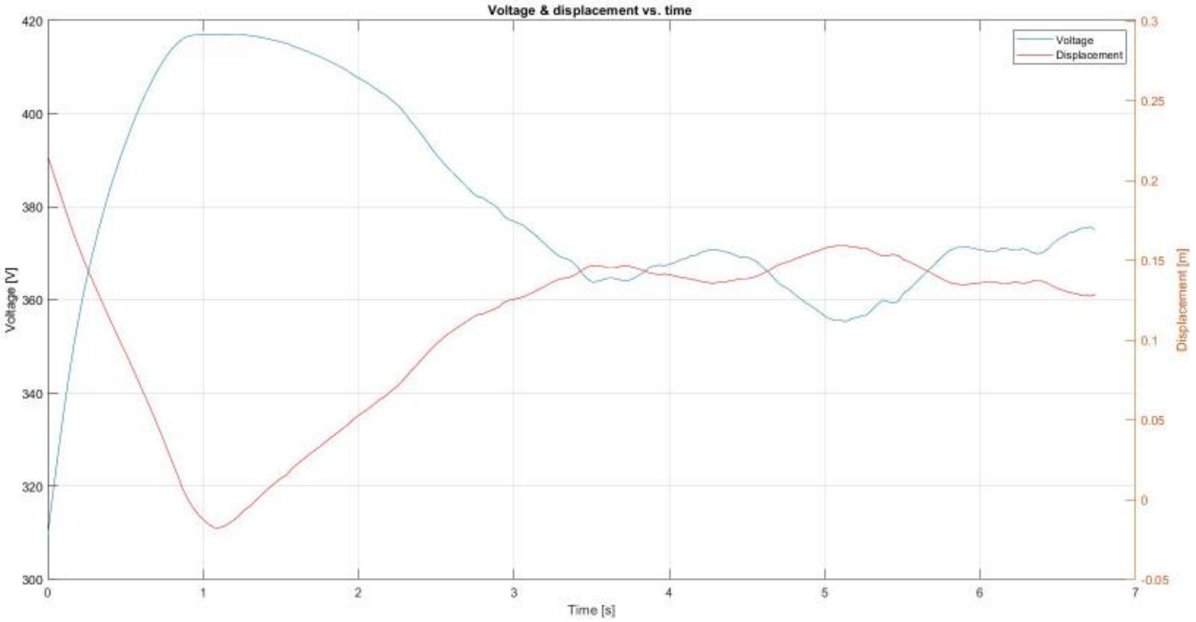
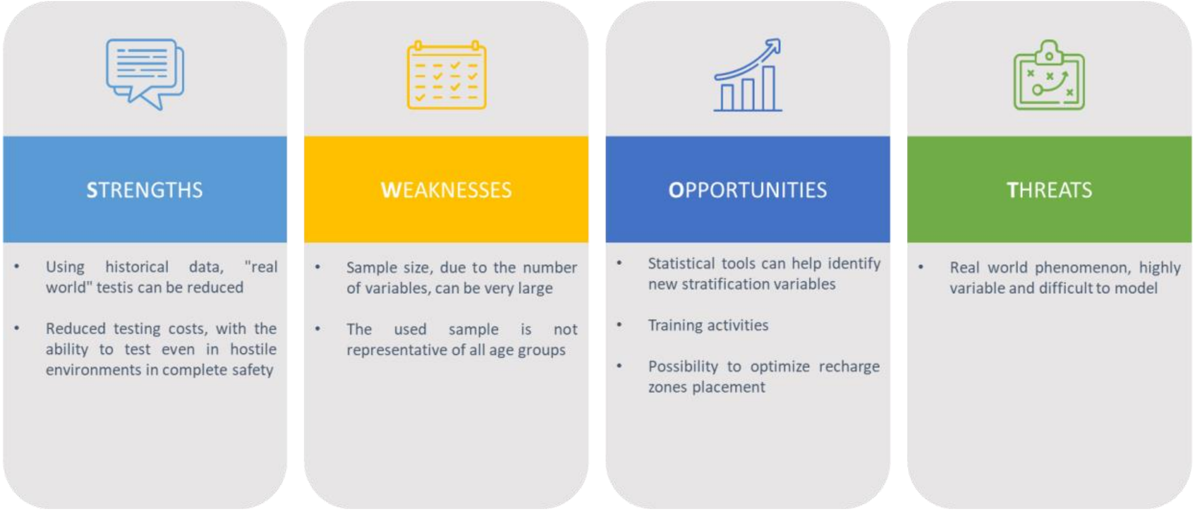


**Figure 21.** An example of good driving behaviour.

In Figure 22 collected data show how the driver tends to maintain a constant offset value and, thus, the voltage can be considered constant during the sampling time.

