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Travel behaviour changes under Work-from-home (WFH) arrangements during COVID-19

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\textbf{ABSTRACT}

Life, including working style and travel behaviour, has been severely disrupted by the COVID-19 pandemic. The unprecedented number of work-from-home (WFH) employees after the outbreak of COVID-19 has attracted much scholarly attention. As it is generally believed that WFH arrangements are not ephemeral, it is imperative to study the impacts of WFH on travel behaviour and its impact on sustainable transport in the post-pandemic era. In relation, this study uses a set of longitudinal GPS tracking data in Switzerland to examine changes in trip characteristics (i.e. travel distance, travel time), travel behaviours (i.e. travel frequency, peak hour departure, trip destination, travel mode), and activities (i.e. trip pattern diversity, trip purpose, and time spent at home). Two groups of participants (WFH and Non-WFH) are identified and compared through three periods (pre-COVID, during lockdown, and post lockdown) from September 2019 to October 2020. Results show that more significant reductions of trip distance, travel time, travel frequency, morning peak hours trips, trips to the CBD are observed among the WFH group. These changes helped to mitigate negative transport externalities. Meanwhile, active transport trips, trip pattern diversity, leisure trips, and time spent at home also increased more significantly for the WFH group when compared to their counterparts. Hence, promoting WFH may not only be beneficial to teleworkers but also to the wider community through more sustainable transport. Future research direction and policy implications are also discussed.

1. Introduction

The outbreak of the COVID-19 pandemic has facilitated the work-from-home (WFH) working style globally. The number of teleworkers has soared to an unprecedented level amid the pandemic. By the end of 2020, with the development of vaccines, many countries have tried to resume “normal”, and employees have started to work in the traditional style (e.g. spatio-temporally concentrated). It is, however, believed that WFH is not “a flash in the pan” (Kaushik & Guleria, 2020; Seethalakshmi & Shyamala, 2021). For instance, Facebook has allowed employees to permanently work from home after the pandemic (Nanji, 2021), and many companies are prepared for the hybrid-mode in the future. Since the last century, WFH has aroused great controversy among scholars from the management (Baker, Avery, & Crawford, 2007; Daniels, Lamond, & Standen, 2001), well-being (DuBrin, 1991; Shamir & Salomon, 1985), and transport (Hamer, Kros, & van Ooststroom, 1992; Pendyala, Goulia, & Kitamura, 1991; Shen, Ta, & Chai, 2020) perspectives. Over the years, much focus was put on changes in travel behaviour, as it is related to sustainable development issues such as urban traffic congestion, energy consumption, and jobs-housing balance (Loo & Wang, 2018; Mokhtarian, 1991b). Existing literature generally concurs that promoting WFH can have sustainability benefits by relieving commuting congestion and reducing VMT, though the impacts of ICT on travel behaviour are still ambiguous. Yet, a holistic framework to evaluate changes in travel behaviour under WFH arrangements is still missing. Furthermore, given the low adoption rate of WFH, limited empirical data have been an obstacle for empirical research.

This study aims to reveal changes in travel behaviour under WFH...
arrangements during the COVID-19 pandemic based on a set of GPS tracking data in Switzerland. Longitudinally, travels for all participants in three phrases (i.e. pre-COVID, during lockdown, and post lockdown) that lasted for more than one year were recorded. Laterally, two groups of participants, WFH and Non-WFH (NWFH), were identified throughout the analysis. This study also developed a holistic framework to depict changes in travel behaviour from nine transport perspectives, including trip distance, travel time, trip frequency, departure time, travel mode, trip destination, trip pattern diversity, trip purpose, and time spent at home. The paper is structured as follows: Section 2 elucidates the research background and hypotheses. Data and methodology are explained in section 3. Section 4 reports the results and discusses the findings, and section 5 concludes the study.

2. Research background and hypotheses

WFH (as known as teleworking, telecommuting, and e-working)¹ is not an innovative working style after the outbreak of the pandemic. It was initially proposed to cope with the Oil Crisis (Loo, 2012; Torten, Reaiche, & Caraballo, 2016), and improve air quality by reducing commuting trips since the last century (Kittamura, Mokhtarian, & Pendyala, 1991; Mokhtarian, 1991b). A keyword search on the Web of Science shows that WFH-related articles first appeared in 1972 and have only slightly increased over the decades.

