

Impact of COVID-19 on Urban Mobility: Empirical Evidence and Lesson Learnt

Antonio Comi[1(✉)] and Antonio Polimeni[2]

[1] Department of Enterprise Engineering, University of Rome Tor Vergata, Rome, Italy
comi@ing.uniroma2.it
[2] Department of Engineering, University of Messina, Messina, Italy
antonio.polimeni1@unime.it

Abstract. The impact of the COVID-19 pandemic on mobility was significant due to the lockdowns imposed by governments around the world. During these periods, a (oblivious) decrease in travel was registered (no travels for school, travels for work limited to some specific worker categories) with a modal choice that has penalized the public transport. But the question is: after lockdowns, have users resumed their travel habits or not? This paper tries to answer this question by considering two aspects: the modal choice and travel for shopping. A survey was carried out to investigate whether any changes were made in the user habits. The main findings are: i) for mode choice, the users struggle to go back to their old habits, with a generalized distrust of public transport and an increase in the use of the private car; and ii) for shopping, the users changed habits, for example reducing the quantity purchased but making more frequent purchases.

Keywords: COVID-19 · mode choice · travel behavior · public transport · city logistics

1 Introduction

The global impact of the COVID-19 pandemic prompted, in each country, the imposition of some restrictions that have attempted to reduce the spread of the virus. Such restrictions, ranging from social distance to general lockdown, combined with the fear of contagion, negatively affected the transportation field in terms of passenger and freight mobility. One of the legal acts issued by the authorities was the telecommuting (e.g. [1, 2]) imposing on some categories of workers the need to stay at home. In parallel, the closure of schools/universities contributed to the collapse of public transport. Obviously, this caused a sudden reduction in travel and a change in behavior related to those users who had to travel anyway [3]. In particular, the means of transport that required traveling together with other people were discarded, to switch to other modes ([4–7]): as an example, an increase in the use of bike sharing was registered in many countries ([8–10]). Another aspect to consider is traveling for shopping: also in this case, the impact of the pandemic disrupted user habits: for example, with an increase in the online shop (e.g., [11–13]).

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2024
O. Gervasi et al. (Eds.): ICCSA 2024 Workshops, LNCS 14821, pp. 79–96, 2024.
https://doi.org/10.1007/978-3-031-65308-7_7

Return to normal is expected to be gradual, but it is not clear whether all users will resume their previous habits or not. Therefore, the aim of this paper is to try to give an answer to this question, considering both the mode choice and the travels for shopping. The survey, carried out in Italy in the first semester of 2023, has been designed to collect data related to a time period before the pandemic and after the national lockdown imposed in Italy. Data related to mode choice and purchase habits were collected.

The paper is structured as follows. Section 2 reports a review of the literature, both on mode choice and travel for shopping. In Sect. 3, the collected data are described, while in Sect. 4, the results are presented. Finally, the conclusions (Sect. 5) are drawn.

2 Literature Review

The pandemic caused modifications to the modal choice aimed mainly at reducing contact with other users. This means a sudden abandonment of collective transport (for those who used it) to move towards individual modes (e.g., car, bike, walking). Another effect was on the shopping habits, with a subsequent increase in e-commerce. The literature on this topic, although a short time has passed since the outbreak of the pandemic, is very extensive. Without the presumption of being exhaustive, in the next paragraphs a literature review related to mode choice and mobility for shopping related to the COVID-19 pandemic is reported.

2.1 Mode Choice

Public transport is perhaps the one that, among the different modes of transport, has suffered more from the impact of COVID-19. Almlöf et al. [14] analyzed the decrease in the use of public transport mode during the pandemic by correlating this choice with the socio-economic data of users. The finding is that the majority of users using public transport during the pandemic are those with low resources, which highlights a disparity in equity for users with different socio-economic characteristics. Abdullah et al. [15] examined travel behavior before and during the COVID19 pandemic, highlighting changes in user choices. From the data collected by the survey (extended to different countries), it emerged that during the pandemic trips are mainly undertaken for shopping and a significant abandonment of public transport in favor of private modes (e.g., car) was revealed. Parker et al. [16] studied how COVID-19 affected user behavior in the USA. From the data, it emerged that 75% of users used public transport less for two main reasons: the risk of COVID-19 transmission and the reduction in service frequencies. Shelat et al. [17], to understand user behavior at the beginning of the pandemic and assess behavior at different stages of the pandemic, designed a stated preferences experiment targeting train travelers in the Netherlands and calibrated a latent class choice model. Wielechowski et al. [18] studied changes in public transport mobility at different territorial levels (national and regional) in Poland, finding a (negative) correlation between public transport use and COVID-19 containment policies. A similar work, but at the urban level ([19]), revealed that 90% of users have stopped using or limited their use of public transport. Aydin et al. [20] evaluated changes in travel modes related to passengers in the city of Istanbul, the results demonstrated a consistent shift from public transport

to other modes, such as private car, bike and walk. Tiikkaja and Viri [21] found a 70% reduction in public transport in the city of Tampere (Finland) and discussed the actions implemented to adapt transport frequencies to the changing level of demand. Downey et al. [19] performed an analysis to understand what could happen to public transport at the end of the pandemic: the result is that more than 30% of users said that, after the pandemic, they will reduce public transport.

In terms of bike sharing, on the other hand, there has been an increase in demand, mainly from users who previously used collective transport [22]. Bustamante et al. [23] analyzed the factors that influence bike sharing in Barcelona before and after the COVID-19 lockdown. The results show that the main predictors in bike sharing choice are the trip distance and income level, other predictors are related to land use, weather, and infrastructural characteristics. Heydari et al. [24] estimated the effects of the COVID-19 pandemic on the London bike-sharing system by comparing the number of bike hires before and during the pandemic. The results demonstrated that, after an initial decline, the values returned to their previous levels. Hu et al. [25] examined the Chicago bike sharing system during the pandemic and estimated some models to foresee the average daily value of the hires. Among the predictors considered in the models, there are the attributes related to land use, the bike sharing station characteristics, and the income. Nikiforiadis et al. [26] studied the impact of COVID-19 on the choice of bike sharing; in this study (conducted in Thessaloniki, Greece), an increase in the use of bike sharing, (with users that shift from public transport and from private cars to bike sharing) has been pointed out. Teixeira et al. [27] examined the use of bike sharing during the pandemic in the city of Lisbon, observing that users used bike sharing to avoid public transport and maintain social distance during the trip. Kubal'ák et al. [28] analyzed how COVID-19 affected the use of bike sharing use in Slovakia, comparing such an use before and during the pandemic. An analysis of the trend of bike rent showed a fluctuating trend during the COVID-19 propagation. Similarly, Arias-Molinares et al. [29] analyzed the spatio-temporal patterns of use of shared services before and during the pandemic, revealing a decrease in their use. Azimi et al. [30] presented a case study related to the bike sharing during the pandemic, highlighting an increase (about the 30%) in ridership, during the COVID-19, with a related increase in trip duration. Basak et al. [31] evaluated the variation in bike sharing from the beginning of the pandemic to the first lockdown: an increase in bike rent was observed at the beginning of the pandemic and a consistent reduction during lockdown due to the lockdown because of the restriction measures adopted.

