**Executive summary of recent COVID-19 studies**

1. Employing longitudinal data analysis retrieved from alternative big data resources to assess the long-term effects of the COVID-19 pandemic ***(longitudinal perspective)***

* To explore changes in people’s mobility spanning more than seven months (long-term effects)
* By contrast, previous studies focused on the first phase of lockdown during Spring2020 (short-term effects)
  + Our paper also examines the trajectories of mobility over seven months while the national lockdown was implemented in all regions of England

1. Characterisation of trajectories of mobility reduction ***(temporal dynamics of mobility in pandemic times)***

* *V-shaped mobility trend* (a sharp mobility reduction followed by a gradual recovery) in mobility in times of the early stage of the COVID-19 pandemic (throughout 2020)
* Also, people’s mobility has been changed through various waves of the pandemic; Wave 1 (before lockdown), Wave 2 (lockdown), and Wave 3 (easing lockdown) for the first year of the COVID-19 pandemic
  + Therefore, it is worth considering how people’s mobility changed during the first national lockdown in the initial phases in a follow-up paper

1. Mobility resilience to COVID-19 (***social inequalities in mobility***)

* The impact of travel measures varies with participants’ socioeconomic characteristics: differences in the ability to restrict mobility in response to countermeasures against COVID-19 among people
* Defining mobility resilience: people’s ability to resist such impact and maintain their mobility routines
* In a recent paper, six metrics were used to assess mobility resilience from the characteristics of trajectories of mobility: Speed of disruption, Maximum impact, Duration of impact, Performance loss, Speed of recovery, and Recovery degree
  + In our manuscript, Table 1 (Characteristics of change in mobility during lockdown by clusters) provides identical metrics to calculate total performance loss (TPL)

1. Policy implications were suggested for sustainable and resilient urban management

* Paying more attention to vulnerable people to mitigate their high COVID-19 exposure risk: different response capabilities (i.e., mobility resilience to COVID-19 pandemic)
* Taking account of people who are more vulnerable to the pandemic to coordinate targeted resource allocations avoiding the problem of social inequality (flexible pandemic control measures)
* This approach helps support sustainable and resilient urban management, which is associated with resource allocation, policy-making, and urban planning

**Bullet points of recent COVID-19 studies**

1 (2022): **longitudinal panel data** analysis; **V-shaped mobility patterns**, **long-term effects** of the pandemic by estimating marginal effects; **US** case study

* 308 drivers provided high-frequency connected vehicle data covering more than one year (from Jan 19 to Jun 21), integrated activity-travel database was generated to combine with land-use data. Focusing on changes in personal vehicle trips made and their activity-travel attributes: travel duration by activity types, stay-at-home, and vehicle miles travelled (VMT)
* **“V-shaped mobility trend”** in the early stage of the COVID-19 pandemic; characterised a sharp decline in mobility and then a quick recovery in the second phase
* “Related studies have been very helpful in understanding short-term effects, but determining the long-term impacts requires the collection of data over an extended period of time long before and after the spread of the pandemic (Concase et al., 2022: 3)”
* CV panel data containing activity-travel attributes of participants who travelled during COVID-19 (e.g., number of trips, travel durations, and so forth) with their socioeconomic characteristics (e.g., age, gender, ethnicity, education attainment, income level, and occupations)
* **The impact of travel measures varies with participants’ socioeconomic characteristics;** young adults (aged 25 and under) stay at home more hours than pre-pandemic. Individual heterogeneity in making inferences about the impact of the COVID-19 pandemic on individual activity-travel behaviours. Also, this study explores the effect of stay-at-home orders and easing lockdown (i.e., reopening) on activity-travel behaviours; travel time is reduced immediately, but a rapid recovery has been detected in the reopening phase

2 (2022): how **mobility behaviours have been changed** over the past two years; focusing on changes in mobility behaviours by different **modes of transportation**; using public open big data; a trade-off between the usage of cycling and driving; **Belgium** case study

* “There seems to be little literature that analyses the longer-term changes in the mobility sector following the varying levels of COVID-19 restrictions (de Séjournetet al., 2022: 108)
* Using Google’s daily community mobility report data for three transportation modes for three dependent variables: changes in driving, cycling, and public transportation use

3 (2022): **inequalities**; examining how socioeconomic characteristics were associated with mobility changes; spatial econometric models **using anonymised mobile data** with cross-sectional data; **Germany** case study

* Unanswered questions from existing studies; 1) heterogeneity of mobility changes, which is associated with regional, socioeconomic, health-related, and political **influencing factors**; 2) whether **direct** (e.g., legal contact restrictions) or **indirect** (e.g., voluntary social distancing) restrictions **lead to greater mobility reduction**; and 3) **regional interactions** of mobility changes **between adjacent areas**, i.e., spillover effects.