Nonetheless, with the widespread adoption of WFH during COVID-19, the number of articles has surged by 223 % in a year (from 168 in 2019 to 543 in 2020). In other words, WFH has intrigued much scholarly attention, inter alia, after the outbreak of the COVID-19 pandemic. To investigate the impacts of WFH on travel behaviours, one needs to focus on teleworkers (Mokhtarian & Salomon, 1994). Generally, the literature suggests that there are four major contributing factors affecting the adoption of WFH, namely organisational, job, individual, and household characteristics (Baker et al., 2007; Peters, Tijdens, & Wetzels, 2004). Specifically, organisational characteristics mainly refer to the management culture, trust of employees, and human resource support, etc. (Harrington & Ruppel, 1999). These characteristics, however, might have a trivial impact on the adoption of WFH during the outbreak of COVID-19 (Ton et al., 2022). Besides, the nature of the job could restrain employees from teleworking. Jobs such as food service, chauffeur, and in-store retail are not suitable for working from home (Baruch & Nicholson, 1997; Loo & Huang, 2022). Empirical studies have found that individual and household characteristics could influence the attitudes towards the adoption of WFH. Mokhtarian and Salomon (1994), for instance, pointed out that employees with a higher need for personal interaction are more likely to work on-site. Mokhtarian, Bagley, and Salomon (1998) and Iscan and Naktyio (2005) found that women prefer WFH because they see telecommuting as a promising solution to ease domestic responsibility. Regarding household characteristics, it is observed that married employees, especially mothers, are more likely to opt to work remotely (Iscan & Naktyio, 2005). Grounded upon the aforementioned literature, teleworkability depends upon organisational and job characteristics; and individual and household characteristics determine the attitude towards telecommuting. A combination of these four characteristics would affect the final adoption of WFH, as shown on the left side in Fig. 1.

Scholars and policymakers generally believed that spatially, traffic congestion in the CBD could be ameliorated by implementing WFH arrangements (Loo & Wang, 2018); temporally, traffic during commuting peaks (i.e. morning and evening peak hours) could be relieved as well (Lachapelle, Tanguay, & Neumark-Gaudet, 2018; White et al., 2010). Meanwhile, negative environmental externalities of traffic congestion, such as carbon emissions, air pollution, and fuel consumption, are expected to be mitigated under WFH arrangements (Bernardino, Ben-Akiva, & Salomon, 1993; Giovanis, 2018; Nilles, 1988). Besides, the well-being of teleworkers, e.g. leisure activities and time spent at home, is anticipated to improve under WFH arrangements (Asgari, Jin, & Du, 2016; Büsingen, 2002). A sizeable literature has attempted to investigate these conjectures using various methods. Questionnaire survey (including self-reported diary) is the dominant methodology among empirical studies. For instance, Mokhtarian (1991a) conducted a questionnaire survey and reported insightful findings of 13 telecommuters in San Diego, US. Using self-reported diaries, Hamer, Kroes, and Van Ooststroom (1991) also depicted changes in travel behaviour (e.g. number of trips, departure time, travel modes) among 30 participants in the Netherlands. Though the sample size was relatively small, these studies have shed light on changes in travel behaviour under WFH arrangements at an earlier stage. With a more comprehensive dataset, travel characteristics survey data were employed in more recent studies. Hu and He (2016) utilised the 2008 household travel survey data of the Chicago metropolitan area to assess the relationships between telecommuting and household travel. Based on the National Travel Survey in England, Budnitz, Transo, and Chapman (2020) investigated the non-work trip patterns among telecommuters. In Sweden, Eldler (2020) made use of the National Travel Survey data to examine the impacts of WFH on teleworkers. Other WFH-related empirical studies were reviewed by Andrew, Salomon, and Plikin (2010) and Eldler (2020). Adopting large-scale datasets, scholars have enriched the understanding of the relationships between WFH and travel behaviours. Notwithstanding, given the drawbacks of the questionnaire survey (e.g. wrong or missing responses) (Inbakaran & Kroen, 2011), changes in trip characteristics and travel behaviour may not be extensively captured. In the era of big data, GPS tracking has become feasible in recording daily activities and travels (Millward, Hafezi, & Daisy, 2019; Molloy et al., 2021; Plazier, Weitkamp, & van den Berg, 2017). GPS tracking has, however, not been widely employed in WFH and travel studies (Kalter, Geurs, & Wismans, 2021). Furthermore, a holistic framework to decipher changes in travel behaviour is still missing. To address these research lacunae, we aim to use a set of GPS tracking data and questionnaire surveys to complement the existing WFH and travel studies through three major perspectives, namely, trip characteristics, travel behaviour, and activities. Several specific research hypotheses are raised under each perspective.