### *5.2. SWOT analysis*

To conclude the research, authors developed a SWOT analysis to highlight technology's Strengths, Weakness, Opportunities and Threads (Figure 22). This approach is very useful in industrial applications because puts the evidence on future developments. It is interesting to underline as a final remark that technology improvements in artificial view [58] or in other field of technology will support both experimental data analysis or ADAS-like tools that will help the driver in raise up their efficiency.



**STRENGTHS**

- Using historical data, "real world" testis can be reduced
- Reduced testing costs, with the ability to test even in hostile environments in complete safety

**WEAKNESSES**

- Sample size, due to the number of variables, can be very large
- The used sample is not representative of all age groups

**OPPORTUNITIES**

- Statistical tools can help identify new stratification variables
- Training activities
- Possibility to optimize recharge zones placement

**THREATS**

- Real world phenomenon, highly variable and difficult to model

**Figure 22.** SWOT analysis.

### *5.3. Conclusions*

In conclusion, dynamic wireless charging systems are suitable for use on motorway sections or on city routes where there are traffic light intersections and high traffic flows.

This work has shown how data from real-world tests can be used in order to reduce them and perform simulator tests, at the same time highlighting the importance of misalignment during the charging phase. A future development of this work will be to analyse real traffic data to create an optimisation tool for the positioning of recharging zones within a city route, training drivers with simulator driving in adverse driving conditions (snow, wet roads, cobblestones, etc.).

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## References

[1] Kittelson D, Watts W, Johnson J, Baltensperger U and Burtscher H 2003 Gasoline Vehicle Exhaust particle sampling study *9th Diesel Engine Emissions Reduction (DEER) Workshop* (Newport, RI (US))

[2] Smith T W, Axon C J and Darton R C 2013 The impact on human health of car-related air pollution in the UK, 1995–2005 *Atmospheric Environment* **77** pp 260–6

[3] Gan W Q, Davies H W, Koehoorn M and Brauer M 2012 Association of long-term exposure to community noise and traffic-related air pollution with coronary heart disease mortality *Am J Epidemiol* **175** pp 898–906

[4] De la Fuente D, Vega J M, Viejo F, Díaz I and Morcillo M 2011 City scale assessment model for air pollution effects on the cultural heritage *Atmospheric Environment* **45** pp 1242–50

[5] Lozhkin V, Lozhkina O and Dobromirov V 2018 A study of air pollution by exhaust gases from cars in well courtyards of Saint Petersburg *Transportation Research Procedia* **36** pp 453–8

[6] Leroutier M and Quirion P 2022 Air pollution and CO2 from daily mobility: Who emits and Why? Evidence from Paris *Energy Economics* **109** p 105941

[7] Braithwaite I, Zhang S, Kirkbride J B, Osborn D P J and Hayes J F 2019 Air Pollution (Particulate Matter) Exposure and Associations with Depression, Anxiety, Bipolar, Psychosis and Suicide Risk: A Systematic Review and Meta-Analysis *Environ Health Perspect* **127** p 126002

[8] Al-Hanahi B, Ahmad I, Habibi D and Masoum M A S 2021 Charging Infrastructure for Commercial Electric Vehicles: Challenges and Future Works *IEEE Access* **9** pp 121476–92

[9] Luo Z, Wang Y, Lv Z, He T, Zhao J, Wang Y, Gao F, Zhang Z and Liu H 2022 Impacts of vehicle emission on air quality and human health in China *Science of The Total Environment* **813** p 152655

[10] Del Carmine P, Lucarelli F, Mandò P A, Valerio M, Prati P and Zucchiatti A 1999 Elemental composition of size-fractionated urban aerosol collected in Florence, Italy; preliminary results *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* **150** pp 450–6

[11] Gualtieri G, Crisci A, Tartaglia M, Toscano P, Vagnoli C, Andreini B P and Gioli B 2014 Analysis of 20-year air quality trends and relationship with emission data: The case of Florence (Italy) *Urban Climate* **10** pp 530–49

[12] 2008 *Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe* vol 152

[13] Jurkauskas A, Mícevičiene D and Prunskiene J 2010 The main principles of modelling the interaction between transport infrastructure development and economy *Transport* **20** pp 117–22

[14] Dargay J, Gately D and Sommer M 2007 Vehicle ownership and income growth, worldwide: 1960-2030 *Energy Journal* **28** pp 143–70

[15] Intini M and Percoco M 2021 Car Sharing and the Impact on New Car Registration *International Encyclopedia of Transportation* ed R Vickerman (Oxford: Elsevier) pp 225–9

[16] 2019 *Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/2011 (recast) (Text with EEA relevance.)* vol 111

