GIS-Based Emission Analysis Using Car-Borne Sensor Data

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Abstract

The concept of Extended Floating Car Data (xFCD) allows to analyse traffic-related CO$_2$ emissions by reading out electronics of cars. In urban environments, CO$_2$ peaks caused by traffic congestion or inept traffic infrastructure are of special concern. This paper gives an overview of GIS-based methods and workflows that can be applied to xFCD in order to appropriately detect those emission peaks. Based on literature and former studies in related fields, three methods are introduced and applied in a case study to investigate their viability. The results suggest that two of three methods are able to detect these kind of spatial patterns even though the data source is restricted in terms of amount and quality. Furthermore, the paper researches the potential benefits that xFCD-based information products might provide for urban planners in climate protection. Expert interviews with pertinent communities are conducted to gain a well-grounded basis for an assessment. Results of those indicate that the factual need of this information does not yet exist and that according information products only conditionally provide valuable benefits at the moment. The work in climate protection rather focus on projects that address emotional aspects in order to change the mobility behaviour of people. Nonetheless, future legally binding guidelines might also require exact emission quantifications. The concept of xFCD could serve those requirements.

1. Introduction

The worldwide amount of cars has grown over the last couple of years to approximately 1.1 billion of cars on the road today. This number is predicted to double until 2030 [1]. Nearly every kind of motorized transportation encompasses the combustion of fossil fuels. It is required to produce energy to be transformed into motion [2]. That is why cars are considered to be major sources for the global air pollution leading to manifold negative effects on the environment and the human health [3].

One of the critical pollutants produced by fossil fuel combustion is carbon dioxide (CO$_2$). Although this product is not considered as harmful to human health, CO$_2$ is the principal gas for the greenhouse effect. It contributes to the global climatic change and causes an increase of average temperature [4]. A dominant sector of carbon dioxide emission is transportation and traffic, which globally accounts for 23 percent of the total amount of CO$_2$ from fossil fuel combustion. This leads to a share of 15 percent in overall greenhouse gas emissions [5]. In Germany, every citizen produces around 11 tons of CO$_2$ per year on average whereas 1.56 tons of CO$_2$ originate just from the motorized individual transport, excluding modes of transportation such as train and airplane [6].

In the last decade, the rising worldwide attention of the critical issue ‘climate change’ triggers new international and national guidelines and directives. They have the goal to reduce carbon dioxide emissions in the long term. Furthermore, automobiles became much more efficient in terms of fuel combustion and energy efficiency. But not only the car engine technology improved, also new technologies on the car-related hard- and software market have been developed. The term Floating Car Data (FCD) refers to data being collected (continuously) by single or a fleet of vehicles which can be considered as a distributed network of sensors. This concept was originally designed and

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developed to build an embedded traffic management system that determines the average travel time in parts of the road network [7]. With the technological progress in positioning and communication systems such as GPS, GSM and GRPS, appropriately equipped vehicles are able to act as moving sensors across the road network. They collect data of the car’s position and thus also of the car’s velocity and direction. Beside the speed of the vehicle, modern bus systems like OBD-II and CAN are also able to provide a more detailed range of other operating and switching data in digital form, basically sensing the electronics of the car. These data refers to as Extended Floating Car Data (xFCD) and includes for instance information of the car’s assistance, light and warning systems [8]. Furthermore, the electronics of the engine can be accessed as well. The MAF sensor measures the amount of absorbed air in proportion to the consumed fuel. This allows to estimate the car’s fuel consumption. Given the fact that carbon dioxide emissions are directly proportional to fuel consumption [9], the concept of xFCD enables the collection of data that can be used in an environmental context as well, e.g. for carbon dioxide emissions related questions and problems.

2. Problem

Traffic emission estimates have been used to allow decision makers to manage regional air quality effectively [10]. But previous emission analyses were mostly conducted at a small scale, usually on regional or national levels. However, greenhouse gas mitigation efforts require to improve quantification of emissions in order to create emission baselines, verify emission trajectories and to identify efficient, economically viable mitigation options [11]. So the quantification of CO$_2$ at a fine space and time resolution is emerging at a critical need in carbon cycle and climate change research [9]. There have been efforts to break correspondent analyses down to a larger, mostly urban scale [12, 13]. But the results are considered as sensitive since their reliability is strongly related to the data on which the emission models are based. The mapping of vehicle emissions at fine scales is mainly challenging due to data limitations [13]. Former studies used a top-down approach in which simple emission factors like population or totally consumed fuel were disaggregated to the areas of interest.