With respect to the literature about the relationships of WFH, travel behaviour and impacts on negative transport externalities, a conceptual framework, as shown in Fig. 1, is developed. In relation to the trip characteristics, we hypothesise that under WFH arrangements, trip distance is shorter in the WFH group (RH1), and WFH participants spend less time in travel (RH2). With respect to travel behaviour, we conjecture that the WFH participants make fewer trips (RH3), and have fewer trips made during peak hours (RH4) and to high-job-density areas (RH5). Also, more active transport trips (that is, walking and cycling) happen in the WFH group, when compared to the NWFH group (RH6). Regarding activities, we believe that trip purposes are more diverse among the WFH group (RH7). In the WFH group, the share of leisure trip increases (RH8), and WFH participants stay longer at home (RH9). As illustrated in Fig. 1, all these changes can lead to mitigation of the negative externalities of transportation. Under this framework, the impacts of WFH on travel behaviour and transport sustainability can be understood more holistically.

3. Data and methodology

A set of GPS tracking data is used in this study. Participants were recruited to participate in a survey, namely Mobility Behaviour in Switzerland (MOBIS), in September 2019. They were required to install an APP on their mobile phones to track the location and record activities (details of the survey can be found in Axhausen et al. (2021)). After the outbreak of the COVID-19 pandemic in Switzerland, participants were

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¹ In this study, we regard that all these terminologies share an analogous interpolation.
invited to continue the tracking survey. During the study period, three online questionnaire surveys were conducted in April, July and November 2020. Three questions (i.e. employment status, options of WFH, days of WFH per week) in the questionnaire were used to define the WFH group and Non-WFH (NWFH) group participants in this study. Only participants with full-time employment during the entire study period were selected for further analysis. Participants who can opt for WFH under COVID-19 and have practised it for more than three days a week are considered as the WFH group. It is worthwhile to mention that the WFH status does not differentiate between the lockdown and post-lockdown periods. The remaining participants (no option of WFH or less than three days WFH per week) belong to the NWFH group. In order to observe changes in behaviour over time, only participants who participated in all three waves were included for this analysis. In the end, there are 252 participants, among which 100 were in the WFH group, and 152 were in the NWFH group. Fig. 2 summarizes the data processing procedures.

It is worth mentioning that this study aims to study differences of travel behaviour by the WFH and NWFH groups. Detailed trip data were collected directly from GPS devices. The GPS tracking data have two main tables (i.e. trip stages table and activities table) about trip and activity information. The data were cleaned and updated in May 2021. In the dataset, a trip is composed of trip stage(s), which means that each trip consists of at least one trip stage. The trip-stage table provides the start time, end time, mode, and geographical coordinates (origin, midpoint, and destination) of each trip stage. Each trip stage also has an independent ID and shares the trip ID with other trip stages in one single trip. In relation to the trip purpose, it is obtained by linking the trip purpose table and trip-stage table via the trip ID. The trip purposes are recorded according to participants’ validation and imputation. Details of purpose imputation can be found in Gao et al. (2021). The combined trip dataset records the participant ID, start time, end time, duration, purpose, and geographical coordinates of each activity. To conduct the longitudinal analysis, three periods (i.e. pre-COVID, during lockdown, and post-lockdown) are used, and only weekdays are taken into account. Periods are defined and labelled based on the local COVID-19 cases and restriction policies. The pre-COVID period starts from 2 September 2019 to the day before the first confirmed COVID cases in Switzerland (25 February 2020) (Swissinfo, 2020). The during lockdown period corresponds to stringent measures imposed by the Federal Council (Federal Office of Public Health, 2020) from 16 March to 24 April 2020. After the third phase of easing measures (from 8 June 2020), the majority of facilities have resumed normal (The Federal Council, 2020), and we regarded this period (till to 18 October 2020) as the post lockdown period. Overall, there are 162,692 trips consisting of 238,807 trip stages; and details of each participant group and period are summarised in Table 1.

In order to investigate the research hypotheses above, various approaches are adopted. Regarding RH1 (distance) and RH2 (travel time), the travel time and travel distance of each trip are the sums of all trip stages of the trip. For RH2 (travel time), the travel time of each participant per day was summed up first, and then the average travel time in each group was calculated. Travel frequency (RH3) is obtained based on the number of trips per day per participant. Regarding the trip departure time (RH4), only the departure time of the first trip stage in the trip is considered. Different from RH4, the trip destination of each trip is identified by the last trip stage of the trip (RH5). To answer RH5 (destination), employment data from Federal Statistical Office (2021) in 2018 are also collected. The employment data (i.e. the number of full-time employees) are first geo-located. Utilising the territory map

![Conceptual Framework](image-url)
and by means of spatial joins, the employment density of each administrative unit is derived. Then, the average employment density of destinations is used to examine the trip destination relocation. Extra steps were taken for testing RH6 (mode). If a trip consists of at least one mechanised trip stage (e.g., in car mode), the walk trip stage(s) in this trip would not be taken into account. With respect to RH7 (pattern diversity), trip destinations’ spatial coordinates, departure times and arrival times were listed in sequence for each participant on each survey day. For each participant, except on the first survey day, the departure time of the trip is grouped into seven categories, namely, night (00:00 to 06:59), morning peak (07:00 to 08:59), inter-peak I (09:00 to 11:59), inter-peak II (12:00 to 15:59), evening peak (16:00 to 17:59), evening (18:00 to 20:59), and late evening (21:00 to 23:59). And finally, we calculate the average similarity rates for the above three variables over each period.

