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A paradigm shift in urban mobility: Policy insights from travel before and after COVID-19 to seize the opportunity

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ABSTRACT
Background: COVID-19 outbreak unfolds as the biggest challenge of this century by far. Virulence of the disease has compelled densely populated countries like India to impose severest measures, which include full or partial lockdown to contain the virus spread. The contagious virus has put the lives of many in urban cities on hold and forced them to abandon or restrict regular activities, which includes a basic human need to travel to satisfy one’s daily needs. The eventual impact of the pandemic on individual mobility and the urban city’s sustainability depends upon the resilience of medium and long-term policies during such disruptive events.

Objective: In order to gauge the impact of this unprecedented disease on travel behavior and mobility patterns of individuals, a web survey is conducted in urban agglomerations of India. The idea is to record travel mode choices before, during and after situations. The study also attempts to elicit responses towards a safer and disaster-resilient public transport, which can also cater to the needs of private vehicle-owning individuals. Further, the study presents and evaluates a set of medium to long-term policy prescriptions to negate the repercussions of this crisis and seize the opportunity it has created so that the long-held dream of sustainable and resilient cities in the context of urban mobility is realized in the best way possible.

Key findings: The study findings indicate an increase in the car-dependency pan-India level post the COVID-19 crisis. Strikingly the captive users of public transport and non-motorized transport mode (walk) are also willing to make a shift towards private motorized vehicles (car, motorized two-wheeler). The eventual mobility shift will depend upon - (a) the recovery period of mass transportation systems to normalcy (b) investments and promotion of active travel modes (non-motorized transport, i.e., walk, bicycle). The findings also reveal that demand and the willingness to pay extra for a safer, faster, cleaner, comfortable, and most importantly, resilient public transport exists. Further, policy evaluations for sustainable and resilient recovery reveal - (a) the provision of bicycle superhighway will push the bicycle share from 31% to approximately 44% (b) travel demand moderation efforts such as (i) staggering of working days demonstrates the reduction in the congestion externalities. (ii) Flexible arrangements for educational activities (two shifts in a day) facilitates overall gain in the system welfare, and (c) incentive such as reducing public transport fare has a positive impact on its share due to the mobility-shift from the private motorized vehicle.

Interpretation and implications of results:
Investment and encouragement of active travel mode should be prioritized for personal well-being and disaster-resilient cities. Resilience planning should be an integral part of public transportation systems to handle the future shock of pandemics and other emergencies. Additionally, self-sustainable neighborhoods should be encouraged to reduce the trip lengths substantially or the need for private motorized transport for various secondary activities.

1. Introduction
1.1. Overview of coronavirus
Severe Acute Respiratory Syndrome associated Coronavirus (SARS-CoV or SARS-CoV-1) was identified and first reported in 2003 and infected more than 8000 persons, of which more than 750 died (Chan-Yeung and Xu, 2003). The SARS-CoV spreads with close contact (typically up to 3 feet). The disease spread across the globe due to a relatively long incubation period (mean = 6.4 days); however, the
highest number of infected persons (5327 and 1755) and deaths (349 and 300) occurred in China and Hong Kong.

In late 2019, a novel Coronavirus, named as SARS CoV-2 (also called as nCov-19 or COVID-19) has emerged in Wuhan, China (WHO, 2020a). The total number of infected persons on January 20, 2020 were 282, of which 278 in China, 2 in Thailand, and one each in Japan and the Republic of Korea. The spread in Thailand, Japan, and the Republic of Korea were exported from Wuhan, China. From here, the numbers increased rapidly and reached 16 million in the world and 1.4 million in India (WHO, 2020).

1.2. Impact of the nCov-19 outbreak

On Mar. 11, 2020, the number of infected persons crossed the 100,000 mark in more than 100 countries; therefore, WHO declared it as a pandemic. The Coronavirus spread through close proximity with an infected person and/or with fomites (e.g., doorknob, clothes, etc.).