[17] Ovaere M and Proost S 2022 Cost-effective reduction of fossil energy use in the European transport sector: An assessment of the Fit for 55 Package *Energy Policy* **168** p 113085

[18] Directorate-General for Mobility and Transport (European Commission) 2020 *EU transport in figures: statistical pocketbook 2020* (LU: Publications Office of the European Union)

[19] Gonzalez R A, Ferro R E and Liberona D 2020 Government and governance in intelligent cities, smart transportation study case in Bogotá Colombia *Ain Shams Engineering Journal* **11** pp 25–34

[20] Richter M A, Hagenmaier M, Bandte O, Parida V and Wincent J 2022 Smart cities, urban mobility and autonomous vehicles: How different cities needs different sustainable investment strategies *Technological Forecasting and Social Change* **184** p 121857

[21] Sadeghian O, Oshnoei A, Mohammadi-ivatloo B, Vahidinasab V and Anvari-Moghaddam A 2022 A comprehensive review on electric vehicles smart charging: Solutions, strategies, technologies, and challenges *Journal of Energy Storage* **54** p 105241

[22] Li B, Ma Z, Hidalgo-Gonzalez P, Lathem A, Fedorova N, He G, Zhong H, Chen M and Kammen D M 2021 Modeling the impact of EVs in the Chinese power system: Pathways for implementing emissions reduction commitments in the power and transportation sectors *Energy Policy* **149** p 111962

[23] Yu H, Niu S, Shang Y, Shao Z, Jia Y and Jian L 2022 Electric vehicles integration and vehicle-to-grid operation in active distribution grids: A comprehensive review on power architectures, grid connection standards and typical applications *Renewable and Sustainable Energy Reviews* **168** p 112812

[24] Lei X, Shang Y, Shao Z, Jia Y and Jian L 2022 Grid integration of electric vehicles for optimal marginal revenue of distribution system operator in spot market *Energy Reports* **8** pp 1061–8

[25] Brinkel N, AlSkaif T and van Sark W 2022 Grid congestion mitigation in the era of shared electric vehicles *Journal of Energy Storage* **48** p 103806

[26] Kubli M 2022 EV drivers' willingness to accept smart charging: Measuring preferences of potential adopters *Transportation Research Part D: Transport and Environment* **109** p 103396

[27] Unterluggauer T, Rich J, Andersen P B and Hashemi S 2022 Electric vehicle charging infrastructure planning for integrated transportation and power distribution networks: A review *eTransportation* **12** p 100163

[28] Muratori M 2018 Impact of uncoordinated plug-in electric vehicle charging on residential power demand *Nat Energy* **3** pp 193–201

[29] Zhang X, Yuan Z, Yang Q, Li Y, Zhu J and Li Y 2016 Coil Design and Efficiency Analysis for Dynamic Wireless Charging System for Electric Vehicles *IEEE Transactions on Magnetics* **52** pp 1–4

[30] Lukic S and Pantic Z 2013 Cutting the Cord: Static and Dynamic Inductive Wireless Charging of Electric Vehicles *IEEE Electrification Magazine* **1** pp 57–64

[31] Metin A 2020 A new evaluation method to quantify drivers' lane keeping behaviors on urban roads *Transportation Letters* **12** pp 738–49

[32] Cho R L-T, Liu J S and Ho M H-C 2021 The development of autonomous driving technology: perspectives from patent citation analysis *Transport Reviews* **41** pp 685–711

[33] Chetan N B, Gong J, Zhou H, Bi D, Lan J and Qie L 2020 An Overview of Recent Progress of Lane Detection for Autonomous Driving *2019 6th International Conference on Dependable Systems and Their Applications (DSA)* 2019 6th International Conference on Dependable Systems and Their Applications (DSA) pp 341–6

[34] Nidamanuri J, Nibhanupudi C, Assfalg R and Venkataraman H 2022 A Progressive Review: Emerging Technologies for ADAS Driven Solutions *IEEE Transactions on Intelligent Vehicles* **7** pp 326–41

[35] Carsten O, Kircher K and Jamson S 2013 Vehicle-based studies of driving in the real world: The hard truth? *Accident Analysis & Prevention* **58** pp 162–74

[36] Domenichini L, La Torre F, Vangi D, Virga A and Branzi V 2017 Influence of the lighting system on the driver's behavior in road tunnels: A driving simulator study *Journal of Transportation Safety & Security* **9** pp 216–38

[37] Rhodes N and Pivik K 2011 Age and gender differences in risky driving: The roles of positive affect and risk perception *Accident Analysis & Prevention* **43** pp 923–31

[38] Song X, Yin Y, Cao H, Zhao S, Li M and Yi B 2021 The mediating effect of driver characteristics on risky driving behaviors moderated by gender, and the classification model of driver's driving risk *Accident Analysis & Prevention* **153** pp 106038