As each trip has only one trip purpose, by linking the trip purpose table to the trip stage table, RH8 (leisure trips) can be tested on the basis of each trip. Yet, it is noted that 7% of the total number of trips was unknown, and these records were excluded from the analysis of RH8. The activity table is used to analyse RH9 (time at home). Duration of two types of activities, home and home office, were added up for each participant in each day to capture the time spent at home.

### 4. Results and discussion

After the data processing, there are 252 participants. 100 (40%) are regarded as the WFH group, and others (60%) are NWFH participants. According to the Federal Statistical Office (2020), before the outbreak of the COVID-19 pandemic, the proportion of teleworkers was about 25% in 2019, among which, only 3% were regular teleworkers (i.e., WFH for more than 50% of the working time). The number doubled during the

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first lockdown period (swissinfo.ch, 2020). It is estimated that there are still 34 % of employees who would like to work remotely during the post-lock period (Deloitte, n.a.). Sample characteristics in this study are generally consistent with these statistics. Furthermore, we have tested all hypotheses by including only participants who switched to WFH during the lockdown period, and the results are consistent.

Table 2 presents the socio-demographic information of participants for both groups. Notwithstanding that the average age in both groups is similar (47-year-old), only 2 % of WFH participants were below 26-year-old, which is 7 % less than NWFH participants. In connection to gender, the number of male WFH participants is three times the number of female WFH participants, while the ratio of male to female participants in the NWFH group is about 1.78. Generally, the WFH group is dominated by higher education participants (68 %). As for the NWFH group, the shares of secondary and higher education participants are quite close (49 % and 45 %, respectively). In a similar vein, WFH participants tend to have higher income compared with the NWFH group. Regarding the household size, patterns in both groups are alike. In general, employees who are allowed and chose to work from home during the pandemic were predominantly male, with higher education and higher income.

4.1. Trip characteristics

Changes in trip distance and travel time under WFH arrangements are of great interest to scholars. Table 3 presents the average trip distance in different phases of the study period. Before the COVID-19 pandemic, the average trip distance of WFH participants was 4.4 km longer than that of NWFH participants. During lockdown, a significant decrease in the average trip distance was found in both groups. Nevertheless, the percentage of decline in the WFH group (-37 %) was 25 % greater than the NWFH group (-12 %). As a result, the average trip distance of both groups became similar at about 10 km. In the post lockdown period, the average trip distances have slightly risen to 12.14 and 11.33 km in WFH and NWFH groups, respectively. Compared with the pre-COVID era, NWFH participants did not show a significant reduction in the average trip distance, while a significant reduction of 24 % was still found in the WFH group.

The results support RH1 (distance) that the average trip distance is shorter for the WFH group under WFH arrangements compared with the NWFH group. It is inferred that WFH participants tended to travel closer around their home locations under WFH arrangements (Pendyala et al., 1991). Moreover, employees with longer commuting distance are more willing to choose WFH (Mokhtarian & Salomon, 1996). Results in the post lockdown era show that WFH arrangements may diminish the average trip distance in the post-COVID period.

In relation to RH2 (travel time), the observed patterns about travel time are similar. Table 4 shows that WFH participants experienced a slightly longer travel time per day compared to NWFH participants before the pandemic. During lockdown, dramatic decreases up to 45 % and 31 % were observed in WFH and NWFH groups, respectively. After the stringent measures were eased, NWFH participants’ average travel time has rebounded, while a significant reduction of 7 % was still detected in the WFH group. Conceivably, the reduction of travel time is related to the shorter average distance. In addition, the alleviated traffic congestion may also have contributed to the shorter travel time (Molloy et al., 2021).

4.2. Travel behaviour

Consistent with RH3 (frequency), the average number of trips per day in the WFH group has been slightly lower than its counterpart (as shown in Table 5). Throughout the entire study period, reductions of up to 38 % and 29 % of trip frequency were detected in the WFH and NWFH groups, respectively. Different from the average trip distance and travel time, significant but trivial reductions of trip frequency were observed in the post lockdown period. Results during the lockdown period (i.e., trip rates are reduced under WFH arrangements) are in line with some of the existing empirical studies (Eldèr, 2020; O’keefe, Caulfield, Brazil, & White, 2016). This could be affected by the lockdown policies since many facilities were closed. When it came to the post lockdown period, the reduction of travel frequency in the NWFH group was greater than that in the WFH group. We deduce that whilst the number of work-