In order to minimize the spread of Coronavirus, researchers are attempting to study the dynamics of the disease. For instance, Qian et al. (2020) used smart-card data from three cities in China and constructed a Metro-Contact-Network to determine the contact duration between two individual travelers. Further, this is associated with the risk of propagating the disease. Zhang et al. (2020) demonstrated that the frequencies of trips by air and high-speed train services out of Wuhan are significantly correlated with the number of persons infected with COVID-19 in the destination cities. To minimize contact with each other, the world has come to a standstill, most of the countries has sealed the borders, closed the ports, harbors, stopped public transport services, locked down the restaurants, pubs, schools/colleges, museums, shopping malls, etc. Such extreme measure are also recommended in various studies (Alexander Müller et al., 2020; Fang et al., 2020). The former study develops a mechanism to determine the start of the lockdown as a function of the number of hospital beds, infection speed, and other factors. In addition to isolating the infected persons, increasing the testing, spreading the awareness, the governments are recommending to follow the physical-distancing strictly, self-isolation if feel unwell, and advertising to maintain hygiene (e.g., washing hands several times a day, not touching the face, covering the mouth and nose, using sanitizers, etc.). Singh et al. (2020) attempted to study the psychological impact of COVID-19 on working persons and correlate them with travel behavior. Similarly, Dubey et al. (2020); Ghosh et al. (2020) discussed the psychological impact on different users groups and the possible interventions to minimize the impact.

1.3. Overview of mobility trends

Google (accessed July 2020) provides an overview of aggregated mobility trends for various activities in various countries (see Fig. 2). A mobility index is defined, which represents the change in the mobility pattern with respect to a baseline value and the mobility pattern is defined as the visits and duration of stay at different activities (places). The numbers are compared with respect to the median value for the corresponding day between Jan. 3 to Feb. 6, 2020. It has been shown that the frequency of visits and visit duration has declined sharply for most of the activities (e.g., retail and recreation, grocery and pharmacy, transit stations, workplaces, etc.) and increased for residential activity (i.e., staying at home or working from home). In the US, the transit ridership had declined sharply compared to 2019 (Van Dam, accessed Apr. 2020); a similar trend has been observed in Santiago, where low-income households preferred to work remotely (Tirachini et al., 2020). In Switzerland, the average daily kilometers traveled by train, tram, bus, and car decreased significantly, and it has increased for bicycle trips (Molloy, accessed Apr. 2020).

1.4. Spread in India

In India, the first case of Coronavirus was reported on Jan. 30, 2020. Similar to other parts of the world, the Govt. Of India has introduced ‘Janta Curfew’ (voluntary public curfew) on Apr. 22, 2020, and thereafter lockdown for 21 days starting from Mar. 25, 2020; at this time, the number of positive cases was just over 500 (see Fig. 2). During the lockdown period, all modes of transport such as flights, railways, public transport (intercity and intracity), public spaces, restaurants, schools, colleges, parks, industries, offices were closed. The essential services such as grocery stores, supermarkets, vegetable stores, grocery stores, milk-stores, banks, etc., were allowed to operate for a limited period, and pharmacies, electronic media, internet and communication services, petrol pumps, etc., are working as before or for extended hours (MHA, 2020). Fig. 1 show the confirmed cases for all states of India up to July 2020 and daily increment in the confirmed cases for 12 worst-affected states. Clearly, even after the lockdown and other restrictions, the number of cases in Maharashtra and Tamil Nadu increased rapidly, whereas the pace has decreased in Delhi.

Further, Fig. 2(a) shows the % change in the mobility trends for India (Apple, accessed July 2020). An interesting observation is that the car (denoted as ‘drive’) and walk trips start decreasing from mid-march, i.e., before announcing the ‘Janta Curfew’ or lockdown (see Fig. 2(d)). This happens because the users realized the risk of getting infected and perceived the costs into their choice behavior and preferred not to travel. Further, a slight increase between ‘Janta Curfew’ and the start of lockdown in the mobility can be explained by the uncertainty and fear among people because of which, people traveled to their hometown, rushed to stock the grocery (panic-buying), etc. Further, from Fig. 2(a), an increase in the drive and walk travel modes have been observed progressively after ‘Lockdown 3.0’ (May 4, 2020), which indicates that people accepted the chances of getting infections and prioritize to travel. The primary purposes of these trips are grocery & pharmacy, work whereas the retail & recreation remains the least priority (see Fig. 2(b)). The lockdown was relaxed in a graded manner starting from June 1st 2020, which is called as “Unlock 1.0”. Clearly, with this, traffic increased slowly on the streets.

