Effects of the Coronavirus Pandemic on Youth Mobility: A Case Study Analysis through Floating Car Data

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Abstract: Among mobility data sources, Floating Car Data plays a very, and increasingly, significant role, and has been extensively used to obtain traffic information. In this study, FCD has been used to shed light upon the youth mobility changes occurred during the first two years of the coronavirus pandemic by focusing on five selected high schools in Modena Municipality (Italy). Mobility indicators computed within the areas under investigation show that two out of the three schools' areas are not associated to a significant variation in the number of detected distinct private probe vehicles from November 2019 to November 2021 (-3% and +1%), whereas within the Modena Municipality results show a 8% decrease. However, one out of the three schools' areas shows a significant decrease in 2021 when compared to 2019 (-11%), suggesting a noticeable decrease in private vehicles traffic density that could be due to an increased use of personal mobility vehicles, such as bikes. Moreover, results within the Modena Municipality suggest that in 2021, even if the number of detected vehicles was lower than in 2019, each vehicle not only covered a longer distance on average, but also the total distance covered by all the vehicles together was longer (14% increase).

1 INTRODUCTION

Floating Car Data (FCD) refers to data collected directly by a vehicle as it is in motion, typically covering its location and speed (ECOSOC, 2021; Zannat, 2019). FCD has been used for a variety of purposes, including estimating the level of service on traffic networks (Dailey, 2002), investigating traffic safety (Axer, 2013; Biral, 2021; Guido, 2012; Kerner, 2005; Vaiana, 2014), and regulating traffic signals (Astarita, 2017). Connected vehicles providing FCD are to be considered as moving sensors, and as such they are extremely different from other data sources traditionally used for traffic prediction such as fixed traffic detectors (e.g., induction loops and traffic cameras) (Altintasi, 2017). The latter, contrary to FCD data sources, provide information about the total traffic, even if only relevant to the road section where the detectors are deployed. In general, however, it is yet unclear how much FCD is necessary for traffic estimations and predictions, considering that not all the vehicles can be equipped with FCD devices such as GPS, smartphones, V2X onboard units, and also considering that these devices may not always actively transmit traffic data (Mena-Oreja, 2021).

Apart from traffic density, by leveraging the information provided by connected vehicles via FCD it is possible to calculate a range of mobility indicators relevant to selected areas and time frames. This study, based on work undertaken for the project YOUMOBIL (T Bridge, 2022)—a project aimed at enhancing the passenger transport system for young people that live in rural areas and at improving their access to the European and national transport networks—attempts to analyse FCD to shed light upon the youth mobility changes occurred during the first two years of the coronavirus pandemic. In particular, since areas and time frames that are mostly related to youth activities—such as schools' neighbouring areas around start times—may be further investigated to find potential clues on how youth mobility has changed between 2019 and 2021, the FCD analysis reported in this article attempts to evaluate the youth mobility changes during the first two years of the coronavirus pandemic by focusing on five selected high schools in the Modena

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Municipality, located in the territory of Emilia-Romagna, a region of northern Italy.

To this purpose, we pursue the following research questions:

RQ1: Does traffic near selected high schools in 2021 significantly differ from 2019? We want to shed light on how youth mobility changed during the coronavirus pandemic. Consequently, we decided to focus on mobility indicators related to areas relevant to youth education, namely, schools' neighbouring areas, in 2019 and 2021.

RQ2: How do the traffic changes near high schools compare to traffic changes in the whole Municipality of Modena in 2019 and in 2021? To better evaluate the traffic changes within areas linked to youth activities, we should compare them to an appropriate baseline. As a consequence, we also evaluated the mobility changes in the whole Municipality of Modena, where the schools' areas are located.

The rest of the paper is organized as follows: Section 2 presents the methodology, starting from the territorial context under investigation and the reference time frames, and then introducing the FCD dataset and the mobility indicators; Section 3 reports the results of the analysis, focusing on the Modena Municipality, the schools' areas, and the FCD penetration rate; Section 4 addresses the research questions and, finally, Section 5 draws the conclusions.