**Table 3**

| Average Trip Distance over the Study Period. |
|---------------------------------------------|
| Pre-COVID | During Lockdown | Post Lockdown |
| WFH | NWFH | WFH | NWFH | WFH | NWFH |
| Average Trip Distance (km) | 15.9 | 11.5 | 10.0 | 10.2 | 12.1 | 11.3 |
| 15th percentile | 0.5 | 0.5 | 0.4 | 0.5 | 0.3 | 0.4 |
| 1st Quartile | 1.0 | 1.0 | 1.0 | 1.2 | 0.7 | 0.9 |
| Median | 4.4 | 4.7 | 3.6 | 4.7 | 3.1 | 4.6 |
| 3rd Quartile | 14.3 | 13.6 | 9.3 | 14.3 | 11.1 | 13.7 |
| 85th percentile | 26.5 | 20.5 | 15.8 | 19.7 | 19.7 | 20.2 |
| Variance | 1736.0 | 780.9 | 743.6 | 241.2 | 1012.0 | 586.5 |
| Difference compared with Pre-COVID | −37 % | −12 % | −24 % | −2 % |

Note: ***p < 0.001, **p < 0.01, *p < 0.05 in Table 3 to 9.

**Table 4**

| Average Travel Time per Day. |
|-------------------------------|
| Pre-COVID | During Lockdown | Post Lockdown |
| WFH | NWFH | WFH | NWFH | WFH | NWFH |
| Average Travel Time (min/ Day) | 112 | 107 | 62 | 74 | 104 | 106 |
| 15th percentile | 38 | 39 | 11 | 26 | 28 | 37 |
| 1st Quartile | 54 | 53 | 20 | 36 | 44 | 51 |
| Median | 87 | 83 | 45 | 58 | 82 | 82 |
| 3rd Quartile | 140 | 134 | 82 | 93 | 136 | 131 |
| 85th percentile | 186 | 173 | 112 | 120 | 180 | 170 |
| Variance | 8653.5 | 8860.5 | 3590.0 | 3728.3 | 9443.7 | 8294.3 |
| Difference compared with Pre-COVID | −45 % | −31 % | −7 % | −1 % |

| Household Size | 1 | 2 | 3 | 4 | 5 or more |
|----------------|---|---|---|---|---------|
| Pre-COVID | 15 | 16 | 17 | 20 | 7 |
| NWFH | 16 | 17 | 18 | 20 | 7 |

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related trips has decreased, other shorter trips might have been generated, especially for the WFH group (He & Hu, 2015; Mokhtarian, 1991a).

Flattening the commuting (i.e. morning and evening) peaks is one of the benefits of promoting WFH. By shifting trips from peak to non-peak hours, not only can the system capacity be released at peaks, but the spare capacity can be more fully utilised during non-peak hours, whereupon rendering the transport system sustainable. We analyse changes in the shares of morning and evening peak hour departures (i.e. number of trips during peak hours/total number of trips in the whole day) separately. As shown in Table 6, peak hour trips, including morning and evening, have accounted for 32.3 % and 30.2 % of all trips in the WFH and NWFH groups, respectively, before the pandemic. During lockdown, changes in the commuting pattern of the two groups varied, leading support to RH4 (departure time). Conceivably, fewer trips were generated among WFH participants under WFH arrangements. Only a trivial reduction (0.6 %) was observed in the NWFH group. Regarding the evening peak, it is surprising that the number of trips happening then was still less than the pre-COVID level, indicating that WFH arrangements have still been practised after the end of the lockdown period.

Shifting trips from peak to non-peak hours has been suggested by previous studies (Lachapelle et al., 2018; Sampath, Saxena, & Mokhtarian, 1991). Yet, differences between the morning and evening peaks were seldom discussed (Pendyala et al., 1991). Results in Table 6 suggest that WFH arrangements can be more effective in alleviating traffic congestion during the morning commuting peak. We conjecturally believe that as trip destinations during the evening peak are more dispersed and purposes are more diverse (e.g. leisure, shopping), evening peak has not been much affected by WFH arrangements.

Traditional job centres (e.g. CBD) are often afflicted by recurrent traffic jams. Under WFH arrangements, trips to high-job-density areas are anticipated to decrease. As shown in Table 7, WFH participants were more likely to visit job centres before the COVID-19 pandemic. During the lockdown, a drastic reduction of up to 50 % was observed in the WFH group, which was 14 % greater than NWFH participants. Hence, the results support RH5 (destination). In the post lockdown period, there was a slight increase in the average destination employment density in both groups, though the value was still lower than that of the pre-COVID period. Throughout the study period, the average employment density of destinations in the WFH group was always higher than in the NWFH group. This probably relates to the residential location. Generally, WFH participants tended to live in areas with higher average job densities than that of NWFH participants. The average employment density of homes of WFH participants is 27 % higher than that of NWFH participants (949 versus 748 jobs/per km2).