2.2 Shopping Mobility

The outbreak of COVID-19 drove users to increase their online shopping, in most cases even for goods that had previously been purchased in traditional stores.

Javadinasr et al. [32] explored the effects of the pandemic in the USA, also in terms of shopping mobility, there was an increase of 78% in grocery shopping comparing the pre-pandemic situation with the first wave and of 83% with respect to the second wave. Furthermore, users say that they are willing to buy online even after COVID-19. Koster et al. [33] evaluated the variation, due to the imposition of anti-COVID measures, in the number of users who move along the main shopping streets of the Netherland; they

found a 25 to 50% reduction in travels (depending on the measure considered). Villa and Monzón [34], analyzing online shopping trends of residents of the central area of Madrid, discovered the doubling of the online orders and evaluated the environmental impact of package transport vehicles. Ben Hassen et al. [35] investigated the impact of the pandemic on food shopping habits, finding that COVID-19 caused a decrease in shopping frequency and an increase in the quantity purchased. Music et al. [2] studied the variation in food online purchases, revealing an increase during the pandemic and the potential for further growth after the end of the pandemic. Focusing on grocery shopping, Xu and Saphores [36] investigated the habits of users in California during and after the pandemic: while there has been an increase in online grocery shopping, many users have continued to shop in 'traditional' stores. Bian et al. [37] examined the frequency of purchases at grocery stores during the COVID-19 pandemic, finding an increase of 20% immediately after the lockdown was declared. Recchia et al. [38] analyzed the use of channels for food purchases during the first lockdown in France, revealing variations in user habits by supply channel. Titiloye et al. [39] analyzed the supply channel (home delivery, curbside pickup, and in-store) chosen by users during the pandemic considering as relevant attributes the price, the shopping time, the delivery time and cost, and the travel time. Zhang et al. [40] investigated the demand for takeout shopping during the pandemic with the aim of identifying the factors influencing such demand. Some of these relevant factors are: population density, road density, house prices. German et al. [41] analyzed the propensity of users to choose a carrier during the pandemic, it emerged that variables such as user attitude, service quality, customer satisfaction affect user choice.

3 The Survey

The survey was designed in order to try to understand how the pandemic affected the preferences of the users in the COVID-19 period, specifically comparing the preferences in the pre-pandemic period and the preferences after the lockdowns suffered in 2020.

The questions were aimed at gathering information regarding both the modal choice and the variation (if any) of habits in travel for shopping (respect to the pre-COVID era). The survey contained a section dedicated to socio-economic data and some sections dedicated to the specific topic under investigation. The following paragraphs report some analyses of the surveyed sample.

The questionnaire has been developed with the aim of analyzing the travel behavior in the period before COVID-19 and in the period following the first Italian lockdown, both on systematic travels (e.g., home-work, home-study travels) and non-systematic travels (e.g., home-shopping). The sample consists of 217 respondents (of which 42% are women). Figure 1 reports some summary data: for the 68% of respondents, the age ranges from 18 to thirty years old, the 39% are employees, and the 49% have an annual income between 10,000 and 30,000 euros. Furthermore, the type and the number of vehicles owned by respondents is recognized (Fig. 2): as an example, the 49% own two cars, the 73% own a motorcycle or a motorbike, the 48% own two bikes, the 78% owns an e-bike.

Since the time interval between the pre-lockdown and the post-lockdown is quite large, the respondents were asked if their professional status had changed in the meantime

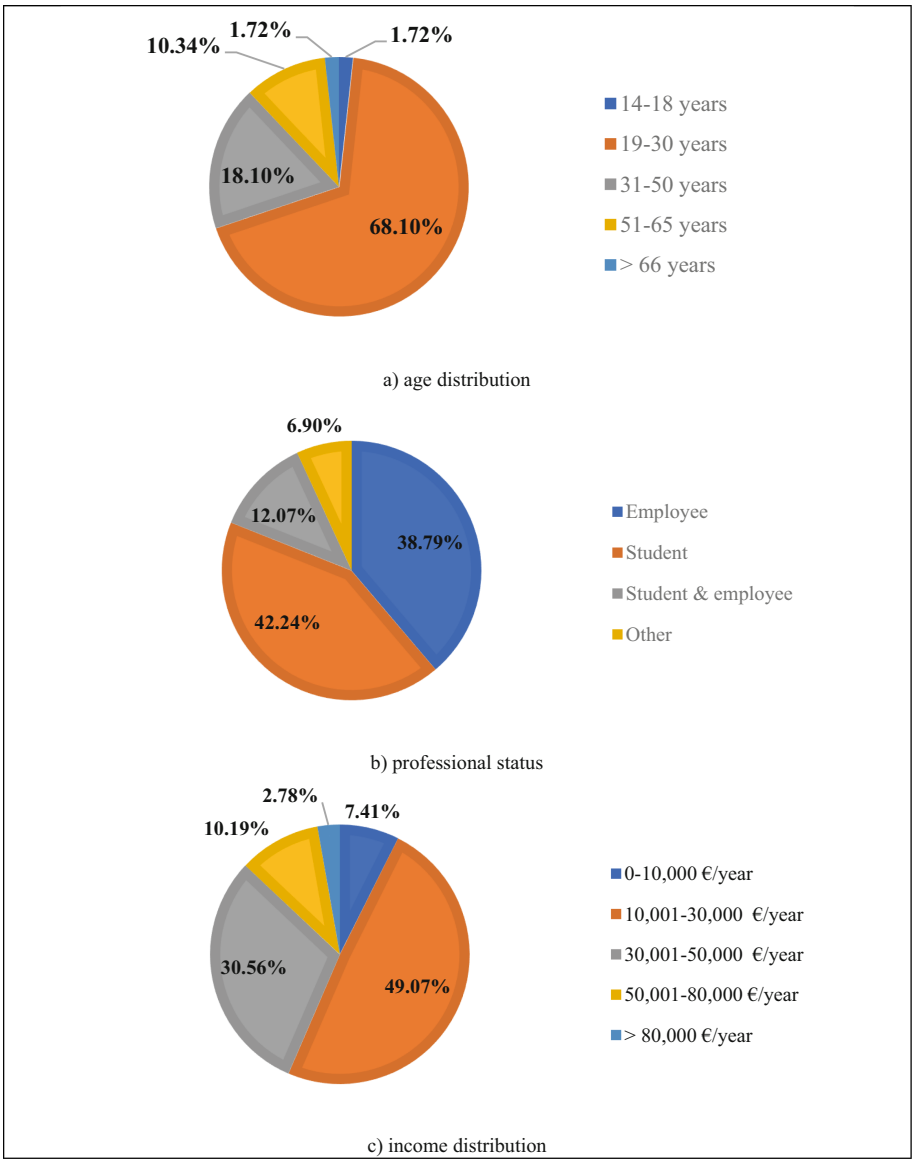

Fig. 1. The sample composition.