2 METHODOLOGY

2.1 Territorial Context

The FCD analysis focuses primarily on the traffic density around five selected high schools in the Modena Municipality, on the south side of the Po Valley, in the Province of Modena in the territory of Emilia-Romagna, a region of northern Italy (Figure 1). The schools, all located to the west of the old city centre, are the following:

- F. Selmi Institute of Higher Education, located at Via Leonardo da Vinci 300, in Villaggio Artigiano district[1];
- F. Corni Institute of Higher Education, located at Via Leonardo da Vinci 300, next to the F. Selmi institute, in Villaggio Artigiano district[2];
- Wiligelmo High School, located at Viale Corassori 101, in San Faustino district[3];
- G. Guarini Institute of Higher Education. The school is located at Via Corassori 95, very close to Wiligelmo High School, in San Faustino district[4];
- Cattaneo-Deledda Professional Institute. The school is located at Strada degli Schiocchi 110, in San Faustino district, close to G. Guarini Institute of Higher Education[5].

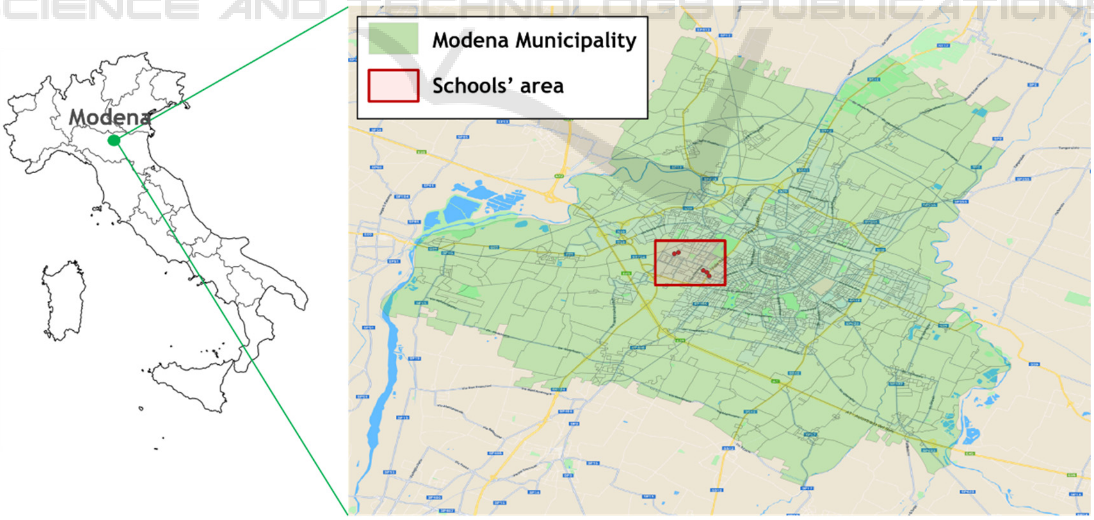

Figure 1: Location of Modena within Italy (left) and location of the five selected schools (red dots, right) within the Municipality of Modena (green shaded area, right).

[1] www.istitutoselmi.edu.it
[2] https://www.istitutocorni.edu.it/
[3] https://www.liceowiligelmo.edu.it/
[4] https://www.istitutoguarini.edu.it/
[5] https://www.cattaneodeledda.edu.it/

Since two or more schools located next to each other share their surroundings, to the purpose of the mobility analysis the five schools can be grouped in three main areas (Selmi and Corni, Wiligelmo and Guarini, and Cattaneo-Deledda) according to the schools' proximity to each other. To allow for a better detection of the impact of the traffic flow generated by the schools, such areas can be made large enough to include the main parking areas and roads where students can get out of a private vehicle after taking a ride to school at start times, leading to the identification of the areas shown in Figure 2 and Figure 3.

Table 1 reports the total number of enrolled students for each area in school year 2021/2022.

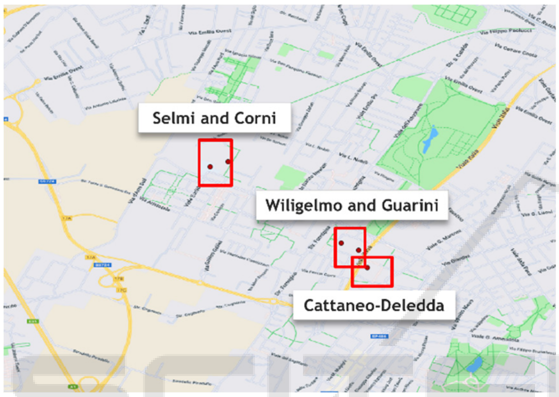

Figure 2: The 3 schools' areas under study (Selmi and Corni, Wiligelmo and Guarini, Cattaneo-Deledda).