Population decentralisation and job concentration have led to job-housing imbalance in urban areas and deteriorating traffic conditions over the years (Loo & Chow, 2011). By prompting WFH arrangements, results proved that traditional job centres received fewer trips, and the CBD gridlock is expected to be mitigated as well. Compared with other policies, such as changing the urban form (Loo & Chow, 2008), advocating WFH would be more efficient in the short term.

Next, the focus is put on modal shift caused by WFH arrangements. Fig. 3 portrays the shares of different modes over different waves in the study period. One can observe that trips were dominated by cars in both groups. Especially during the lockdown period, the share of car trips has increased by 5 % and 6 % for the WFH and NWFH groups, respectively. Public transport-related travels, as well as train trips, dropped remarkably during the pandemic, especially for the WFH group. Though public transport ridership has recovered in the post lockdown period, it was still lower than the level before the outbreak of the pandemic. Among WFH participants, active transport (i.e. walking and bicycle) trips burgeoned from 31 % (pre-COVID) to 43 % (during lockdown), and the share has remained high at 38 % even after the lockdown policy was eased. All these support RH6 (mode). Notably, only a 3 % increment in active transport trips was found in the NWFH group during the lockdown.

During the COVID-19 pandemic, regarding the fear of being infected by the coronavirus and service reduction of public transport, the share of car trips was expected to increase. Amid the pandemic, it was reported that the share of active transport (i.e. walking and cycling) has soared (Kalter et al., 2021; Molloy et al., 2021). Our study supplemented this finding by unveiling that active transport trips increased more significantly among WFH participants. Meanwhile, results of this study are also in conformity with previous studies (Chakrabarti, 2018; Lachapelle et al., 2018; Mokhtarian, 1991a).

### Table 5

| Trip Frequency. | Pre-COVID | WFH | NWFH | During Lockdown | WFH | NWFH | Post Lockdown | WFH | NWFH |
|-----------------|-----------|-----|------|-----------------|-----|------|---------------|-----|------|
| Number of Trips per Day | 4.9 | 5.3 | 3.0 | 3.8 | 4.7 | 5.1 |
| 15th percentile | 2 | 2 | 1 | 2 | 2 | 2 |
| 1st Quartile | 2 | 3 | 2 | 3 | 3 | 3 |
| Median | 4 | 5 | 2 | 3 | 4 | 5 |
| 3rd Quartile | 6 | 7 | 4 | 5 | 6 | 6 |
| 85th percentile | 7 | 8 | 5 | 6 | 8 | 8 |
| Variance | 6.56 | 8.52 | 4.25 | 5.32 | 7.53 | 7.93 |
| Difference compared with Pre-COVID | *** | *** | *** | *** | *** | *** |

### Table 6

| Table 6 Percentage Shares of Morning and Evening Peak Hour Departures. | Pre-COVID | WFH | NWFH | During Lockdown | WFH | NWFH | Post Lockdown | WFH | NWFH |
|---------------------------------------------------------------|-----------|-----|------|-----------------|-----|------|---------------|-----|------|
| % of Departure Time (7 to 8 am) | 13.9 | 12.5 | 11.1 | 11.9 | 11.3 | 12.1 |
| % of Departure Time (4 to 5 pm) | 18.4 | 17.7 | 20.4 | 20.5 | 17.5 | 17.5 |
| Difference compared with Pre-COVID (7 to 8 am) (in percentage point) | –2.8 | –0.6 | –2.6 | –0.4 |
| Difference compared with Pre-COVID (4 to 5 pm) (in percentage point) | 2.0 | 2.8 | –0.9 | –0.1 |

### Table 7

| Average Employment Density of Trip Destinations. | Pre-COVID | WFH | NWFH | During Lockdown | WFH | NWFH | Post Lockdown | WFH | NWFH |
|-------------------------------------------------|-----------|-----|------|-----------------|-----|------|---------------|-----|------|
| Average Job density of destinations (thousand jobs/km2) | 4.9 | 3.28 | 2.43 | 2.09 | 3.45 | 2.79 |
| 15th percentile | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 1st Quartile | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Median | 1.0 | 0.7 | 0.5 | 0.6 | 0.6 | 0.6 |
| 3rd Quartile | 4.0 | 2.3 | 1.4 | 1.4 | 1.8 | 1.8 |
| 85th percentile | 8.3 | 5.1 | 2.7 | 3.7 | 5.1 | 4.8 |
| Variance | 89.2 | 51.0 | 39.5 | 25.0 | 61.4 | 46.6 |
| Difference compared with Pre-COVID | *** | *** | *** | *** | *** | *** |
4.3. Activities