(e.g., from student to employee). This question can help to understate whether changes in mode choice are also linked with the transition from a professional status to another. It was revealed that (Fig. 3) about 66% of the respondents kept the previous status, about 20% changed the type of work, about the 6% passed from high school to university, about the 3.5% entered the world of work. It should be noted that around 5% enrolled in university.

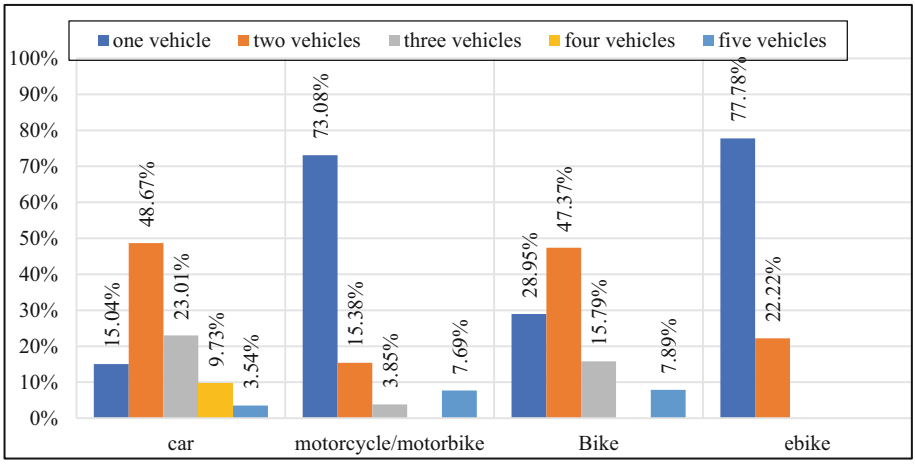

Fig. 2. Number and type of vehicles owned.

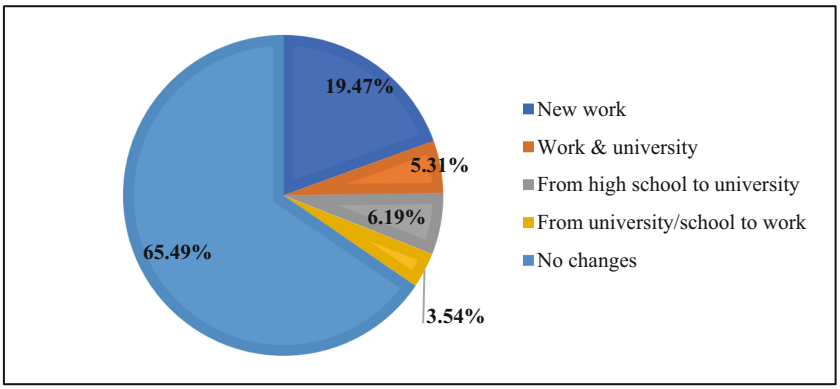

Fig. 3. Changes in professional status

Since shopping mobility is affected by the number of family members, a question on the composition of the household has been included. The responses showed that 68% of the families taking part in the survey are made up of at least 3 people, while 9% is made up of just one person.

4 Results

4.1 Data Analysis: Mode Choice

Analyzing the time distribution of the systematic travels (Figs. 4 and 5), no striking differences emerged between pre-lockdown and the post-lockdown. Outward travels are concentrated between 8 and 11 in the morning, the biggest differences are travels starting at eight o'clock (about 10%) and the afternoon trips between 3 p.m. and 7 p.m.. The

return travels are scattered in the afternoon with few relevant differences. As regards the non-systematic travels (Figs. 6 and 7), the situation before and after lockdown is very similar, with differences off less than 7%.

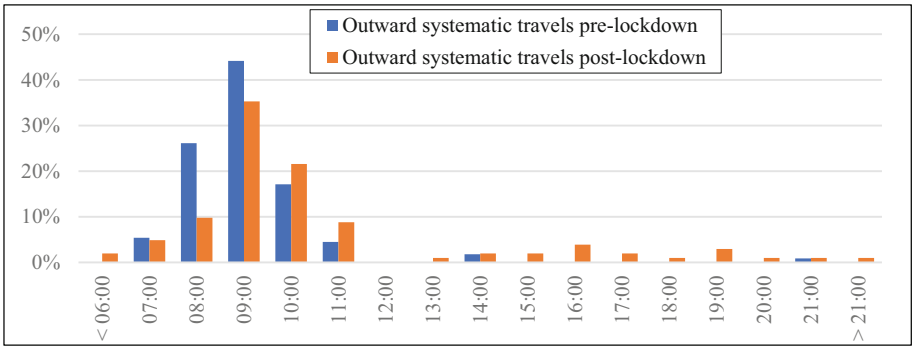

Fig. 4. Outward systematic travels.

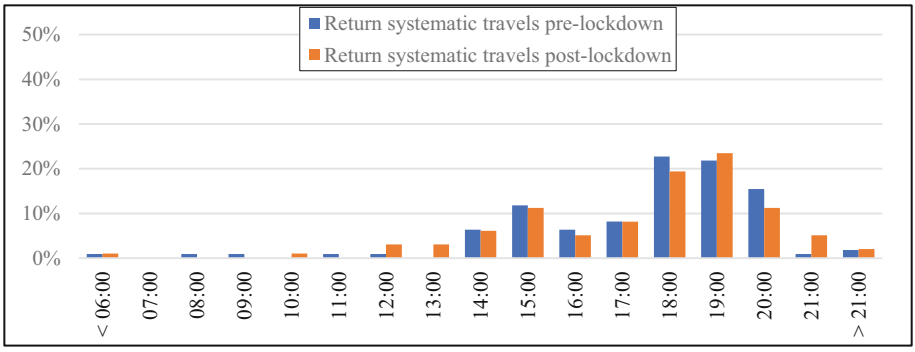

Fig. 5. Return systematic travels.

From the analysis of the mode choice (Figs. 8 and 9), it emerges that the public transport was already few used before the lockdown (38% for systematic and 16% respectively for non-systematic travels), its share goes down after the lockdown (18% and 6%, respectively). After the lockdown, the choice of public transport is reduced in favor of private transport and walking.

Focusing on the travels performed with the use of private transport (Figs. 10 and 11), among these also including walking, there are only small changes between the pre-lockdown and post-lockdown situation. In fact, for systematic travels, an increase of approximately 4% in the use of the car as a driver can be observed, accompanied by a decrease in the use of the car as a passenger. There is also a 5% decrease in travels by walking. The other percentages fluctuate by about 2%. Similar considerations can be done for non-systematic travels, where the use of two-wheeled vehicles (motorized or not) is also noted.

