GĘSTOŚĆ RUCHU JAKO CZYNNIK ZUŻYCIA ENERGII W POJAZDACH ELEKTRYCZNYCH[1]

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Streszczenie. *Właściwa i skuteczna nawigacja pojazdów elektrycznych powinna uwzględniać kilka czynników wpływających na zużycie energii wzdłuż trasy przejazdu. Obok specyficznych parametrów pojazdu na zużycie energii wpływają również czynniki infrastrukturalne i środowiskowe. Głównym celem badań obok ruchu są dodatkowe czynniki mające wpływ na jego wielkość. Prezentowana metodologia obejmuje modele makro- i mikrosymulacji oraz wykorzystanie odpowiednich narzędzi. W celu weryfikacji modelu wybrano region Zachodniej Saksonii ograniczony przez 5 kampusów Westsächsische Hochschule Zwickau. Projekt był finansowany przez rząd Saksonii.*

Słowa kluczowe: *pojazdy, modelowanie ruchu, zużycie energii*

1. Introduction

Proper and efficient route navigation for electric vehicles has totake into consideration the variation of energy consumption along the route. Key features of energy consumption depend on specific parameters of the vehicles. Each type of electric vehicle acts differently in various situations. The factors that affect the energy consumption may be divided into groups of: infrastructure, environment and traffic. Infrastructure connected features consist of e.g. vertical and horizontal alignment, traffic lights, speed limits.Environment affects the energy consumption by weather conditions, temperature etc. All those impacts can be measured and taken into consideration in calculations.On the contrary, for analysis of the influence of traffic in this study a more indirect approach is used. With the help of macrosimulation methods those links are identified, where a significant influence of traffic density on energy consumption is expected. It should be mentioned, that in principle also the use of floating-car data would be possible. The methods of creating velocity profiles and simulation described here would remain valid also in that case.

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2. Literature review

Literature review of the introduced topic shows many ambiguous results and there is nopreferable approach. The whole matter of efficient management of electric vehicles is relatively new, so there are not many researches dealing with the problem. Most cases concentrate on combustion engines, where the problem of energy consumption is the problem of fuel consumption. Paper [5] shows the use of microsimulation software PTV VISSIM combined with gas emissions module CMEM. Fuel consumption and emissions are used here to evaluate various traffic management solutions. In [1] apart from microscopic AIMSUN, macrosimulation software EMME2 was used. Traffic assignment served for determining traffic volumes, travel times and average speeds in the area of Florence,whereas AIMSUN with added TEE module calculated the energy consumption and gas emissions. The authors of [2] describe the use of macroscopic tools and come up with micro modelling PARAMICS. It enables to establish the behaviour of single vehicles, their trajectories and speed profiles. Also, the influence of traffic conditions was mentionedas well as factors like drag and rolling resistance, road slope or vehicles' accelerations. Determination of resistances and the influence of infrastructure were examined in [4]. Analytical calculations, depending on conditions and level of congestion were used here for comparison of two competing roads in Great Britain. Comprehensive description of parameters influencing the energy consumption for energy vehicles is shown in [7] where all environmental and infrastructure conditions, such as weather, temperature, existence of intersections, pedestrian crossings, traffic lights, speed limits, charging infrastructure etc., are mentioned.

Another approach can be found in [11] where energy consumption is calculated from a physical point of view. Kinetic energy of vehicles was calculated and the energy consumption was determined by energy dissipation considering the fundamental relationship between traffic flow, velocity and density. Energy expenditures are calculated for various levels of congestion, also taking into consideration the slope of the road. A more practical approach was shown in [3]. Here the influence of driving behaviour on fuel consumption was examined. Numerous test drives were conducted in real conditions with various drivers. Then, alsoa driving simulator was used.The authors took into consideration hybrid and electric vehicles pointing out the significant importance of determining the energy demand for them. The publication [6] focuses strictly on electric vehicles. It describes four different analytical models of determining the energy consumption. In conclusion, the comparison of the models is enclosed, but without its verification in practice.

The subject of calculating the energy consumption of electric vehicles was presented by authors in [10]. The publication describes the whole methodology of the project and the process of creating an energy efficient route navigation for electric vehicles.