Trip pattern diversity reflects the variability of travel behaviour. There are three indicators in this study to examine RH7 (pattern diversity) (as shown in Table 8). The percentage of same destinations as the last survey day has increased in both groups during the lockdown period. In other words, participants repeatedly visit at least half of the places they visited the day before. Temporally, the home departure and arriving time varied a lot from day to day, especially in the WFH group. Before the pandemic, the shares of same time leaving home were 53.5 % and 60.7 % for WFH and NWFH participants, respectively. Different from trip destinations, the percentages declined by 19.8 % and 10.6 % in the WFH and NWFH groups, respectively. The results support RH7 (pattern diversity). Similar patterns are observed in terms of the time arriving home among WFH participants. In the post lockdown period, trip destinations were more diverse compared with the pre-COVID

Table 8
Trip Pattern Diversity.

|                       | Pre-COVID WFH | NWFH | During Lockdown WFH | NWFH | Post Lockdown WFH | NWFH |
|------------------------|---------------|------|---------------------|------|-------------------|------|
| % of the same destinations as the last survey day | 42.7          | 45.6 | 49.0                | 49.3 | 36.5              | 43.1 |
| 15th percentile (%)    | 0.0           | 12.5 | 0.0                 | 0.0  | 0.0               | 0.0  |
| 1st Quartile (%)       | 20.0          | 25.0 | 20.0                | 25.0 | 9.1               | 20.0 |
| Median (%)             | 40.0          | 50.0 | 50.0                | 50.0 | 33.3              | 42.9 |
| 3rd Quartile (%)       | 66.7          | 66.7 | 75.0                | 75.0 | 50.0              | 66.7 |
| 85th percentile (%)    | 75.0          | 75.0 | 100.0               | 100.0| 66.7              | 75.0 |
| Variance               | 0.09          | 0.09 | 0.13                | 0.11 | 0.09              | 0.10 |
| Difference compared with Pre-COVID (in percentage point) | 6.3***        | 3.7***| -6.2***             | -2.5***|
| % of the same time leaving home as the last survey day | 53.5          | 60.3 | 33.7                | 49.7 | 36.0              | 53.5 |
| 15th percentile (%)    | 29.5          | 38.7 | 10.4                | 24.7 | 18.3              | 31.1 |
| 1st Quartile (%)       | 39.0          | 44.6 | 19.7                | 31.8 | 25.8              | 40.9 |
| Median (%)             | 53.6          | 57.6 | 31.4                | 47.7 | 33.0              | 53.2 |
| 3rd Quartile (%)       | 68.8          | 77.6 | 43.9                | 66.7 | 44.1              | 67.9 |
| 85th percentile (%)    | 78.4          | 82.4 | 55.5                | 81.1 | 53.9              | 71.3 |
| Variance               | 0.04          | 0.04 | 0.05                | 0.06 | 0.03              | 0.04 |
| Difference compared with Pre-COVID (in percentage point) | -19.8***      | -10.6***| -17.5***            | -8.2***|
| % of the same time arriving home as the last survey day | 40.6          | 39.2 | 33.6                | 40.5 | 32.4              | 35.9 |
| 15th percentile (%)    | 27.6          | 26.0 | 14.0                | 20.9 | 21.1              | 24.8 |
| 1st Quartile (%)       | 30.5          | 30.6 | 21.3                | 26.0 | 24.7              | 27.2 |
| Median (%)             | 38.9          | 38.0 | 33.3                | 39.6 | 32.1              | 35.4 |
| 3rd Quartile (%)       | 50.0          | 46.5 | 43.1                | 54.5 | 39.8              | 42.9 |
| 85th percentile (%)    | 52.8          | 51.8 | 50.0                | 60.8 | 45.0              | 48.5 |
| Variance               | 0.02          | 0.02 | 0.04                | 0.04 | 0.02              | 0.02 |
| Difference compared with Pre-COVID (in percentage point) | -7.0**        | 1.3  | -8.2***             | -3.3*|
Trip pattern repetition/variability has been examined by scholars over the last few decades (Huff & Hanson, 1986; Susilo & Axhausen, 2014), but the existing literature has rarely linked it to WFH arrangements. Results in this study show that WFH arrangements can improve the flexibility of departure time and trip destinations even without implementing restraint measures (i.e., in the post-lockdown period). And trip patterns have become less monotonous among WFH employees. The findings also merit further investigation for transport demand management.