Table 1: Enrolled students by area in school year 2021/2022.

Area	District	Schools	Students (2021-2022)
Selmi and Corni	Villaggio Artigiano	2	3,033
Wiligelmo and Guarini	San Faustino	2	1,587
Cattaneo-Deledda	San Faustino	1	1,281

2.2 Reference Periods for Comparison

To allow for an effective comparison on mobility changes between the period before the coronavirus pandemic and the most recent times, we first identified a recent time period in which tough coronavirus restrictions affecting mobility (and especially youth mobility) were not in place (e.g., no lockdowns, limited distance learning), so that the impact of the coronavirus pandemic on mobility patterns could possibly be observed devoid of the temporary effects of harsh COVID-19 measures.

To this purpose, we selected November 2021 as a suitable candidate time frame for the study (Lombardi, 2021). This choice also led to select November 2019 as the corresponding counterpart in the period before the coronavirus pandemic, since the two time frames correspond to the same period of the year and consequently allow for a meaningful comparison between 2019 and 2021.

More specifically, we focused on the periods 9-29 November 2019 and 8-28 November 2021, because the two time frames:

1. Are the same length (21 days);
2. Cover the same period of the year almost exactly (1-day difference);
3. Each features exactly 3 occurrences of each day of the week;
4. Do not include public holidays (1 November), only regular weekends.

In addition, to specifically address the impact of schools' activity on mobility, we also focused on the hours 7:00-9:00 a.m., since the start time of the schools under study is 8:00 a.m.

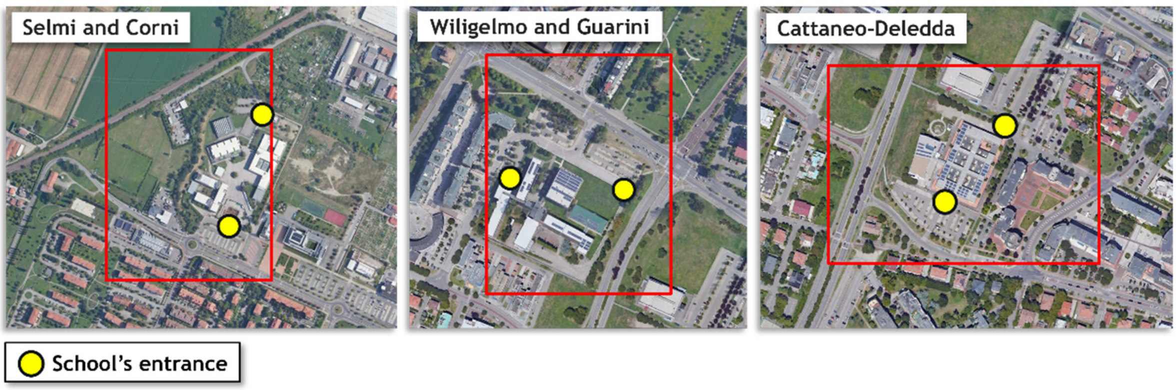

Figure 3: Schools' areas under study and main entrances.

2.3 The FCD Dataset

To the purpose of the study, an appropriate FCD dataset was queried in order to extract meaningful information on mobility changes.

Such dataset, acquired from a third-party provider and constituted by FCD collected by private and commercial vehicles equipped with an onboard GPS device, comprises of two tables. The most significant table is a collection of GPS records, each corresponding to a specific probe vehicle's position. Each record contains a *trip identifier*, and all the records with the same *trip identifier* are part of the same *trip*. A *trip* is defined as a collection of GPS records between two points where the vehicle remained stationary for at least 5 minutes. The other table of the dataset is constituted by records each containing the start and end GPS position of each identified trip, with additional information on the distance covered during the trip as provided by the vehicle's odometer.

Each record of the main table of the dataset also includes additional data other than the GPS position (latitude and longitude) and the trip identifier; among these additional data is the *vehicle identifier*, the corresponding *timestamp*, the vehicles' *direction* (0-360), the vehicle *type* (private/commercial), and other data related to the vehicle's position, including the address and the municipality.

To focus on the Modena case study, the dataset only comprises the trips which have at least one GPS record within the Modena Municipality in November 2019 and November 2021.

2.4 Mobility Indicators

To perform the FCD analysis, different queries were devised to allow for the extraction of meaningful mobility indicators relevant to the context (e.g., number of distinct vehicles, average distance per trip), both on the whole of the Modena Municipality, as it constitutes the baseline against which schools' areas were compared, and the schools' areas themselves, as such areas constitute the main subject of the analysis. In particular, we focused on the number of distinct probe vehicles identified in each area, as this is an indicator which might reflect traffic density.