3. Macrosimulation

The purpose of creating route navigation requires also a method of its validation. As atest area the region of West Saxony was chosen. The area is defined by 5 campuses of WestsächsischeHochschule Zwickau. First step for determining the influence of traffic on energy consumption was to create a macrosimulation model of the area. The model is a basic, four step model created in PTV VISUM software. The model consists of the supply part and the demand part. Supply model gives the information about the roads, junctions and accompanying infrastructure. It was created with the data from a given shapefile. On this basis, the road network was built. It consists of all motorways, national roads, state roads and district roads. The result is shown in Fig. 1.

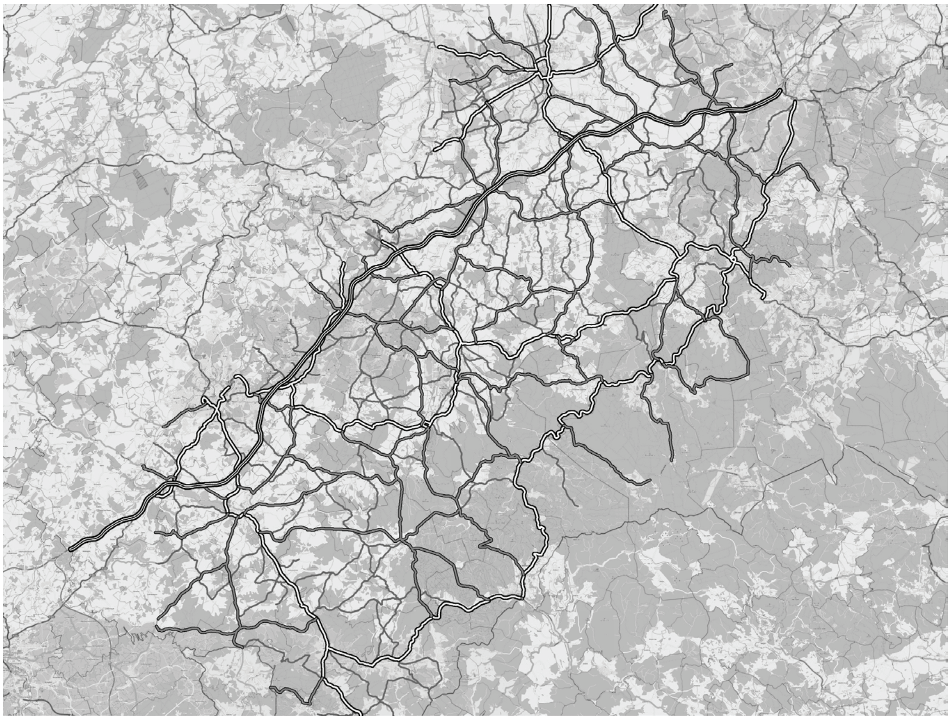

Fig. 1. Validation area

Source: own

The whole area was divided into traffic analysis zones which are the separated parts of the area characterised by homogenous transport behaviours. The natural size of a zone in such a regional model is acommunity. The test area consists of 49 traffic analysis zones situated in 3districts: Zwickau, Vogtland and Erzgebirge. For the completion of the model there was also a need to create 24 outside zones. These are connected to major roads outgoing from the considered area. Traffic analysis zones connect the supply model and the demand model by assigning the demanded trips into the road network. The complete supply model is shown in Fig. 2.