The concept of xFCD enables spatial referencing of real, non-modelling based fuel consumption data of vehicles, and thus also spatial referencing of emission pollution at much finer scales. Nevertheless, very little is known about according emission analyses based on xFCD data and spatial analysis concepts [14]. This car-borne sensor data has certain specifics and constraints that need to be addressed in spatial analyses in order to produce valid results. On the one hand, these results might be able to leverage decision making in local traffic management in order to reduce the impact of CO$_2$ as a greenhouse gas. On the other hand, it can serve as the basis of according information products which might help to enhance the public work of traffic-related carbon dioxide emission.

While former research claims these kind of products for enhanced decision making in the transport sector of climate protection, very little is known about the factual potential benefits of xFCD-based information products such as CO$_2$ maps for urban planners. Furthermore, so far it is an uncertainty in research if local planning authorities have the actual necessity of these information.

3. Research Questions

In order to provide fine-scale emission analysis to detect CO$_2$ emission peaks, it is necessary to spatially analyse the car-borne sensor data in a valid way. In that context, this paper tries to provide answers to the following research question: “What methods and workflows are appropriate for a spatial analysis of automobile sensor data in order to assess local peaks of CO$_2$?”

The results of those analyses support the establishment of information products such as CO$_2$ maps and statistics. To be able to assess the additional benefits of these information products for urban
planners in the context of climate protection, this work also raises the hypothesis “Car-borne sensor data based information products provide additional benefits for communities and urban planners in climate protection and emission reduction.” To either reject or accept the hypothesis, the potential benefits for two aspects of the urban planners’ work are assessed: the quantification of CO₂ emissions and the public work and awareness raising.

4. CO₂ emission peak analysis for the city of Münster
To answer the research question, a case study for the city of Münster is conducted, using xFCD from ‘enviroCar’. The enviroCar platform was developed in the framework of a student’s project at the WWU Münster (Westfälische Wilhelms-Universität) in cooperation with the open R&D network 52° North. This citizen-science-driven project aims at supporting urban planners in climate protection and traffic planning by providing a freely available xFCD source. Based on that data, the case study proposes three different GIS-based (Geographic Information System) methods and workflows that can be applied to xFCD: a statistically driven hot spot analysis, a road segment based emission analysis and a density analysis of top emission locations. Because comparable spatial analyses concerning these exact matter have not been applied yet [14], the selection of methods is based on literature of related studies as well as on studies which have been performed at a different scale or based on a different input data. The spatial analyses are implemented using the Esri software ArcGIS 10.1.

Figure 1 exemplary illustrates results of the hot spot analysis at a federal highway exit, including according on-ramps and exit lanes. The used algorithm, the Gi* statistics, calculates the statistical significance of every measurement feature of the input xFCD to be either a hot spot, a cold spot or a statistical not significance measurement [15]. To do so, every feature is evaluated according to the similarity of high or low values in his neighbourhood, which was defined as 40 meters. It can be seen that on-ramps are dominated by CO₂ hot spots while exit lanes are dominated by cold spots. The federal highway itself is rather populated with not significant measurements. Within the
context of real world traffic conditions, these observations might indicate reasonable results because cars usually accelerate on on-ramps and slow down on exit lanes.

For the GIS-based density analysis, the top ten percent of the xFCD data set for the city of Münster were filtered. In a next step of the workflow, the density of those locations were analysed using the KDE algorithm (Kernel Density Estimation). Figure 2 shows an excerpt of the results, highlighting the detection of CO$_2$ peaks which were caused by speed bumpers. So the analysis can be linked to real world traffic infrastructure. That insights might be a chance for traffic planning authorities in order to create a sustainable traffic infrastructure in the future, or to rebuild the existing infrastructure.

![Figure 2: Detection of local CO$_2$ peaks according to the density analysis (left) and the real situation, showing speed bumpers as the cause for the peaks (right).](image)

The presented results might deliver valuable information about the degree of sustainability of a city’s traffic infrastructure as well as enable the detection of local emission peaks. However, there are several issues regarding the viability of those analysis: missing map matching of xFCD leads to impracticality of results in the neighbourhood of bridges and bigger roads with more separated lanes. Map matching describes the process of aligning a sequence of observed user positions with the road network on a digital map [16]. Furthermore, xFCD is collected in defined time intervals which leads to the issue that faster vehicles produce less data on the same stretch of way than slow cars. This influences the results because high emission values tend to be underrepresented in the calculation.