4 (2022): **longitudinal data** analysis to examine **changes in mobility behaviours** over three pandemic waves for 20 months; **V-shaped mobility patterns**; **wave-specific dynamics** from the long-term assessment of COVID-19; **using mobility data** collected by smartphone applications from voluntary users; **Germany** case study

* Countermeasures to tackle the spread of COVID-19; range from travel restrictions to social distancing orders, curfews, quarantines, and the implementation of complete or partial lockdowns
* Why is a longitudinal perspective needed to understand mobility changes during the COViD-19 pandemic? Existing studies published in the early stage of the pandemic focused on a single lockdown period (particularly Spring 2020), so **longitudinal and comparative perspectives may fill the lack of understanding of the intra-pandemic dynamics** because **mobility behaviour was directly related to the various pandemic waves** or whether mobility behaviours show a kind of **“adaptation pattern” that potentially disconnects from the pandemic’s actual metrics**
* **Intra-pandemic dynamics:** the pandemic period is **decomposed into three major waves**, delineating periods of high incidences and high reproduction rates. The first wave showed changes in mobility behaviours that appeared rather late, relative to fast-spreading infections, which can be interpreted as a first adaptive response against COVID-19.

5 (2021): **longitudinal data** analysis for measuring **daily mobility leve**l (by the median value of the maximum distances from home to any daily activity locations) **using mobile-phone data;** **V-shaped mobility patterns** consisting of **two consecutive waves** in the early stage (seven months) of COVID-19 pandemic in 2020; **inequalities**: area-level deprivation impacts on mobility changes; **US** case study

* Longitudinal data analysis to examine changes in mobility levels over time (i.e., seven months in 2020) during the COVID-19 pandemic in the US
* **V-shaped mobility trend**: first declined at the early stage of the COVID-19 pandemic (Mar-Apr) but quickly recovered to the pre-pandemic mobility levels (Apr-June), and it was significantly associated with socioeconomic characteristics, including political partnership, poverty level, and the policy stringency
* Travel restrictions and stay-at-home orders were effective only for a short period, yet poor people, mostly essential workers, kept travelling during the pandemic
* Thus, it is vital to pay more attention to vulnerable people to mitigate their high COVID-19 exposure risk

6 (2023): **resilience perspective** into human mobility; different resilience capabilities among different population groups and **under different waves** of COVID-19; assessing human **mobility resilience to COVID-19** by the change curve of human mobility over time using mobile phone data for ten months; to what extent to assess human mobility resilience to the pandemic **make implications for sustainable and resilient urban management**

* New conceptual framework of the resilience of human mobility in the COVID-19 pandemic: **people’s ability to resist such impact and maintain their normal mobility.**
* It helps reveal **heterogeneities and variations in people’s response capabilities** (i.e., mobility range and diversity) to the pandemic. It also provides insights for **sustainable and resilient urban management** to identify the more vulnerable to the pandemic and targeted resource allocations to reduce the inequalities.
* Several mobility metrics have been proposed to measure human mobility: intensity, spatial patterns (i.e., a radius of gyration), and diversity of mobility in existing studies. This study used the number of visited places, the radius of gyration, daily movement distance, and activity entropy to measure human mobility.
* *“The data we used in this research were anonymised mobile phone signalling data collected from one of the three communication operations in China, which continuously collect the location information of mobile phone users by recording the signal connection relationship between mobile phones and phone towers (Liu et al., 2023; 10)”*
* Resilience assessment has been performed **over four phases in times of the COVID-19 pandemic: the original phase, the disruptive phase, the recovery phase, and the new steady phase.**
* An integrated **resilience assessment framework with six detailed metrics** was introduced to quantify the system’s resilience capability during different phases; 1) the speed of disruption, 2) maximum impact, 3) performance loss, 4) duration of impact, 5) speed of recovery, and 6) recovery degree.

Diagram

Description automatically generated

* Next, different mobility metrics were used to test the **difference in mobility characteristics among population groups**. Finally, this paper exhibits the **significant heterogeneities and variations in different mobility metrics by gender and age groups**. In particular, young adults showed relatively higher resilience compared with older adults.
* In the first wave, the psychological fear of the pandemic would be the driver to curb people’s willingness to travel to the minimum. However, human mobility resilience was significantly enhanced in the second wave because people have adapted to the pandemic, and it stimulated people’s travel demands which were suppressed by travel restrictions and stay-at-home orders.
* **Implications for sustainable and resilient urban management**: 1) refinement of pandemic-control measures, 2) tackling social inequality problem during the pandemic accounts for differences in people’s response capabilities to the pandemic, 3) sustainable city recovery taking people’s compulsory mobility associated with social and economic activities into consideration

7 (2022): **longitudinal data** analysis; measuring three **daily mobility metrics** using mobile-phone data; **V-shaped mobility consisting of three consecutive waves** in the early stage (a year) of the COVID-19 pandemic in 2020; **inequalities**: the associations between socioeconomic variables and mobility levels changed throughout the pandemic in 2020; **Canada** case study

* Examining the **associations between aggregate mobility levels and socioeconomic variables using multiple mobility metrics**; a radius of gyration, time outside the home neighbourhood, and diversity of places visited
* Modelled changes in mobility relative to a pre-pandemic baseline as Feb 2020 accounts for day-of-week variability in the baseline, and a seven-day rolling average approach was implemented to smooth out daily differences from 1 Jan to 29 Dec 2020
* Using the spatial seemingly unrelated regression (SUR-SEM) models account for a spatial error model approach, and the fit of this model varied over time. In other words, COVID-19 immediately caused changes in mobility at the first lockdown (first wave), but the relationships changed during the summer months as **people settled into new lockdown routines and could selectively participate in discretional travel**
* The pattern of association between mobility and economic deprivations is further evidence to support the disproportionate impact COVID-19 has had on mobility levels economic gradients - the luxury of social distancing, transition to home-based working
* Less has been reported on how changes in mobility were related to the ethnic diversity of regions and a strong negative association in a radius of gyration model with ethno-cultural index values. In other words, people living in that area spend more time in the home-neighbourhood than in other regions.