Four types of trips are investigated in this study, namely work, leisure and shopping, errand and assistance, and education (shown in Fig. 4). Before the pandemic, WFH participants showed a “work-leisure balance” trip pattern regarding the number of trips, while a work-related trip in the NWFH group was 17% higher than leisure and shopping trips. During the lockdown period, a conceivable reduction (14%) of work trips was observed in the WFH group. On the contrary, the proportion of work trips in the NWFH group has risen by 5%. With respect to the other three types of trips, it is found that leisure and shopping trips and work trips are substitutes. With respect to RH8 (leisure trips), errand and assistance trips are not influenced significantly by WFH measures, and education-related trips are relatively low in our study as the participants are full-time employees. In the post-lockdown period, the share of work trips has increased but it was still lower than the pre-COVID period among WFH participants. As aforementioned, while work-related trips have diminished, other trips could have increased. From a well-being perspective, an increasing number of leisure activities is beneficial to the mental health of teleworkers (Brajsa-Zganec, Merkas, & Sverko, 2011).

In relation to RH9 (time spent at home), it is anticipated that WFH employees can spend longer time at home. As presented in Table 9, the average duration spent at home for both groups was about 13 h per day before the COVID-19 pandemic. Under the lockdown measures, WFH participants have spent 3.55 h more at home per day, and NWFH participants have spent 2.07 h more. Even when the lockdown measures were eased in the post-lockdown period, WFH participants have still spent 21% more time at home.

There is no consensus on whether spending longer at home is favourable to well-being. On the one hand, some suspect that staying at home for a long time can trigger “cabin fever” (He & Hu, 2015), especially during the COVID-19 pandemic (Chen, Bao, & Li, 2021). On the other hand, it is reported that increasing family leisure activities is positively related to the subject’s well-being (Brajsa-Zganec et al., 2011). We envisage that teleworkers not living alone and a larger household size may benefit more from the longer time spent at home with family (Mannering & Mokhtarian, 1995).

5. Conclusion

The outbreak of the COVID-19 pandemic has affected people’s lives. Conventional working venues have been relocated from office to home for many employees. Given the unprecedented surge in the number of teleworkers, changes in travel behaviour under WFH arrangements have elicited scholarly attention. Using a set of GPS tracking data, this study...
attempts to unveil the mutations of trip characteristics, travel behaviour, and activities for both WFH and NWFH employees in Switzerland in different time periods (i.e. pre-COVID, during lockdown, and post lockdown). Nine research hypotheses have been tested based on the GPS tracking data and associated questionnaire surveys. Through a general conceptual framework, findings in the study supplement the existing empirical literature and shed light on changes in travel behaviours and implications on sustainable transport in the post-COVID era.

Findings of this study indicate that implementing WFH can be conducive to sustainable development by mitigating the negative externalities of transportation. Under WFH arrangements, trip distance and travel time have reduced significantly, thereby reducing fuel consumption and pollution emissions. Meanwhile, the increased share of active transport trips among teleworkers also has a positive impact on reducing traffic carbon emissions. Our results also find that a great proportion of morning commuting trips has shifted to non-peak hours, and high-job-density areas have attracted relatively fewer trips. Under these circumstances, the capacity of the transport system in urban areas can be utilized more evenly, and road traffic congestion during peak hours can be ameliorated as well. Compared with WFH participants, NWFH employees have shown a more diverse trip pattern. With more short leisure trips, it is believed that the well-being of teleworkers can be improved under WFH arrangements. Though WFH participants have spent longer time at home, it is obscure whether this enhances well-being or not. As most participants’ household size is greater than one (as shown in Table 2), spending longer at home is beneficial to family life (Manning & Mokhtarian, 1995). Yet, changes in trip frequency in the post lockdown period suggest that the average number of trips per day may not diminish as significantly as expected among teleworkers.

Findings of this study have provided some initial sketch of the picture in the post-COVID era. For instance, the average trip distance, the share of morning peak departure time, average employment density of destinations, and the share of active transport modes are significantly different from those during the pre-COVID period. Policymakers should pay extra attention to these changes. To illustrate, improving the walkability around residential areas and adjusting public transport frequency (especially by increasing the frequency during non-peak hours) may be considered to further promote sustainable mobility in the post-pandemic era.

The disparities between WFH and NWFH participants in relation to travels and activities invoke another question, that is, who can WFH? With the outbreak of COVID-19, it is believed that employers would adopt telecommuting as far as possible to reduce the transmission of virus (Mauras et al., 2021). Nonetheless, a large proportion of people adopt telecommuting as far as possible to reduce the transmission of virus (Mauras et al., 2021). In addition, disadvantaged groups, such as, family time), the inequity issues between teleworkers and non-workers can benefit from the WFH arrangement. As negative externalities, such as air pollution, fuel consumption, and carbon emissions, can be alleviated under WFH arrangements (Lam et al., 2021; Zhang et al., 2021), it is anticipated that the wider community can also benefit from the promotion of WFH. In the future, the impact of WFH arrangements on non-teleworkers may need to be more carefully examined.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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