Among others, those main issues have the strongest influence on the road segment based analysis where firstly xFCD measurements were collected in 10 meter buffers around a road segment (road network data source: OpenStreetMap). As a second step, the mean of those measurements per road segment is calculated and re-assigned to the road. However, due to the given issues, this concept is not considered as an appropriate tool to detect local CO$_2$ peaks with xFCD.

5. Assessment of potential benefits of xFCD-based information products

The analyses shown in Chapter 4 deliver certain results which can be used for the creation of information products like maps and statistics. Those products might support the work of urban plan-
ners and environmentalists in climate protection. On the one hand, they might support the detection of local emission peaks. On the other hand, they might help to raise environmental awareness among citizens, and to leverage communication among deciders and stakeholders. To evaluate the potential benefit for climate protection planners, four expert interviews are conducted. The interview partners are a selection of urban planners and environmentalists of public authorities and climate protection related non-profit organizations in Germany. The concept and the guideline of the conducted expert interviews is focusing on to two main aspects: the potential benefit of xFCD-based information products for communal planners in emission modelling, and the potential benefit of those in the public work and awareness raising in the process of climate protection related CO₂ reduction. Accordingly, the results were grouped in two sections.

The first one enlightens the status of emission models in the work of communities. It is shown that the importance of such models is mostly restricted to the use in climate protection plans. Beyond that, the quantification of CO₂ emissions is constantly taken only as coarse evidence to prove the necessity of measures which fight emissions from the transport sector. Besides, the georeferencing of emissions is neither a topic so far nor planned for future projects. The communities tend to focus on starting projects that address the modal shift. Here, the goal is to totally avoid car driving and to leverage modes of transportation like going by food, by bicycle or by train. Measures that address the CO₂ reduction based on traffic infrastructure concepts are not planned explicitly. Since this is the assumed number one mitigation measure at which xFCD-related information products aim, the additional benefit of those is seen critically by the experts. Moreover, there are more disadvantages in the process of xFCD-based information products: the necessary data acquisition is considered as too cost intensive and time consuming. Since the concepts of communal emission monitoring intends to create time series in order to see the temporal change of emissions, several data acquisitions would be necessary, and thus requiring an even bigger financial and time effort. Although potential benefits were named by the experts too – mostly highlighting the opportunities of real data such as model validation – the conclusion is that xFCD-based information are at the moment not creating additional benefit for planners in the field of climate protection related emission modelling.

The second aspect of the results is concerning the potential benefits of xFCD-based information products in public work and awareness raising of the topic. Here, the experts stress the general importance of public work and communication, which intends to lead to a change of mind and an increased consciousness of the issue. However, the evaluation of potential benefits from xFCD are cleaved: on the one hand, the communities stress the benefits of maps showing the actual CO₂ emissions and the opportunity to positively influence the mobility behaviour. On the other hand, the communities highlight the complexity of the topic and doubt that CO₂ maps have the potential to communicate that topic. Therefore, the strategy of communities is more focusing on the emotional aspects as well as raising incentives for CO₂ reduced mobility behaviour.

6. Conclusions
This paper presents the concept of Extended Floating Car Data and evaluates its ability to enhance decision making of urban planners in climate protection. The presented case study proposes three different GIS-based methods and workflows. As shown, two of those methods (a, hot spot analysis and b, data extraction and density analysis) lead to largely valuable results, while the applicability of the third method is lacking due to missing map matching and the inconsistency in the xFCD data acquisition process. Although, compared to other emission models and methods, xFCD generally provides the means for fine-scale emission modelling. The paper shows that GIS-based methods might allow to appropriately analyse the data to draw conclusions on local emission peaks, as the example of speed bumpers shows (cf. Figure 2).
Nevertheless, this concept is not yet adopted by communities that are dedicated in communal climate protection. Their strategy focuses more on a complete avoidance of CO$_2$ emissions in traffic planning than on the mitigation of existing emissions with a smarter traffic infrastructure. However, social research amongst groups that have a different focus in their work, for instance traffic planners, might lead to different results.

In the future, there is the need to research the usability of xFCD in emission modelling. xFCD has the power to serve as an advanced data source for car-based emissions, which might feed bigger emissions models that also consider several other CO$_2$ sources like aircrafts and industrial plans.

References