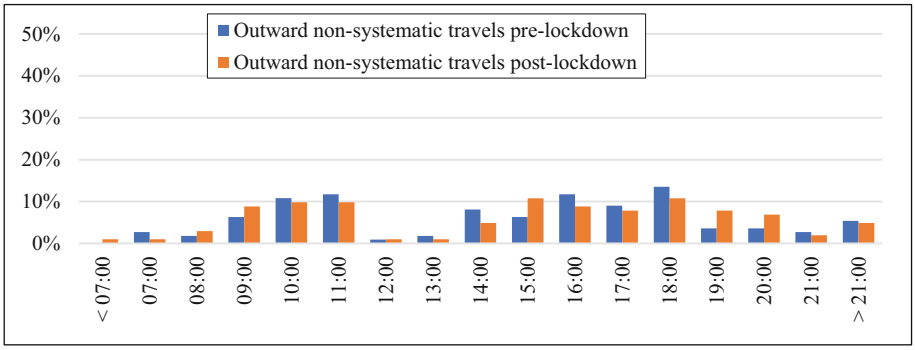

Fig. 6. Outward non-systematic travels.

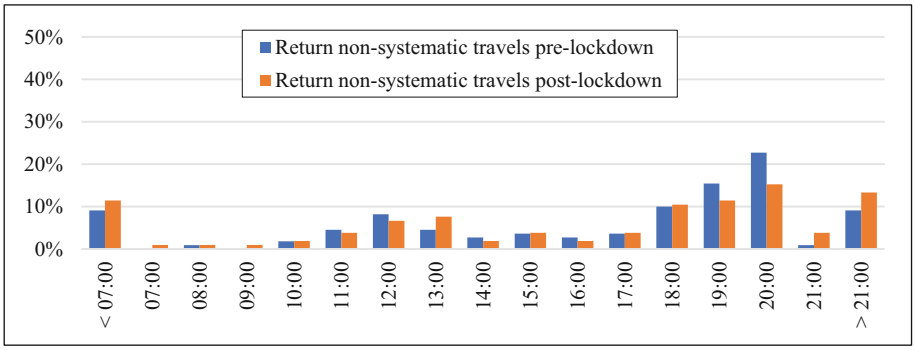

Fig. 7. Return non-systematic travels.

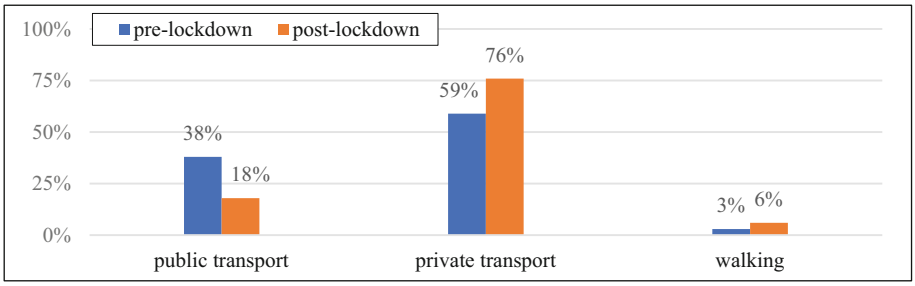

Fig. 8. Mode choice for systematic travels.

Focusing on systematic travels (Figs. 12 and 13), in relation to the choice of public transport, the weights given to the single factor remain substantially the same (the only obvious change is in the vehicles owned). The choice of private transport undergoes significant changes in factors consideration: in fact, while in the pre-lockdown situation

the main factors were the travel time and the comfort (44% and 51%), in the post-lockdown, factors such as social distancing and disinfection play a key role (18% and 14%, respectively).

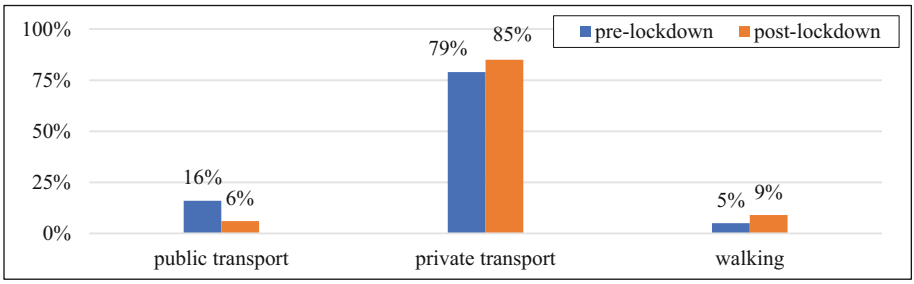

Fig. 9. Mode choice for non-systematic travels.

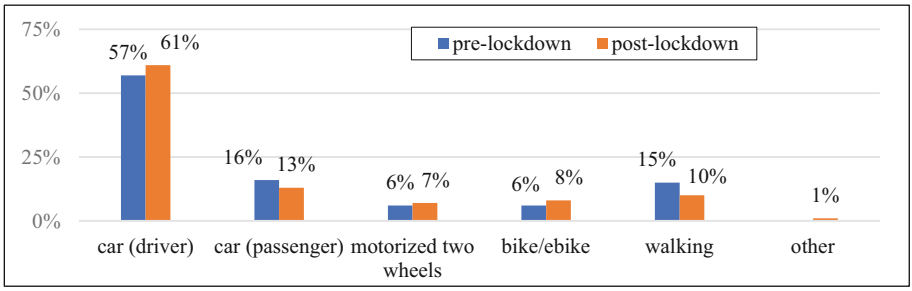

Fig. 10. Systematic travels with a private vehicle

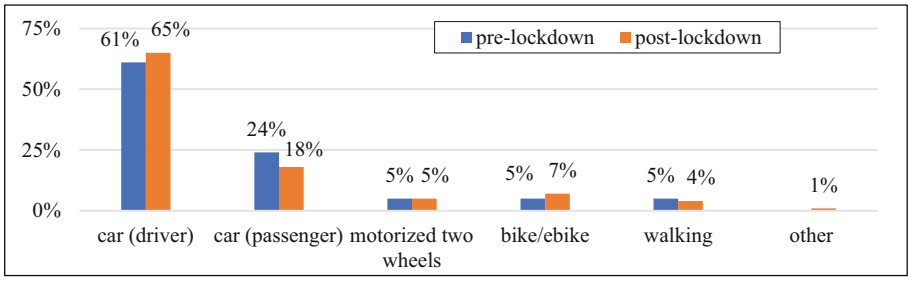

Fig. 11. Non-systematic travels with private vehicle

Focusing on non-systematic travels (Figs. 14 and 15), in relation to the choice of transport mode (public or private), the same considerations seen for the systematics can be made, the importance of the factors remains unchanged.

From the previous data, a multinomial logit model for mode choice was calibrated (by the Maximum Likelihood method) for the pre-lockdown and the post-lockdown scenarios. The modes considered are: car, bike (including also e-bike), public transport,

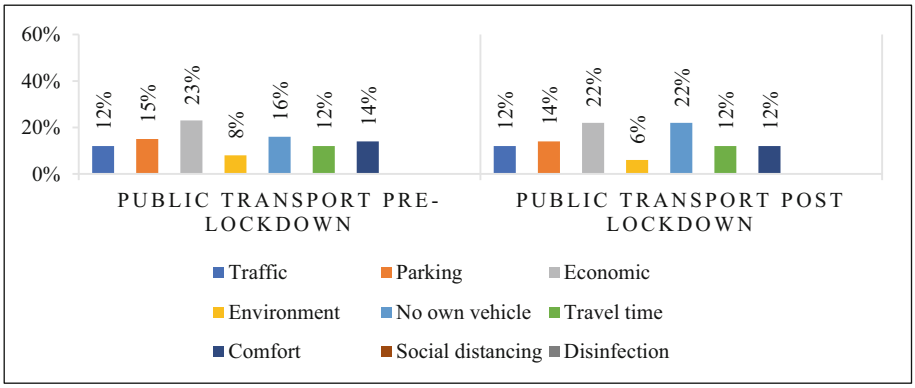

Fig. 12. Factors that affect the choice of public transport for systematic travels.