For each of the areas considered, all the queries were executed separately for each time frame of interest—namely, 9-29 November 2019 and 8-28 November 2021—averaging the results per each day of the week and per the five-day school week (Monday through Saturday). Since the FCD dataset allows for a separate analysis of private and commercial vehicles, we specifically focused on private vehicles, due to the fact that hardly any commercial vehicle may be associated to students' home-to-school trips.

After extracting the data for the selected time frames in 2019 and 2021, relative deltas were calculated to compare the difference between the most meaningful indicators in each area. As a result, the deltas relevant to the schools' areas could also be compared to the deltas relevant to the Modena Municipality.

Finally, we estimated the FCD penetration rate both in 2019 and 2021 to evaluate its impact on the resulting key mobility indicators.

3 RESULTS

3.1 Modena Municipality

To the purpose of focalising on the changes directly related to schools' activities, mobility changes around schools were compared to the changes in the whole of the Modena Municipality, whose FCD were analysed specifically to build a baseline for comparison. As previously stated, the municipality's FCD were analysed focusing between 7 and 9 am, as such time slot is the most relevant to schools-related mobility, being 8:00 am the start time for lessons for all the 3 selected schools.

Table 2 reports the number of distinct private probe vehicles detected within the municipality of Modena between 7 and 9 am, averaged from Monday to Saturday over the time frames 9-29 November 2019 and 8-28 November 2021, and the resulting delta between 2019 and 2021.

Table 2: Average daily distinct private probe vehicles (Monday to Saturday, 7-9 am) within Modena Municipality.

Area	Daily average 2019	Daily average 2021	Delta 2021/2019
Modena Municipality	685.8	632.9	-8%

Results show that, within the Modena Municipality, the number of distinct private probe vehicles detected in 2021 is 8% lower than in 2019.

In addition, we also calculated the variation of the total distance covered by all the private probe vehicles in the same time frame, and also the average distance covered per vehicle, to the purpose of detecting if such variations reflected that of the number of distinct vehicles (Table 3).

Table 3: Deltas 2021/2019 of the average of total distance covered and distance per vehicle relative to private probe vehicles (Monday to Saturday, 7-9 am) within Modena Municipality.

Area	Total distance (delta 2021/2019)	Distance per vehicle (delta 2021/2019)
Modena Municipality	+14%	+22%

The results show that the total distance travelled by private probe vehicles in 2021 increased by 14% on an average day between Monday to Saturday between 7 and 9 am, and that the average travelled distance per vehicle increased by 22%. Thus, in 2021 were detected 8% fewer private probe vehicles than in 2019, but the total distance travelled by the detected vehicles increased by 14%.

3.2 Schools' Areas

The FCD detected within the 3 identified schools' areas were analysed focusing between 7 and 9 am, as such time slot is the most relevant to schools-related mobility, being 8:00 am the start time for lessons for all the 3 selected schools.

Table 4 reports the number of distinct private probe vehicles detected within each of the 3 schools' areas between 7 and 9 am, averaged from Monday to Saturday over the time frames 9-29 November 2019 and 8-28 November 2021, and the resulting delta between 2019 and 2021.

Table 4: Average daily distinct private probe vehicles (Monday to Saturday, 7-9 am) within the schools' areas.

Area	Daily average 2019	Daily average 2021	Delta 2021/2019
Selmi and Corni	10.3	9.2	-11%
Wiligelmo and Guarini	19.7	19.0	-3%
Cattaneo-Deledda	8.6	8.7	+1%

Results show that in 1 of the 3 schools' areas the number of distinct private probe vehicles detected in 2021 is around 1% higher than in 2019, whereas in the other 2 schools' areas the number decreased. Within the area where the number decreased, only that of Selmi and Corni (-11%) decreased more (and only slightly so) than that of the whole Modena Municipality (-8%), whereas in the Wiligelmo and Guarini's area the extent of the decrease is considerably less noticeable (-3%) when compared to the whole Modena Municipality (-8%).