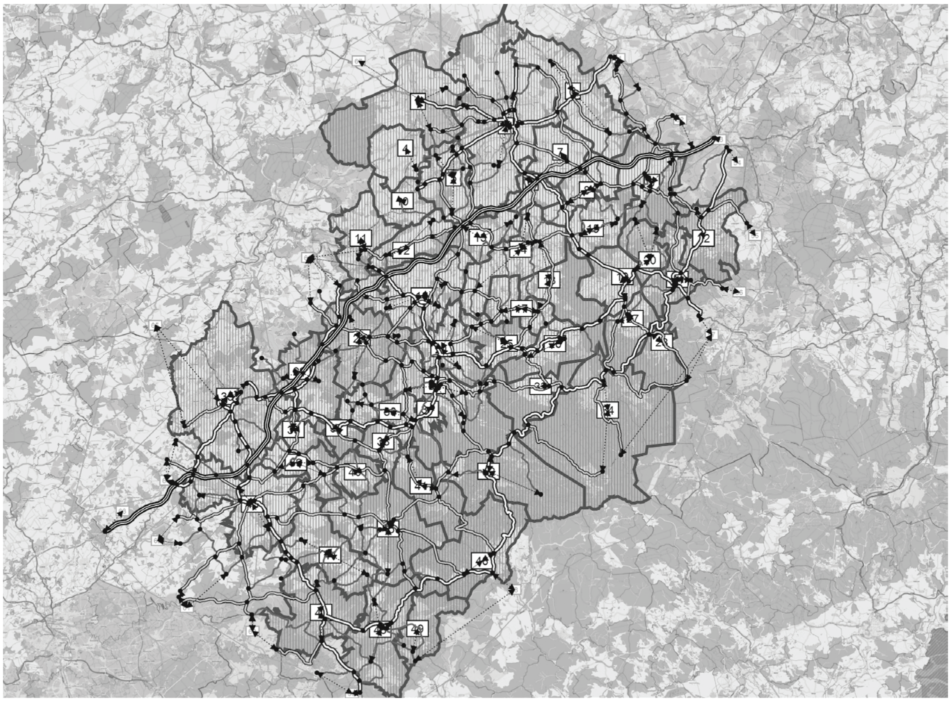

Fig. 2. Supply model
Source: own

3.1. Traffic Generation and Modal Split

The first step of the demand model is traffic generation. For this, every traffic analysis zone is represented by potentials of production and attraction. These potentials show how many trips are there starting or ending in each zone. Production and attraction are calculated by joining the demographic, statistical data with the trip behaviour of inhabitants by regression analysis. The data on trip behaviour are taken from a large number of complex household and driver surveys. Because of the limitations of the project there was a need to collect these data in other way. By the courtesy of scientists from Cracow University of Technology it was possible to obtain data collected during the works on the regional model of Malopolska. It was created by using 4400 household surveys from the whole region for the purpose of public transport plan of the voivodeship. This information was gathered in Polish conditions but the values were adjusted by using specific data for Germany. The information on demography, employment and education were taken from the website of Saxonian statistical office [8].

The potentials of production and attraction were calculated by multiplying regression data from Malopolska region with suitable statistical data. The calculations were done for 7 motivation groups (Home-Work, Work-Home, Home--Education, Education-Home, Home-Others, Others-Home and Not Related with Home). During the creation of Malopolska model the share of peak hour for each motivation group was calculatedon the basis of the survey data. These calculations served for the determination of morning and afternoon peak hour in the described model. As the model uses only primary modal split it had to be taken into consideration prior to the traffic assignment. That means that the classical third step of the model – modal split was determined during the calculation of potentials. The essential data was taken from Mobilitaetin Deutschland (MiD) [9]. It gathers the necessary data about mobility all over Germany depending on numerous factors. This allowed calculating modal split for each motivation group separately.

3.2. Traffic Distribution

Research data from Mobilitaet in Deutschland [9] were used also in calculation of the second step of the four-step model. This is the traffic distribution and it represents the spatial distribution of trips. It answers the question where the people are travelling. Tables in MiD contain the information about the length of the trips in dependence of the size of the community. That information served in calculation of the friction functions for various traffic analysis zones. All communities were divided into five groups considering how many inhabitants they have. That is necessary because people tend to have different behaviourswhen they live in asmall village and in a mid-sized town. For each of those five groups the data from MiD were taken. After mathematical analysis usingMATLAB software the relationship was calculated. Inbound trips were excluded from the analysis.

After the calculations five combined exponential functions were created for distributing the traffic. These friction functions show how often the trips occur in the community of specified size in dependence of the trip distance. For illustration, Fig. 3 shows one of these regression analyses (communities with less than 2000 inhabitants). Here an approach in form of $y=a^{xb}e^{cx}$ is chosen, the results for the parameters a, b, c can be seen in Fig. 3.