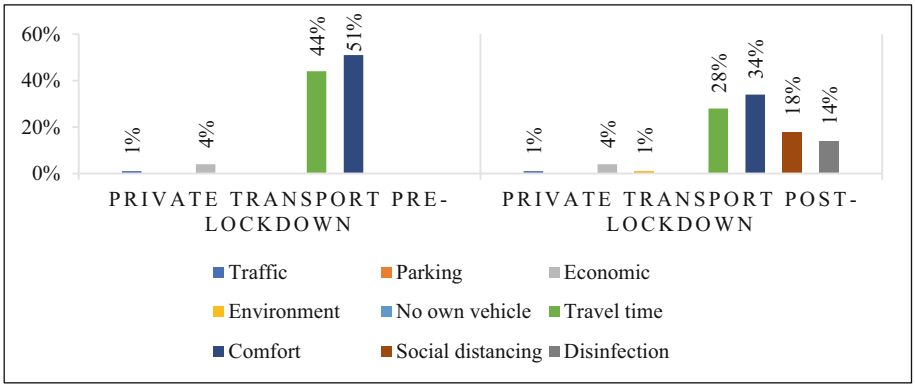

Fig. 13. Factors affecting private transport choice for systematic travels.

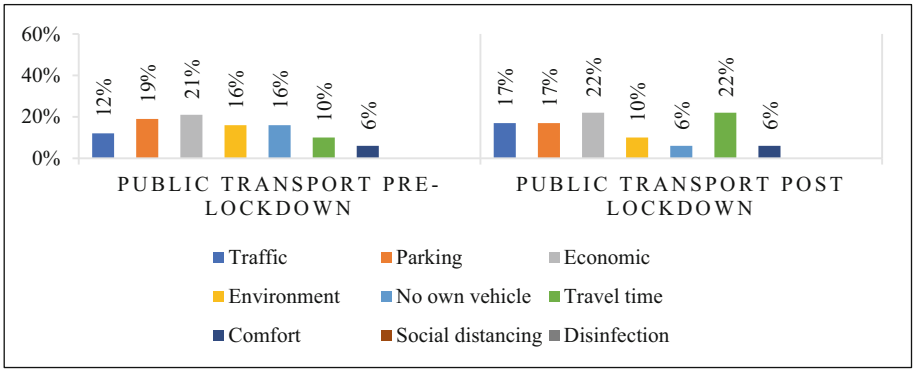

Fig. 14. Factors affecting public transport choice for non-systematic travels.

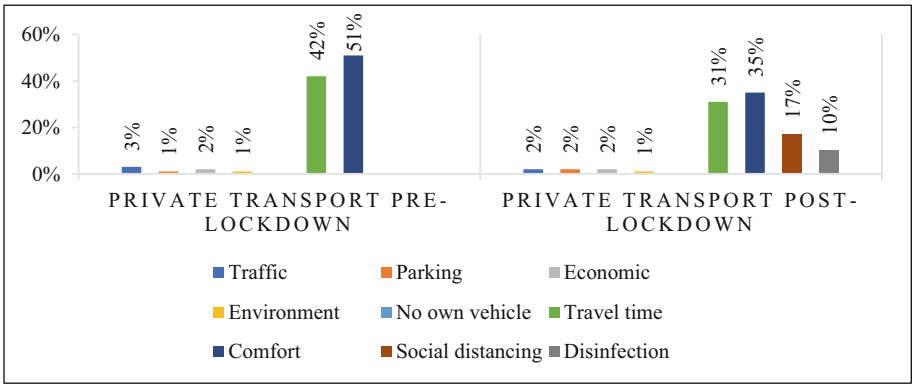

Fig. 15. Factors affecting private transport choice for non-systematic travels.

motorcycle, and by foot. The systematic utility for the generic mode m is specified as follows:

$$V_m = \beta_{dist} \cdot dist + \beta_{inc} \cdot inc + \beta_{ts} \cdot ts + \beta_{hh} \cdot hh + \beta_{fm} \cdot fm + \beta_{asc} ASA$$

where:

- *dist* is the distance of the travel;
- *inc* is the income of the respondent;
- *ts* is the time interval in which the travel begins, express in hours from the midnight;
- *hh* is the number of family members;
- *male* is a dummy variable equal to *1* if the respondent is male, *0* otherwise;
- *ASA* is the alternative specific attribute,
- β_x are the parameters to be calibrated.

This model allows us to simulate the mode choice of users under the two different scenarios, and to point out how the reciprocal weights are changed before and after the pandemic. Tables 1 and 2 show the calibrated parameters. The systemic utility of the alternative "by-foot" is the reference one and it is assumed to be equal to zero. From these values emerges that strong relevance of weight associate with the distance to travel by bus on long travel (for commuting trips). The user behaviors are quite changed before and after the pandemic. In fact, although distance represents a cost attribute, the reciprocal sign with respect to the base alternative, i.e. by-foot, needs to be discussed. When increasing the distance, users prefer to use a car more than ride a bike, as well as to use public transit services (public) for commuting trips. But the change of the parameter of bike shows that before the pandemic, users do not prefer the bike with respect to the foot, after the pandemic the attitude to use the bike is completely changed and they prefer to ride a bike than to go by foot. Similarly, increasing the family income, users prefer to use car more than other modes, however there is an inclination to go by foot (negative values of parameters after pandemic).

Table 1. Calibrated parameters for the pre-lockdown scenario

	β_{dist}	β_{inc}	β_{ts}	β_{hh}	β_{fm}	β_{asc}
car	0.354	0.103	−0.042	−0.030	0.098	0.785
bike	−0.283	0.642	−0.115	−0.284	0.786	−0.287
public	0.410	0.046	−0.066	0.108	−0.711	−1.227
motorcycle	0.212	0.046	−0.122	0.231	−0.164	−1.145
ρ^2	**0.48**					

Table 2. Calibrated parameters for the post-lockdown scenario

	β_{dist}	β_{inc}	β_{ts}	β_{hh}	β_{male}	β_{asc}
car	0.351	−0.260	0.258	0.823	0.911	−0.031
bike	0.089	−1.578	−0.424	0.700	3.639	0.284
public	0.707	−0.450	−0.481	0.748	0.042	−0.075
ρ^2	**0.43**					

4.2 Data Analysis: Shopping Mobility

The pandemic caused some changes in purchase habits: 36% of respondents have increased the amount of goods purchased on each trip, 10% have switched to online purchases, and 9% have changed the type of store. A 3% of the sample stated that they have increased the frequency of purchases (Fig. 16).