1.5. Impact on travel during past pandemics

The convenience of domestic and international travel has been one of the major factors of many contagious diseases and converting epidemic into a pandemic (e.g., Spanish Flu, SARS outbreak, Swine Flu, COVID-19). The outbreak of the Spanish flu in 1918 has infected over 500 million people and killed more than 50 million worldwide, which was caused by H1N1 influenza. In order to control the spread of the virus, a public gathering was restricted, schools, offices, playgrounds, churches, etc., were shut down (Ott et al., 2007). In 2003, commercial air travel was considered the main cause of the SARS outbreak (Baker, 2015). The cities from many countries having direct flights to Hong Kong, Beijing, Shanghai, etc., reported more SARS cases than the cities which were not directly connected. Consequently, International (air) travel dropped by 50–70% during the outbreak (WHO, 2003). A simulation model is developed to study the impact of mass gathering and holiday traveling on the spread of the 2009 H1N1 influenza pandemic (Shi et al., 2010). The authors show that a second peak can be expected as a consequence of trips for tourism. On the other hand, Bajardi et al. (2011) demonstrate that travel restrictions cannot prevent the spread rather can delay it.
1.6. Travel choices and public transit ridership

Typically, the choice of a travel mode depends on monthly income, trip purpose, travel time, travel cost, comfort, convenience, etc. Monetary payments for the trip (e.g., fare, toll, parking charges) and enforcement also trigger a major change in the travel choices (travel mode, route, etc.) Agarwal and Kickhöfer (2018) illustrates the changes in the travel (route and mode) choices of the urban travelers, commuters on the application of tolls based on marginal congestion and emission pricing. An Odd-Even scheme was enforced in Delhi in 2016 and in subsequent years. Consequently, an increase in car occupancy, public transit ridership has been observed Mohan Rao et al. (2017). As a consequence of the frequent ‘Odd-Even’ scheme, a spike in used-car sales has been observed.

The attributes affecting the travel choice are not the same under special circumstances (e.g., pandemic, terrorist threats, etc.) because the perception of danger overcomes other parts of the individual utility (choice) model. For instance, air travel was dropped sharply during SARS pandemic (WHO, 2003), H1N1 influenza disease (Bajardi et al., 2011) and 9/11 terrorist attack (Ito and Lee, 2005). The impact of the latter continued to be observed for about two years. Post-September 11 attacks, long-distance trips increased substantially, i.e., a mode switch from air travel to road travel (Gaissmaier and Gigerenzer, 2012). Similar to this, after the London subway bombing in 2005, a decrease in train trips and an increase in bicycle trips are observed (Ayton et al., 2019). With this evidence, it can be outlined that with any changes in travel policy, travel restrictions, incidents, pandemics, public transport (PT), ridership is affected most, which is followed by higher transport negative externalities (e.g., accidents, air pollution, congestion, etc.).

In India, PT is an essential mode of transport for many persons, including the captive riders who cannot travel to essential purposes (e.g., work, education) in the absence of PT (Tiwari et al., 2016). The transit vehicles are already running at their capacity in many cities of India (Suman et al., 2017). During the pandemic, fear of getting the infection in the PT vehicles overcomes the other factors in the travel choice models, and a reduction in the ridership is likely to be observed.

1.7. Sustainable and resilient mobility

Sustainable transportation systems can be an enabler in creating sustainable cities of the future. Another promising alternative for realizing sustainable communities is transit-oriented development (TOD) in urban areas, which can negate the negative transport externalities by creating compact, self-sustainable communities using convenient, safe and efficient PT systems (Zheng and Peeta, 2015). The TOD concept, minimally, integrates efficient transit systems such as rapid transit systems (e.g., on-road, on-rail) and personal rapid transit (PRT) (Parent, 2006). PRT has gained attention due to (i) linkage between personal, private and PT modes (ii) flexible operational characteristics (iii) financial viability, etc. (Muir et al., 2009; Parent, 2007). PRT system’s construction cost is one-third of the light rail transit (LRT) due to use of lighter PRT Vehicle and less stricter design standards for PRT guideways (Tegner and Andre). Further, PRT is also well suited to facilitate TOD development as it offers the same door-to-door flexibility, which a personal car provides at an acceptable cost and also serves as a public transit mode at the same time. PRT can further supplement the TOD deployment by means of feeder services, i.e., a service within a wider area in the locality of a mass rapid transit (MRT) station to the MRT station. In terms of energy savings and CO2 emission reduction, PRT fares much better than automobiles (Lowson, 2003). The infrastructure setting of PRT is also relatively less visually intrusive and less expensive than other rail-based modes as it uses miniature vehicles, which allow smaller stations and structural components. Possibility of having a minimum turning radius and steep gradients further facilitate designing PRT alignments with ease and renders them best suited for use in dense urban areas (Juster and Schönfeld, 2013).

A study by Jain et al. (2016) highlights the urban transport system deficit in the Indian context (New Delhi) and demonstrates how a PRT has the potential to meet this deficit by increasing the accessibility levels and, thereby, the share of PT users in the study area. The authors
Fig. 2. Mobility trends India.