After calculating the friction functions with given potentials from previous traffic generation, the onlymissing objects are the distances in the test area. For these, VISUM software contains a functionality of calculating skim matrices. The matrix with the distances between every community in the network was created. This was the data for friction functions formulas. Each kind of trip between two various traffic analysis zones was calculated with the distances from skim matrix, production of the origin zone and attraction of destination zone and congruent friction function. This leads to creating inbound OD matrices for both morning and afternoon peak hour.

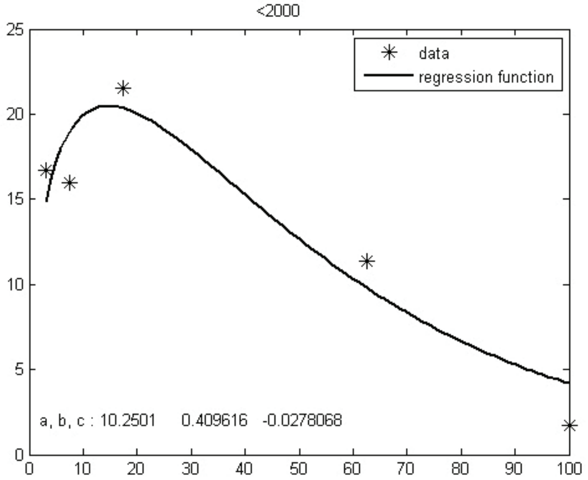

Fig. 3. Regression model $y=a^{x^{b}}e^{cx}$

Source: own

Next step of calculating demand is to complement the OD matrices with external traffic. It distinguishes between inbound, outbound and through traffic. External traffic is realized by inlets on the borders of the research area. Main inlets through national and state roads were identified. For those inlets and congruent regions adjacent to the research areas additionally external traffic analysis zones were created. This led to addition of 24 zones. To estimate the numbers of trips starting on every inlet it was necessary to measure the traffic flows on each road on the borders. Such counts were made and published by Sächsisches Staatsministerium für Wirtschaft, Arbeit und Verkehr [12]. Volumes on inlets may be treated as the potentials of production and attraction of external traffic zones. But these values have to be divided into inbound, outbound and through traffic. For that, there was a necessity to make some assumptions. Through traffic was estimated to be 80% on the motorway, 30% on national roads and 20% on state roads. The value for motorways was calculated as average through traffic observed in the section in the test area on the basis of real traffic flows on its boundaries. Other values were estimated by evaluating existing flows and taking into consideration values used in other similar studies for Polish conditions. Some of the counts selected to calculate the external traffic were detailed, continuous counts, which helped to determine the share of peak hour for all other daily volumes. It was also used to check what the share of inbound and outbound traffic is in various part of day. Calculated values are 55% of inbound traffic in the morning and 40% in the afternoon. Outbound would be in that case accordingly 45% for morning and 60% in the afternoon peak hour. After determining all parts of external traffic it was possible to calculate the matrices. Traffic from inlets was distributed on all traffic analysis zones proportionally to the attractions of zones as well as the outbound traffic proportionally to the attractions of inlets. Through traffic was also distributed proportionally among inlets. The final step of creating the complete OD matrix is to put together all external matrices with the internal one. This was done for both morning and afternoon peak hour and resulted in two complete OD matrices of a size 73x73 traffic analysis zones.

3.3. Traffic Assignment

For traffic assignment the values from OD matrix, which represents the demand for trips, are distributed with the connectors from the centre of traffic analysis zones to the road network. Traffic assignment was done in VISUM software using standard equilibrium assignment procedure. The conditions and the maximum number of iterations were specified as the default ones in VISUM software. Subsequently, after the assignment procedure is done, it is crucial to verify the results. The verification process was completed with a wide set of traffic counts. Database created for Sächsisches Staatsministerium für Wirtschaft, Arbeit und Verkehr [12] consisted of 310 spots inside the research area. These were the daily traffic volumes with the share of heavy traffic enclosed. However, the study also required more detailed data. That is why the information from 24 spots was taken as a long lasting, continuous measurement. This led to the determination of the peak hours and their share in the overall daily traffic. Inresult, it turned out that the morning peak hour is at 7 – 8 am and amounts 6.5 % of the whole day traffic, whereas the afternoon peak hour is at 4 – 5 pm and its share in daily traffic is 8%. The detailed counts were also used for the analysis of direction variations on those 24 and adjacent sections. Complete counts database was analysed considering the location of the spot. Sections situated in the city centres as well as some sections on the peripheries of the research area had to be excluded from the study. Since the regional model does not consider the inside traffic in each city, those values could not be represented properly. Also, due to the limited representation of inlets, measurements located in the surroundings of the borders would give non-satisfyingresults. Volumes from the corrected database were put into VISUM software as additional user-defined attributes.