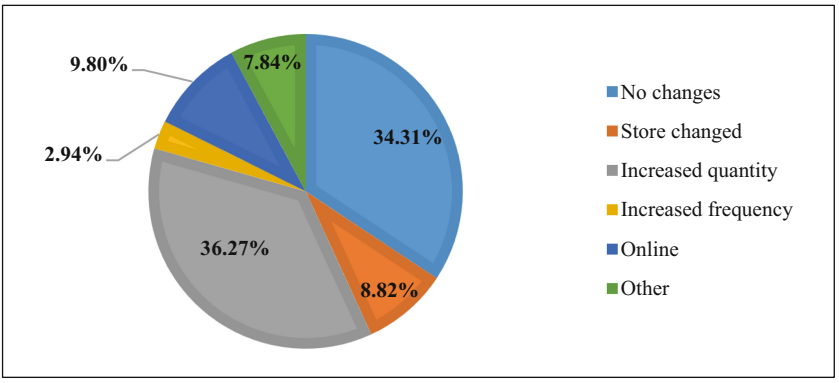

Fig. 16. Changes in users' habits

Another aspect that emerged in the survey is a change in the purchase frequency that, in general, decreases (excluding the fresh products) in the post-lockdown period (Fig. 17). In relation to expenses, a decrease of 7.93% which was seen considering

products as a whole, but when analyzing the single category of products, only the decrease in expenses for the purchase of foodstuffs (not fresh) should be observed (Table 3).

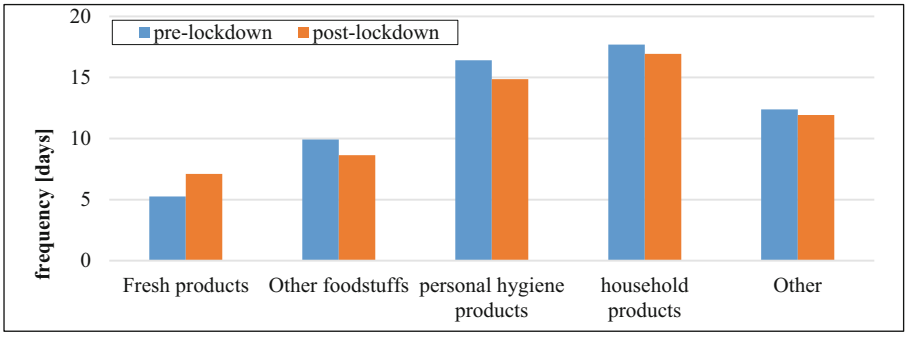

Fig. 17. Refresh frequency

Table 3. Comparing expenses pre and post the lockdown (reference: week)

	Pre-lockdown		Post-lockdown		Δ (on average)
Product	*Average [€]*	*Standard deviation [€]*	*Average [€]*	*Standard deviation [€]*	
Fresh	33.68	38.64	39.28	46.26	16.62%
Other foodstuffs	40.99	34.79	38.93	30.49	−5.02%
Personal hygiene	18.90	10.35	19.82	14.05	4.85%
Household	18.40	10.54	21.29	14.98	15.70%
Other	24.37	18.55	24.48	18.95	0.48%
All products	120.83	74.11	111.25	72.54	−7.93%

From the analysis of the days chosen for shopping (Fig. 18), it does not appear a very revolution between after and before the lockdown. Sunday continues to be the least used day for shopping; the other days are chosen (on average) in 15% of cases. On Saturdays there is a peak in the number of users who go shopping, less evident in the post-lockdown. Furthermore, in relation to the time interval and the transport mode chosen for shopping (Figs. 19 and 20), there do not appear to be any major changes. There are some small differences, but the trend remains the same.

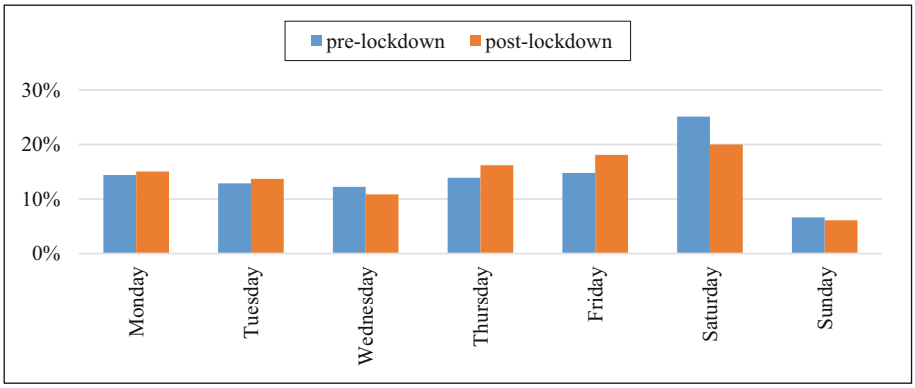

Fig. 18. Distribution of purchases by day.

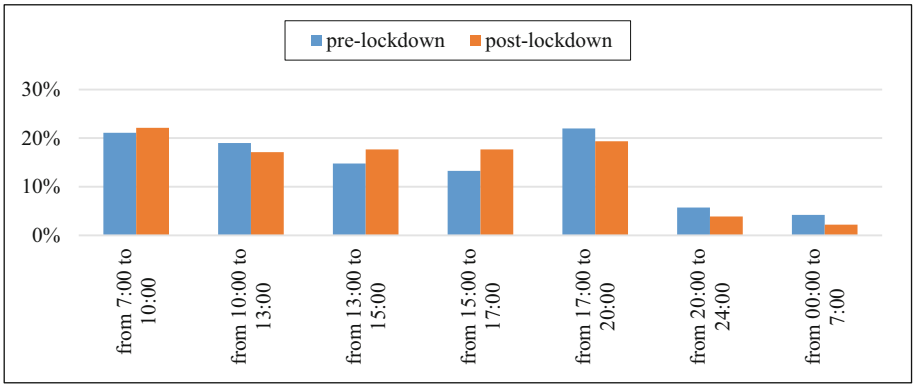

Fig. 19. Distribution of purchases by time slice.

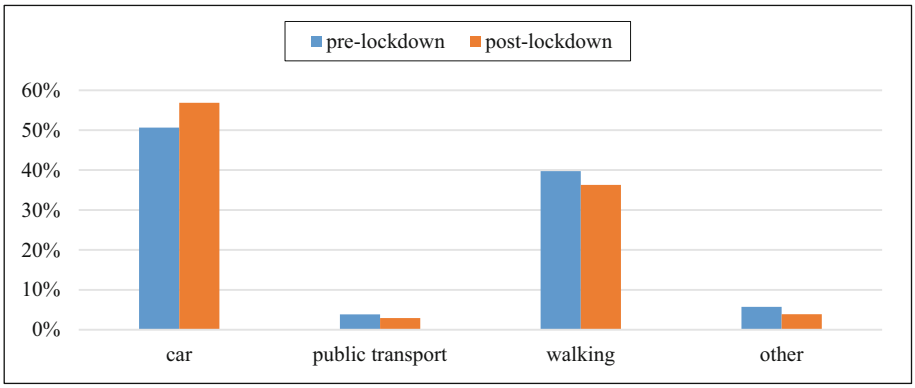

Fig. 20. Distribution of purchases by transport mode.