(a) % change in the mobility trends for India (Apple, accessed July 2020)

(b) % change in the mobility trends for India (Google, accessed July 2020)

(c) Activities (Google, accessed July 2020)

(d) Drive and walk (Apple, accessed July 2020)
demonstrate that in Dwarka, New Delhi, about 36 percent of trips per day can switch from the existing modes to PRT, of which more than 43% are expected to come from personal car trips. Sarkar and Jain (2017) addressed the uncertainties associated with the PRT network operations and finances by developing a dynamic model for bench-marking the PRT system, which can then be used to assess the parameters (e.g., fare/km and route length) to achieve the optimum internal rate of return (IRR).

In terms of challenges encountered for the broader PRT implementation, the risk of failure in implementing new technology is the largest (Juster and Schonfeld, 2013), followed by unattractiveness guideways and the lack of operating experience (Andréasson, 2012). Another critical aspect is the relatively high initial cost (a fraction of PRT) and can be overlooked as the lower operating cost than other forms of PT (Tegnér, 2005).

Fatnassi et al. (2015) investigated the potential of integrating a shared goods freight rapid transit (FRT) and passenger PRT system in urban areas to enhance urban mobility and integration with the urban areas. The authors demonstrate the potential gain of implementing the PRT–FRT modes. For this, wasted energy and waiting time of PRT-FRT modes are compared to the existing transportation modes. Further, disruptive events such as COVID-19 have also highlighted the need for resiliency in transportation systems, which is a reaction of a system to tremors, shocks, or catastrophes (OECD, 2014). The impact due to such events can last over a short or long period. The performance of a transportation system during these changes would heavily depend on the resiliency of these systems (TRB, 2017).

1.8. Problem statement and objectives

With the aforementioned discussion, it has become evident that uncertainty due to the ongoing pandemic situation will have a bearing on individual travel choices and behavior. Further, the overcrowded PT system is likely to take a severe hit as cities move towards normal, which necessitates physical distancing (staying 3–6 feet away). However, such extraordinary circumstances require extraordinary measures during and post-pandemic situations. The primary aim of travel restriction during a pandemic is to curb public gatherings to contain the spread of the disease. As soon as the virus spread is contained, the govt. will start relaxing the lockdown, which is likely to impose a huge load on the existing transportation system provided no measures are taken. This brings an opportunity to transform existing or devise new policies towards a resilient and sustainable transportation system. The present study attempts to study the current situation and attempt to draw inferences in terms of future policies. The objectives of the present study are:

- to study the travel choices made by travelers before, during, and after-COVID-19 pandemic, and capture likely mobility-shift
- to realize the need for a safer and disaster-resilient PT system,
- to prescribe the policies for mid to long term derived from the survey insights, and
- to exploit the potential of policy prescriptions using simulation experiments.

2. Data collection

2.1. Survey design

A web-based survey was created and floated a few days before the “Lockdown 1.0” to assess the travel behavior before, during, and after the outbreak of Coronavirus. The survey is conducted using Google Forms. The whole questionnaire has five sections, (i) the first section consists of questions related to travel during normal situation (ii) the second section asks about travel during the outbreak of Coronavirus (iii) third section focus on questions related to travel post-COVID-19 (iv) fourth section attempts to identify the choices for the planning of a new PT system and (v) the last section requests for socio-demographic attributes. The trip purpose has been categorized in two, named as primary and secondary. The former activity corresponds to trip related to work or study, whereas the latter activity refers to trips for social, shopping, gym, leisure, etc. The responses are collected during different lockdown phases between 20 March to June 30, 2020. Given the pandemic situation and lockdown across the nation, an online medium for collecting the survey data was found to be the most appropriate to record the impact on travel. Social media platforms (Facebook, LinkedIn, Whatsapp, etc.) and e-mails were used for this online stated preference survey.

2.2. Responses

Five hundred seventy-six survey responses are received, of which many are from students of the Institute, which are excluded from the survey for two reasons; they are (a) to exclude the biased responses and (b) this work primarily focuses only on commuters and urban travelers. After removing blanks, outliers, a total of 470 responses are used for the analysis purpose. These responses were obtained and categorized as Tier-A for five megacities, and as Tier-B for 42 million-plus cities and 50-plus (less than a million population) cities, respectively.