3.3 FCD Penetration Rate

As previously mentioned, the FCD analysed in this study might be used as a basis to estimate traffic within the case study areas, which means we have to first determine how many vehicles the employed FCD actually represent. To this purpose, assuming that the probe vehicles are uniformly distributed across the network—even if this is not realistic in many cases—we calculated the ratio of the probe vehicles (FCD penetration rate), as suggested by Nagle and Gayah (Nagle, 2014). More specifically, Nagle and Gayah suggested to use such ratio to estimate network-wide variables from FCD, also proposing to acquire the ratio by dividing the number of vehicles tracked by GPS in the analysis area for a specific time period to the number of vehicles that crossed the fixed traffic detectors in the same area and period. Traffic density can be then estimated by multiplying the number of vehicles detected with FCD in a specific area by the reciprocal of the penetration rate of the FCD devices.

Although the FCD penetration rate can vary in space and time, it must be noted that the mobility indicators calculated in the previous sections were averaged over a period of three weeks both in 2019 and 2021, thus limiting the impact of temporary variations in the FCD penetration rate and, especially regarding the indicators calculated for the Modena Municipality, rate variation in space were smoothed out by the considerable extension of the area of the analysis.

Given the previous considerations, we estimated the 2019 and 2021 FCD penetration rate related to the area under study on the basis of the number of vehicles that crossed the fixed traffic detector with identification number 328, located around 3.5 km south-west of the 5 schools under investigation on SP486 road (Figure 4), on the peak day of November 2019 and November 2021 (13/11/2019 and 11/11/2021) .

To determine the FCD penetration rate we identified all the trips that crossed the fixed traffic detector on the monitored road section by analysing on map the private probe vehicles' GPS positions in chronological order. We then divided the number of identified trips by the traffic detected by the fixed traffic detector, thus estimating the FCD penetration rate both in 2019 and 2021 (Table 5).

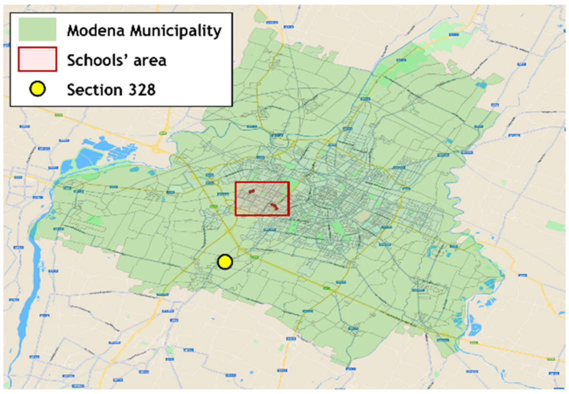

Figure 4: Location of the fixed traffic detectors on road SP486 with respect to the schools' area.

Table 5: Estimation of the 2019 and 2021 FCD penetration rate for private vehicles on the monitored SP486 road section.

Year	Detected traffic	FCD traffic	FCD penetration rate
2019	26,294	195	0.85%
2021	25,389	184	0.82%

The difference between the estimated FCD penetration rates in 2019 and 2021 does not appear to be significant. This suggests that the deltas calculated in the previous sections between the number of detected private probe vehicles in the 3 schools' areas and the Modena Municipality in 2019 and 2021 could effectively reflect the deltas between the real traffic densities in the same areas, even if it is not possible to draw such a conclusion from the sole comparison of the estimates in one road section.

4 DISCUSSION

In this section, we discuss the results of the FCD analysis and investigate the possible reasons behind the difference between the mobility indicators calculated within the Modena Municipality and the 3 selected schools' areas, thus trying to answer the research questions introduced at the beginning of this chapter. We first address RQ1, and then RQ2.

RQ1. Does traffic near selected high schools in 2021 significantly differ from 2019?

As reported in Table 6, two out of the three schools' areas under investigation, namely Wiligelmo and Guarini's and Cattaneo-Deledda's areas, do not show a significant variation in the number of detected distinct private probe vehicles from November 2019 to November 2021 (-3% and +1% respectively). This would suggest that the traffic density around schools in November 2021 grew back to the traffic density characterizing the period before the COVID-19 pandemic. However, one out of the three schools' areas, namely Selmi and Corni's area, shows a significant decrease in the number of detected private probe vehicles in 2021 when compared to 2019 (-11%), suggesting a noticeable decrease in private vehicles traffic density within such area. As a consequence, these results are further investigated and discussed at the end of this section, so as to first provide additional insights on the local context through addressing the second research question.

Table 6: Average daily distinct private probe vehicles (Monday to Saturday, 7-9 am) within the 3 selected schools' areas and Modena Municipality.