3.4. Calibration

After conducting the procedure of traffic assignment it was possible to evaluate the quality ofresults. As a parameter of correlation for the resulting traffic flows and data from traffic counts the coefficient of determination was used. First, the results were that R^2 was $R^2=0.63$ in the morning and $R^2=0.66$ in the afternoon. These results showed that the demand matrix needed calibration. It was done with the built-in VISUM procedure TFlowFuzzy. It enables updating a demand matrix using fuzzy logic fundamentals to adjust the matrix to the real supply observed. After this procedure the assignment results are closer to the survey data observed on real network. With the broad set of traffic counts data it was possible to obtain satisfying outcomes. Final results of the coefficient of determination were

$R^2=0.82$ in the morning and $R^2=0.86$ in the afternoon. Concerning the purpose of the study these values were regarded as suitable for further research.

4. Microsimulation

After calibrating, the model was ready for further studies. For the purpose of creating a route navigation it was necessary to identify sections of the network were the influence of traffic was significant to the energy consumption of electric vehicles. As a parameter, Volume/Capacity Ratio was chosen. When the value of traffic flow on the link of the model network exceeded 50% of its capacity, the section was taken for further studies in microscopic scale. Fig. 4 shows the selected sections in the case of afternoon rush hour.

Fig. 4. Selected sections – afternoon rush hour

Source: own

Each of the selected sections had to be separately derived from the whole network using the subnetwork generator functionality in VISUM. Single sections were put into separate VISUM files from where they could be easily exported into VISSIM. Each of these single files consists ofall necessary information for microsimulation. Exporting selected sections to VISSIM was used to ensure getting the exact characteristics of the section also in microscopic studies. The shape of each link matches the data taken from shapefile. A section can be also defined with its parameters of capacities and free flow speeds. After the assignment this data were supplemented with actual, traffic related information. For further examination, the exact volume of traffic taken from macrosimulation study was taken. Traffic flow influences also the speeds of vehicles and travel times on a considered section. Current velocities (current as for after traffic assignment) and travel times in loaded network were used also to verify the results of VISSIM studies.

The idea concerning microsimulation for the project was to run the simulation with the traffic calculated in the macroscopic scale. At first, the volumes in each direction were taken from macrosimulation study by exporting single VISUM files. Those files consisted of network data, so the supply information on physical characteristics (length and shape of section) and demand data, that isa matrix with the information on how many vehicles want to travel on that section and in which direction they travel. Moreover, these exported sections were enriched with the details on driving behaviour of their users. Depending on the location and the type of the road different sets of behaviours were chosen. Due to the lack of detailed research in our test area, default set of urban and freeway behaviours were taken. Such set of information was then imported in VISSIM. Heavy traffic had to be added in every selected section in order to accurately convey the conditions. The exact share of heavy traffic was taken from the set of counts mentioned before. Simulation consisted in putting the specific amount of vehicles to ride through the sections on its routes. To ensure the validity of the simulation results all cars have the speeds drafted from actually observed distributions. For this purpose, continuous counts from induction loops were taken. Each section of the motorway had its own speed distribution function for private vehicles and heavy goods vehicles. On national and state roads overall functions were created for urban areas and outside of urban areas on the basis of various researches presenting such speed distributions. Separate functions were entered also for both: private cars and heavy goodsvehicles.