2.3. Limitations

The urgency emerging from the pandemic situation and lockdown incur some limitations to the study. These are:

- Use of online mediums (Facebook, Linked In, Whatsapp, etc.) limits the participation of certain population groups which are not habitual of these tools or applications; for instance, elderly, migrants/homeless, younger (below 18 years), etc. The former is a risky group with respect to COVID-19, the middle is a disadvantaged group and the latter may not be able to understand the survey. Non or limited participation of the above groups limits the representation to inclusive groups and their views only and therefore, the findings of the survey need to be interpreted accordingly.
- For the present study, a ‘convenience’ sampling is used to identify the respondents, who can enter the choices online. However, this may have sampling bias. Given the pandemic situation and urgency to collate the short/medium/long-term impact on the urban mobility, the convenience sampling is found to be acceptable.

3. Survey data analysis

3.1. Social-demographics

Fig. 3 reports some of the important socio-demographic characteristics of the survey sample.

- From Fig. 3(a), a good mix of both genders is observed in the survey sample, with women share of (31%) and men having a higher share of (67%).
- The survey captured those individuals in the urban cities with access to the internet, about 48% of the respondents reported a monthly income less than 40,000, and these were grouped under the lower-income category (see Fig. 3(b)). Approximately 23% of the respondents reported monthly income between 40,000 and 75,000 bracket and were classified under the middle-income category.

3 As per UN (2018), five cities have population more than 10 million; they are: Mumbai, Delhi, Chennai, Kolkata, Bangalore.
Fig. 3. Socio-demographic attributes of the respondents.
Further, 25% of the respondents reported monthly income varying from 75,000 to more than 1 lakh, and these respondents were grouped in the high-income category group. Considering the constraints caused due to the pandemic situation and online medium for conducting the survey, the survey sample has a good mix of respondents across all income categories.

- It is likely that the profession of a person influences his/her travel choice. As shown in Figs. 3(c), 44% of the total respondents are employed in private industry, 32% are students, 16% are government employees and about 3% are self-employed.

3.2. Before nCoV-19

3.2.1. Primary activities

In tier-A cities, more than 40% of primary activity (e.g., work, education) locations are reachable in less than 30 min. As shown in Fig. 4, it can be observed that walk is a preferred choice for most of the trips with a trip time less than 15 min. For trips taking 15 min–30 min, the choices are car and public transport (PT) respectively. For trips longer than 30 min, PT is the most preferred transport mode. Due to the smaller spatial extent of tier-B cities, more than 60% of primary activity locations are reachable in less than 30 min. Non-motorized transport (NMT, i.e., walk, bicycle) is the most preferred travel mode for trips less than 15 min, and intermediate public transport (IPT, i.e., auto-rickshaw, taxi), PT are preferred travel modes for trips less than 30 min. Surprisingly a few persons reported using NMT for trip times between 15 min and 1 h. These highlights emphasize the importance of the NMT infrastructure in urban cities.

In tier-A cities, for primary activities, the order of preferences for lower-income households is PT and walk, respectively. Interestingly, the most preferred travel mode for middle-income respondents is PT. Motorized two-wheeler (MTW) is the second most common travel mode followed by IPT modes among low and middle-income respondents. For higher-income households, the order of preferences is car and PT, respectively.

In tier-A cities, about 72% of PT users reported waiting time less than 10 min; however, a considerable proportion (25%) of PT users also reported waiting time varying between 10 min and 1 h, which encourages users to switch to other travel modes. In tier-B cities, about 57% of PT users reported waiting time less than 10 min; however, a sizable proportion (39%) of PT users reported waiting time varying between 10 min and 1 h, which can be explained by the lesser frequency compared to the transit services in tier-A cities.

3.2.1.1. Secondary activities. In tier-A cities, the typical frequency of secondary trips (e.g., leisure, shopping, visiting friends, etc.) is about three times a week for 69% of the respondents. About 47% of secondary trips are shorter than 3 km. For trips up to 1 km, people walk, whereas, for trips between 1 and 3 km, the predominant preferences are car and walk. 21% of the secondary trips are ranging between 3 and 5 km, and IPT is the most preferred travel mode for this category. About 32% of secondary trips are longer than 5 km, and the order of preferences is car and IPT. Similarly, in tier-B cities, for secondary trips, a frequency of about three times per week is reported by approximately 58% of the respondents, and a frequency of about 3–5 times per week is reported by approximately 23% of the respondents. Among total secondary trips in tier-B cities, 40% trips are shorter than 3 km, 26% trips have a length between 3 and 5 km, and the rest 34% trips are longer than 5 km. Walk, car modes are used for trips up to 1 km, car, MTW are used for mid to long-distance trips. Surprisingly, PT is the most preferred transport mode for secondary trips longer than 10 km.