[39] Monfort S S, Reagan I J, Cicchino J B, Hu W, Gershon P, Mehler B and Reimer B 2022 Speeding behavior while using adaptive cruise control and lane centering in free flow traffic *Traffic Injury Prevention* **23** pp 85–90
[40] Savino G, Lot R, Massaro M, Rizzi M, Symeonidis I, Will S and Brown J 2020 Active safety systems for powered two-wheelers: A systematic review *Traffic Injury Prevention* **21** pp 78–86
[41] Berzi L, Delogu M and Pierini M 2016 Development of driving cycles for electric vehicles in the context of the city of Florence *Transportation Research Part D: Transport and Environment* **47** pp 299–322
[42] Yahoodik S and Yamani Y 2021 Effectiveness of risk awareness perception training in dynamic simulator scenarios involving salient distractors *Transportation Research Part F: Traffic Psychology and Behaviour* **81** pp 295–305
[43] Prohn M J and Herbig B 2020 Evaluating the effects of a simulator-based training on knowledge, attitudes and driving profiles of German ambulance drivers *Accident Analysis & Prevention* **138** p 105466
[44] Mathworks 2022, Blob Analysis - Statistics for labeled regions - Simulink, https://it.mathworks.com/help/vision/ref/blobanalysis.html (accessed Nov. 05, 2022).
[45] Stephens J, Bostjancic M and Koskulitz T 2019 A Study on Parallax Error in Video Analysis *The Physics Teacher* **57** p 193
[46] Choi S Y, Gu B W, Jeong S Y and Rim C T 2015 Advances in Wireless Power Transfer Systems for Roadway-Powered Electric Vehicles *IEEE Journal of Emerging and Selected Topics in Power Electronics* **3** pp 18–36
[47] Lee C H, Jung G, Hosani K A, Song B, Seo D and Cho D 2020 Wireless Power Transfer System for an Autonomous Electric Vehicle *2020 IEEE Wireless Power Transfer Conference (WPTC)* 2020 IEEE Wireless Power Transfer Conference (WPTC) pp 467–70
[48] Jung G, Song B, Shin S, Lee S, Shin J, Kim Y, Lee C and Jung S 2013 Wireless charging system for On-Line Electric Bus(OLEB) with series-connected road-embedded segment *2013 12th International Conference on Environment and Electrical Engineering* 2013 12th International Conference on Environment and Electrical Engineering pp 485–8
[49] Shin J, Song B, Lee S, Shin S, Kim Y, Jung G and Jeon S 2012 Contactless power transfer systems for On-Line Electric Vehicle (OLEV) *2012 IEEE International Electric Vehicle Conference* 2012 IEEE International Electric Vehicle Conference pp 1–4
[50] Muzakkir Ahamed M and Natrayan L 2022 Structural and dynamic analysis of automotive quarter car model suspension system for different materials *Materials Today: Proceedings* **62** pp 2291–6
[51] Bartolozzi M, Savino G and Pierini M 2021 Novel high-fidelity tyre model for motorcycles to be characterised by quasi-static manoeuvres – rationale and numerical validation *Vehicle System Dynamics* **0** pp 1–27
[52] Crolla D A and Cao D 2012 The impact of hybrid and electric powertrains on vehicle dynamics, control systems and energy regeneration *Vehicle System Dynamics* **50** pp 95–109
[53] Choi Y, Lee S and Kim J 2010 The Lateral Position Estimation System for Autonomous Driving of the Online Electric Vehicle *IFAC Proceedings Volumes* **43** pp 407–12
[54] Wen F, Zhang D, Han C, Zhang G, Li G, Zhang X, Ma J, Yao Z and Yu K 2022 Anti-offset performance optimization of coupling coils in wireless power transfer system based on genetic algorithm *Energy Reports* **8** pp 1–9
[55] Ahmad A, Alam M S and Mohamed A A S 2019 Design and Interoperability Analysis of Quadruple Pad Structure for Electric Vehicle Wireless Charging Application *IEEE Transactions on Transportation Electrification* **5** pp 934–45
[56] Bi Z, Keoleian G A and Ersal T 2018 Wireless charger deployment for an electric bus network: A multi-objective life cycle optimization *Applied Energy* **225** pp 1090–101

[57] Wang Z, Shi Y, Ma X and Wei Y 2020 A coreless hybrid magnetic coupling coil structure for dynamic wireless power charging system *Energy Reports* **6** pp 843–50

[58] Galteri L, Seidenari L, Bertini M, Uricchio T and Del Bimbo A 2019 Fast Video Quality Enhancement using GANs *Proceedings of the 27th ACM International Conference on Multimedia* MM '19 (New York, NY, USA: Association for Computing Machinery) pp 1065–7