5 Conclusion

The rise of COVID-19 infection impacted all aspects of human life, and among these, the habits in travels. The data analyzed in this paper explored mode choice and shopping mobility, comparing habits before and after the lockdown in Italy. The respondents to the survey confirmed relevant changes in mode choice, in particular, the decline of modes in which it is made together with others. Thus, there was not only a collapse of public transport, but also, for example, of car sharing. Public transport has collapsed between 10 and 20%, depending on non-systematic or systematic trips. Similarly, the car as a passenger suffered a decrease of 3 and 8% .

From the analysis of the collected responses on mobility for shopping, there is no marked difference between behaviors before and after lockdown. There are slight changes in the distribution of purchases during the week, but the trend remains the same.

These results could be the starting point for defining policies to try to change users' choices in terms of transport mode for both systematic travels and travels for shopping, towards more sustainable means of transport ([42, 43]. This, for example, could reduce impacts due to the interaction between user journeys and those of commercial vehicles ([44, 45]). Future developments involve a further survey to understand whether habits acquired after lockdown have been maintained even in the decline phase of the COVID-19 disease.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

References

1. Balbontin, C., et al.: Impact of COVID-19 on the number of days working from home and commuting travel: a cross-cultural comparison between Australia, South America and South Africa. J. Transp. Geogr. **96**, 103188 (2021). https://doi.org/10.1016/j.jtrangeo.2021.103188
2. Music, J., Charlebois, S., Toole, V., Large, C.: Telecommuting and food E-commerce: Socially sustainable practices during the COVID-19 pandemic in Canada. Transp. Res. Interdisc. Perspect. **13**, 100513 (2022). https://doi.org/10.1016/j.trip.2021.100513
3. De Vos, J.: The effect of COVID-19 and subsequent social distancing on travel behavior. Transp. Res. Interdisc. Perspect. **5**, 100121 (2020). https://doi.org/10.1016/j.trip.2020.100121
4. Eisenmann, C., Nobis, C., Kolarova, V., Lenz, B., Winkler, C.: Transport mode use during the COVID-19 lockdown period in Germany: the car became more important, public transport lost ground. Transp. Policy **103**, 60–67 (2021). https://doi.org/10.1016/j.tranpol.2021.01.012
5. Das, S., Boruah, A., Banerjee, A., Raoniar, R., Nama, S., Maurya, A.K.: Impact of COVID-19: a radical modal shift from public to private transport mode. Transp. Policy **109**, 1–11 (2021). https://doi.org/10.1016/j.tranpol.2021.05.005
6. Cirianni, F.M.M., Comi, A., Luongo, A.S.: A sustainable approach for planning of urban pedestrian routes and footpaths in a pandemic scenario. TeMA – J. Land Use. Mobility Environ., 125–140 (2022). https://doi.org/10.6093/1970-9870/8629
7. Di Gangi, M., Comi, A., Polimeni, A., Belcore, O.M.: E-bike use in urban commuting: empirical evidence from the home-work plan. AoT. **62**, 91–104 (2022). https://doi.org/10.5604/01.3001.0015.9568

8. Choi, S.E., Kim, J., Seo, D.: Travel patterns of free-floating e-bike-sharing users before and during COVID-19 pandemic. Cities **132**, 104065 (2023). https://doi.org/10.1016/j.cities.2022.104065
9. Chen, Y., Sun, X., Deveci, M., Coffman, D.: The impact of the COVID-19 pandemic on the behaviour of bike sharing users. Sustain. Cities Soc. **84**, 104003 (2022). https://doi.org/10.1016/j.scs.2022.104003
10. Shang, W.-L., Chen, J., Bi, H., Sui, Y., Chen, Y., Yu, H.: Impacts of COVID-19 pandemic on user behaviors and environmental benefits of bike sharing: a big-data analysis. Appl. Energy **285**, 116429 (2021). https://doi.org/10.1016/j.apenergy.2020.116429
11. García-Salirrosas, E.E., Acevedo-Duque, Á., Marin Chaves, V., Mejía Henao, P.A., Olaya Molano, J.C.: Purchase intention and satisfaction of online shop users in developing countries during the COVID-19 Pandemic. Sustainability **14**, 6302 (2022). https://doi.org/10.3390/su14106302
12. Roy, P., Datta, D.D.: Impact of COVID-19 on consumer buying behavior towards online and offline shopping (2022). https://papers.ssrn.com/abstract=4144203
13. Kunytska, O., Comi, A., Danchuk, V., Vakulenko, K., Yanishevskyi, S.: Optimizing last mile delivering through the analysis of shoppers' behaviour. In: Sierpiński, G., Macioszek, E. (eds.) Decision Support Methods in Modern Transportation Systems and Networks, pp. 129–147. Springer International Publishing, Cham (2021). https://doi.org/10.1007/978-3-030-71771-1_9
14. Almlöf, E., Rubensson, I., Cebecauer, M., Jenelius, E.: Who continued travelling by public transport during COVID-19? Socioeconomic factors explaining travel behaviour in Stockholm 2020 based on smart card data. Eur. Transp. Res. Rev. **13**, 31 (2021). https://doi.org/10.1186/s12544-021-00488-0
15. Abdullah, M., Dias, C., Muley, D., Shahin, M.: Exploring the impacts of COVID-19 on travel behavior and mode preferences. Transp. Res. Interdisc. Perspect. **8**, 100255 (2020). https://doi.org/10.1016/j.trip.2020.100255
16. Parker, M.E.G., et al.: Public transit use in the United States in the era of COVID-19: Transit riders' travel behavior in the COVID-19 impact and recovery period. Transp. Policy **111**, 53–62 (2021). https://doi.org/10.1016/j.tranpol.2021.07.005
17. Shelat, S., Cats, O., van Cranenburgh, S.: Traveller behaviour in public transport in the early stages of the COVID-19 pandemic in the Netherlands. Transp. Res. Part A: Policy Pract. **159**, 357–371 (2022). https://doi.org/10.1016/j.tra.2022.03.027
18. Wielechowski, M., Czech, K., Grzęda, Ł: Decline in mobility: public transport in Poland in the time of the COVID-19 pandemic. Economies. **8**, 78 (2020). https://doi.org/10.3390/economies8040078
19. Przybylowski, A., Stelmak, S., Suchanek, M.: Mobility behaviour in view of the impact of the COVID-19 pandemic—public transport users in gdansk case study. Sustainability. **13**, 364 (2021). https://doi.org/10.3390/su13010364
20. Aydin, N., Kuşakcı, A.O., Deveci, M.: The impacts of COVID-19 on travel behavior and initial perception of public transport measures in Istanbul. Decis. Anal. J. **2**, 100029 (2022). https://doi.org/10.1016/j.dajour.2022.100029
21. Tiikkaja, H., Viri, R.: The effects of COVID-19 epidemic on public transport ridership and frequencies: a case study from Tampere, Finland. Transp. Res. Interdisc. Perspect. **10**, 100348 (2021). https://doi.org/10.1016/j.trip.2021.100348
22. Mashrur, Sk.Md., Wang, K., Habib, K.N.: Will COVID-19 be the end for the public transit? Investigating the impacts of public health crisis on transit mode choice. Transp. Res. Part A: Policy Pract. **164**, 352–378 (2022). https://doi.org/10.1016/j.tra.2022.08.020
23. Bustamante, X., Federo, R., Fernández-i-Marin, X.: Riding the wave: predicting the use of the bike-sharing system in Barcelona before and during COVID-19. Sustain. Cities Soc. **83**, 103929 (2022). https://doi.org/10.1016/j.scs.2022.103929