Area	Daily average 2019	Daily average 2021	Delta 2021/2019
Wiligelmo and Guarini	19.7	19.0	-3%
Cattaneo-Deledda	8.6	8.7	+1%
Selmi and Corni	10.3	9.2	-11%
Modena Municipality	685.8	632.9	-8%

RQ2. How do the traffic changes near high schools compare to traffic changes in the whole Municipality of Modena in 2019 and in 2021?

As reported on Table 6, in the Municipality of Modena the decrease in the number of detected distinct private probe vehicles from November 2019 to November 2021 is around 8% and, therefore, noticeably different from the results obtained within Wiligelmo and Guarini's and Cattaneo-Deledda's areas. Nevertheless, as previously mentioned, the results from Selmi and Corni's areas differ considerably from those obtained around the other schools' areas, suggesting an even higher decrease in traffic density than that detected in the whole Municipality of Modena. This prompted a more in-depth investigation into the local context to find possible reasons that could explain such difference, as Selmi and Corni's 11% decrease in distinct private (probe) vehicles could actually be due to many factors, or a combination of them. Among the various possible reasons, one could be that of an increased use of personal mobility vehicles, such as e-scooters and bikes/e-bikes, also considering that a nearby brand-new bicycle route was inaugurated at the beginning of October 2021—just one month before the time frame investigated in 2021— which effectively connect Selmi and Corni schools to the Central Station in a very convenient way. Such infrastructure could have led many citizens that regularly move to or from the areas crossed by the cycling route—thus including the Selmi and Corni's students—to rely on personal mobility vehicles instead of private ICE vehicles.

With regard to the RQ2, we must also highlight the results concerning the total distance travelled by private probe vehicles in 2019 and 2021 within the Municipality of Modena (Table 7).

Table 7: Deltas 2021/2019 of the average of total distance travelled and distance per vehicle relative to private probe vehicles (Monday to Saturday, 7-9 am) within Modena Municipality.

Area	Total distance (delta 2021/2019)	Distance per vehicle (delta 2021/2019)
Modena Municipality	+14%	+22%

As previously reported, the total distance travelled by the detected vehicles increased by 14%, with a 22% increase in the average travelled distance per vehicle, but in 2021 8% fewer private probe vehicles were detected than in 2019. These results suggest that in 2021, even if the number of private vehicles was lower than in 2019, not only each of these vehicles covered a longer distance, but they all together also travelled a longer distance (14% variation). This might have led to a higher traffic density within the Municipality of Modena on the whole.

We must also remark that hypothesis such as the one reported previously are based on the results from the FCD Analysis, and thus should be further verified with real traffic density data since, as previously stated, the FCD penetration rate relative to the analysed dataset is slightly lower than 1% and could also vary considerably in space and time. Nevertheless, the FCD analysis provides interesting information which can be leveraged to further investigate the local context and the related changes in traffic density.

5 CONCLUSIONS

Floating Car Data refers to data collected directly by a vehicle, typically covering its location and speed (ECOSOC, 2021; Zannat, 2019). FCD has been used, among others, to estimate the level of service on traffic networks (Dailey, 2002), to investigate traffic safety (Axer, 2013; Biral, 2021; Guido, 2012; Kerner, 2005; Vaiana, 2014), and to regulate traffic signals (Astarita, 2017).

In this study, FCD has been used to attempt to investigate the effects of the coronavirus pandemic on mobility within the areas around five selected high schools in the Italian Municipality of Modena and the wider Municipality area. The mobility indicators computed through the FCD analysis show that, from November 2019 to November 2021, two out of the three schools' areas under investigation are not associated to a significant variation in the number of detected distinct private probe vehicles (-3% and +1%), while in the Modena Municipality results show a 8% decrease. Nevertheless, one out of the three schools' areas shows a significant decrease in 2021 (-11%), suggesting a noticeable decrease in private vehicles traffic density which can be attributed to an increased use of personal mobility vehicles, such as e-scooters and bikes/e-bikes, also considering the recent inauguration of a nearby brand-new bicycle at the beginning of October 2021.

In addition, the number of detected vehicles in the Municipality of Modena was lower in 2021 than in 2019, but the average distance covered by each vehicle was longer (22% increase), as well as the total distance covered by all the vehicles together (14% increase). Even if further validation with real traffic density data is needed to draw more detailed conclusions, FCD proved to be able to provide interesting information which can be leveraged to investigate the mobility changes within specific regions.

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