One hour was chosenas a length of the simulation. Vehicles appeared with stochastic variability and with changing parameter of desired speed. The values of speed, desired speed and acceleration in each second of the simulation for each vehicle on the section were gathered. The difference between the desired and the actual speed along the section, caused by the presence of slower vehicles, results in the fluctuation of velocity. This variation is the cause of growing energy consumption. To calculate the changes in energy consumption velocity profiles derived from the database were transferred to driving simulator which could measure the energy demandduring test drives. From prepared database it is possible to derive any desired number of vehicles. A created application was used to derive a random group of vehicles and create velocity profiles for the driving simulator.Each set of resulting data consisting of overall average speeds and time spent in the network can be used for comparison with such macrosimulation parameters as travel times and current velocities collected for selected sections in VISUM files. After validating the results velocity profiles in both directions of all selected sections were exported to driving simulator, for example see Fig. 5.

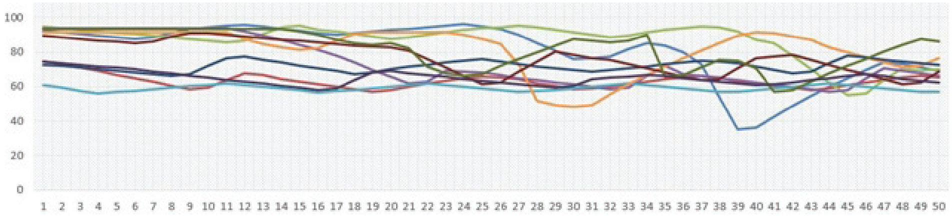

Fig. 5. Velocity profiles for simulation
Source: own

5. Further steps

Deriving from the velocity profiles and giventhe shape information of the considered sections, automatic driving simulations were done. Therefore, the driving simulator of the Zwickau University of Applied Sciences (see Fig. 6) was used.

Fig. 6. Drivingsimulator
Source: Westsächsische Hochschule Zwickau, Institut für Energie und Verkehr

In addition to the velocity profiles, car data (like geometry, power unit and other car specifications) dealt as input data for the simulation. With the help of the car makersoftware for several simulation runs the energy consumption was simulated (the main principle can be seen in Fig. 7).

Derived from this information, a routing algorithm is employed, where the energy consumptions of each link (including those links, where no significant influence of traffic is expected) deal as weights in the objective function. This results in optimal routes with respect to energy consumption. Regardless of the actual study, the simulated energy consumption processes have to be compared in a comprehensive statistical analysis with these, in the case of free traffic flow, where other environmental factors are the same in both situations. The aim is to formulate the relationship between energy consumption and traffic density in a formal, mathematical way to avoid the necessity of simulations for each relevant link in general applications. These statistical studies are still in the main focus of interest in current research.

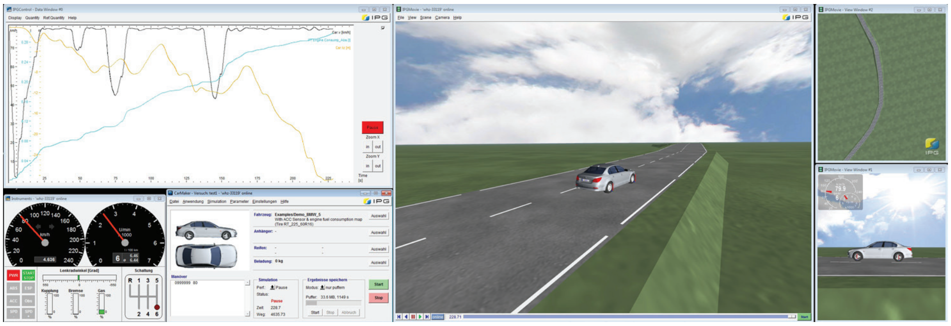

Fig. 7. Car maker software

Source: own

6. Conclusion

In the presented study, an indirect approach is used to analysethe influence of traffic. With the help of macrosimulation methods, identified are those links, on which asignificant influence of traffic density on energy consumption is expected. These links are considered in detail with microsimulation methods to estimate energy consumption under predefined conditions. The results are used in a routing algorithm in order to find optimal routes with respect to energy consumption. The next step consists of statistical studies with the aim to formulate the dependence of energy consumption on traffic density in a formal way. If this step is successful, it opens the opportunity to avoid comprehensive simulations as described above for comparable situations. Another expansion of the methodology could be the use of floating-car data to find optimal routes.

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