24. Heydari, S., Konstantinoudis, G., Behsoodi, A.W.: Effect of the COVID-19 pandemic on bike-sharing demand and hire time: evidence from Santander Cycles in London. PLoS ONE **16**, e0260969 (2021). https://doi.org/10.1371/journal.pone.0260969
25. Hu, S., Xiong, C., Liu, Z., Zhang, L.: Examining spatiotemporal changing patterns of bike-sharing usage during COVID-19 pandemic. J. Transp. Geogr. **91**, 102997 (2021). https://doi.org/10.1016/j.jtrangeo.2021.102997
26. Nikiforiadis, A., Ayfantopoulou, G., Stamelou, A.: Assessing the impact of COVID-19 on bike-sharing usage: the case of Thessaloniki. Greece Sustain. **12**, 8215 (2020). https://doi.org/10.3390/su12198215
27. Teixeira, J.F., Silva, C., Moura e Sá, F.: The motivations for using bike sharing during the COVID-19 pandemic: insights from Lisbon. Transp. Res. Part F: Traffic Psychol. Behav. **82**, 378–399 (2021). https://doi.org/10.1016/j.trf.2021.09.016
28. Kubaľák, S., Kalašová, A., Hájnik, A.: The bike-sharing system in Slovakia and the Impact of COVID-19 on this shared mobility service in a selected city. Sustainability. **13**, 6544 (2021). https://doi.org/10.3390/su13126544
29. Arias-Molinares, D., García-Palomares, J.C., Gutiérrez, J.: Micromobility services before and after a global pandemic: impact on spatio-temporal travel patterns. Int. J. Sustain. Transp. **17**, 1058–1073 (2023). https://doi.org/10.1080/15568318.2022.2147282
30. Azimi, M., Wali, M.M., Qi, Y.: Studying the Impact of the COVID-19 pandemic on bikeshares as a mode of shared micromobility in major cities: a case study of Houston. Future Transp. **4**, 270–282 (2024). https://doi.org/10.3390/futuretransp4010014
31. Basak, E., Balawi, R.A., Fatemi, S., Tafti, A.: When crisis hits: bike-sharing platforms amid the COVID-19 pandemic. PLoS ONE **18**, e0283603 (2023). https://doi.org/10.1371/journal.pone.0283603
32. Javadinasr, M., et al.: The Long-Term effects of COVID-19 on travel behavior in the United States: a panel study on work from home, mode choice, online shopping, and air travel. Transport. Res. F: Traffic Psychol. Behav. **90**, 466–484 (2022). https://doi.org/10.1016/j.trf.2022.09.019
33. Koster, H.R.A., van Ommeren, J., Tang, C.K., Bras, N.: COVID-19 restriction policies and shopping streets. PLoS ONE **17**, e0267160 (2022). https://doi.org/10.1371/journal.pone.0267160
34. Villa, R., Monzón, A.: Mobility restrictions and E-Commerce: holistic balance in Madrid Centre during COVID-19 lockdown. Economies **9**, 57 (2021). https://doi.org/10.3390/economies9020057
35. Ben Hassen, T., El Bilali, H., Allahyari, M.S.: Food shopping during the COVID-19 pandemic: an exploratory study in four Near Eastern countries. J. Islamic Market. Ahead-of-print (2022). https://doi.org/10.1108/JIMA-12-2021-0404
36. Xu, L., Saphores, J.-D.: Grocery shopping in California and COVID-19: transportation, environmental justice, and policy implications. Transp. Res. Part D: Transport Environ. **113**, 103537 (2022). https://doi.org/10.1016/j.trd.2022.103537
37. Bian, R., Murray-Tuite, P., Wolshon, B.: Predicting grocery store visits during the early outbreak of COVID-19 with machine learning. Transp. Res. Rec. **2677**, 79–91 (2023). https://doi.org/10.1177/03611981211043538
38. Recchia, D., et al.: Changes in food purchasing practices of French households during the first COVID-19 lockdown and associated individual and environmental factors. Front. Nutr. **9** (2022)
39. Titiloye, I., Sarker, M.A.A., Jin, X., Watts, B.: Examining channel choice preferences for grocery shopping during the Covid-19 pandemic. Int. J. Transp. Sci. Technol. (2023). https://doi.org/10.1016/j.ijtst.2023.03.006

40. Zhang, F., Ji, Y., Lv, H., Ma, X., Kuai, C., Li, W.: Investigating factors influencing takeout shopping demand under COVID-19: Generalized additive mixed models. Transp. Res. Part D: Transport Environ. **107**, 103285 (2022). https://doi.org/10.1016/j.trd.2022.103285
41. German, J.D., et al.: Choosing a package carrier during COVID-19 pandemic: an integration of pro-environmental planned behavior (PEPB) theory and service quality (SERVQUAL). J. Clean. Prod. **346**, 131123 (2022). https://doi.org/10.1016/j.jclepro.2022.131123
42. Nigro, M., Comi, A., De Vincentis, R., Castiglione, M.: A mixed behavioural and data-driven method for assessing the shift potential to electric micromobility: evidence from Rome. Front. Future Transp. **5**, 1391100 (2024). https://doi.org/10.3389/ffutr.2024.1391100
43. Comi, A., Polimeni, A.: Assessing potential sustainability benefits of micromobility: a new data driven approach. Eur. Transp. Res. Rev. **16**, 19 (2024). https://doi.org/10.1186/s12544-024-00640-6
44. Musolino, G., Rindone, C.: Freight distribution in urban area: estimating the impact of commercial vehicles on traffic congestion. In: Gervasi, O., et al. (eds.) Computational Science and Its Applications – ICCSA 2023 Workshops, pp. 323–334. Springer Nature Switzerland, Cham (2023). https://doi.org/10.1007/978-3-031-37111-0_23
45. Russo, F., Musolino, G., Trecozzi, M.R.: A system of models for the assessment of an urban distribution center in a city logistic plan. Presented at the URBAN TRANSPORT 2013, Kos, Greece May 29 (2013). https://doi.org/10.2495/UT130641