8 (2022): **average hourly temporal dynamics** of human mobility; daily temporal patterns of **human activity changed nonuniformly**: morning activity later, and evening activity started earlier; using longitudinal mobile phone data; **US** case study

* “How and when individuals move from place to place influences what the population distribution for a given area might be depending on the time of day or day of the week…understanding human mobility has become increasingly important during the outbreak of COVID-19 (Sparks et al., 2022: 1)”
* Examining aggregate temporal signatures using unsupervised clustering methods and defining semantic temporal zones of Morning, Day, Evening, and Night, describing temporal changes in activity throughout a 24-h period.
* “Each increase and decrease cycle colloquially referred to a *wave”*
* Potential economic implications: employers in certain industries may consider how later wake-up times and later activity times influence employees' desire for altered working hour policies in future, and future work will investigate associations with temporal dynamics and sociodemographic characteristics

9 (2022): **changes in modal shift** during the national lockdown; **comparing changes in mobility** under COVID-19 between standardised mobility datasets: Google and Apple; **India** case study

10 (2022): **data-driven approach**: understanding the impact of the COVID-19 pandemic on human mobility; measuring **26 mobility metrics** from 9 different datasets; **fewer studies** describing changes in mobility in times of COVID-19 pandemic using **multiple datasets**; **US** case study

* using generated mobility metrics to calculate the global and local Morans’ I to contrast the locations of hot- and cold spots, to demonstrate the consistency of spatial clusters in 2020
* Discussion items: differences in population representation (i.e., sampling bias) across datasets, different spatio-temporal coverage between collected mobility sources, and inconsistent temporal trend of mobility (i.e. dynamics), which represent the magnitude of social distancing

11 (2022): defining and **measuring travel behaviour resilience** throughout the COVID-19 pandemic; by using **public transit records** which collected trips paid by smartcards or virtual payment platforms; **the resilience triangle** could be drawn with mobility reduction and recovery periods; measuring the area of this triangle is equal to the magnitude of resilience, in terms of the **capability to adapt to a particular negative disruption**; policy implication: **travel restriction or intervention** **should consider the diverse needs of mobility groups;** **China** case study

* “Inter-personal differences make travel behaviour spatially and temporally diverse” consider group heterogeneity and travel behaviour resilience for transport management and city restoration
* Travel behaviour resilience can be measured with the triangle denoting; the degree of mobility change and the periods of reduction and recovery

12 (2022): **V-shaped mobility patterns** throughout the COVID-19 pandemic; the importance of designing mitigation policies whereabout the **immediate recovery of visits to retail locations, restaurants, and bars**; using mobility data over 23 months; **five pandemic stages**: pre-pandemic., lockdown, reopening stage, restriction, and complete opening stage; **inequalities:** the effects of areal deprivation levels on mobility changes over time; using linear mixed effect regression models, US case study

* “Stay-at-home orders to limit out-of-home activities and restrict non-essential travel”
* “1) Where did people travel during the lockdown, and how did it differ from travel before the pandemic? 2) Were these impacts consistent for all socioeconomic groups? 3) How did people’s travel behaviour-activity change during the reopening stage, and how did these changes differ among different social-economic groups?”
* “Understanding the impacts of the COVID-19 pandemic on the activity-travel behaviour can **provide useful insights for health policy makes into efficiently designing public health and mitigation policies.**”
* “People with low income and low educational attainment tended to show **less reduction in mobility because of their ability to work remotely.**”
* The shortcomings of related studies using mobile phone data to examine human mobility behaviours in times of COVID-19 pandemic: 1) under-represents low-income people with limited access to smartphones, particularly 24% of US adults with household income below $30,000 reported no access to a smartphone, 2) could not **differentiate trips between employee’s trips (mandatory) and consumers’ (discretionary) trips,** and 3) examined then activity-travel behaviour (i.e. the average number of visitors to each type of destinations) by geographical levels without individual information - no permissions to grant access and track individual-level detailed mobility data
* Policy implications: analysis results would be helpful for health policymakers to control the spread of COVID-19 and for transportation planners to design a sustainable and equitable transportation system.
* In addition, **visits to restaurants and bars and retail stores bounced back immediately during the reopening stage** despite the severe COVID-19 situation: public health makers should remind **the immediate recovery of visits to essential premises, even life under stay-at-home orders** and carefully design and implement public health policy and measures before another pandemic is coming

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