3.3. During nCoV-19 lockdown

The immediate impact of COVID-19 imposed lockdown is on the primary activity trips for work/study, and the data reveals that in the tier-A cities, about 66% of the respondents had to switch to teleworking (work/study from home), whereas this number is slightly lower in tier-B cities (57%). Persons who are working/studying from home in tier-A cities are experiencing higher stress/anxiety/fear (88%) than persons working/studying from home in tier-B cities (80%) during the imposed lockdown due to COVID-19.\(^4\) An interesting observation is about 44% of the persons working remotely are already in their hometown, and another 10% of the respondents may go to their hometown in both categories of cities. A possible explanation for the former group of persons is that most of these persons perceived the risk by following the trends across the globe and reacted to it by traveling to their hometowns before the start of the lockdown or after the announcement of the lockdown. This is likely to result in a higher influx of inter-city/inter-state travel demand using air, train, bus, etc.

During the lockdown, very few persons are traveling for primary activities and are using the private mode of transport. A significant drop is also observed for secondary activities. About 47% in tier-A cities and 51% in tier-B cities have already stocked their grocery need. Walk mode emerged as the most preferred travel choice for secondary activities in tier-A cities and second-most in tier-B cities. The importance and resilience of active travel mode (walk) compared to other motorized modes is also evident (see Fig. 2(d)).

3.4. After nCoV-19

3.4.1. Travel post-COVID-19

As soon as the travel ban and lockdown are lifted/relaxed, 38% of the respondents in tier-A cities and 35% of respondents in tier-B cities will start traveling. About 36% of the respondents in tier-A cities and 32% respondents at other places are unsure and may travel. People will travel immediately after lockdown mainly for primary activities, i.e., work and study. The sudden influx of people into tier-A cities/dense cities post lockdown for work/study, which will not only increase the load on transport services but at the same time increase the chances of infection spread. The primary cause of the change in the travel choices, as reported by the respondents, was the fear of getting infected. A sizable share of respondents also reported that post-lockdown certain travel modes might not be available, which triggers the change of choices. The findings highlight that due to the prevailing uncertainty in travel behavior among the respondents, the transportation demand and travel mode preferences will be significantly impacted and altered.

3.4.1.1. Primary activities. In terms of travel mode used to reach workplace and educational institutions in tier-A cities post-COVID-19 lockdown, traveling by foot remains the preferred choice for short-distance (up to 3 km) trips. A comparison of modal distance distribution between before and after COVID-19 situation for primary activities in tier-A cities are shown in Fig. 5. However, a decrease of about 9% is expected in walk trips for distances between 1 and 3 km. Reduction in PT usage is apparent in medium (3–5 km), and long-distance (more than 10 km) trips, and the respondents have switched to IPT modes for medium-distance trips and private motorized vehicles (PMVs, i.e., car, MTWs) for long-distance trips. This suggests that vehicle km traveled by personal vehicles in tier-A cities could increase significantly. Substitution of PT services with IPT modes and MTW is also evident in medium-distance trips, which is likely to avoid crowded PT vehicles.

Similarly, in tier-B cities, there is a marked change from before COVID scenario observed in the travel choices based on trip length (a comparison of before and after situations are shown in Fig. 6). For trips less than a km, PT and walk travel modes have been reported most

\(^4\) Refer to Sigh et al. (2020) for detailed discussion on the psychological impact of COVID-19 on the working population.
preferred travel choices for primary activity trips. The share of PT trips shorter than 5 km increased significantly, whereas it has dropped for longer trips. A noteworthy increase in the share of car trips for all distance categories is observed. Due to the traveler’s perception of the risk, significant shorter trips are likely to be made by car. For short distances (1–3 km), NMT modes lead by bicycle dominate; however, there is a marginal decrease in the overall share of NMT modes. For medium distance trips (3–5 km), PMVs and PT are predominant travel modes. For long distance trips also PMV lead by the car dominate. It can be inferred from the analysis that urban areas have a swing towards private motorized vehicles, especially towards the car, as MTW share has also slightly decreased across all distance categories. PT has gained users in the short-distance category; however, they have also lost some ridership for long-distance travel. IPT modes have also suffered a significant loss across all distance categories, which in the long run is bound to affect PT ridership since the first and last mile connectivity will suffer.

In terms of travel mode choice for primary trips based on monthly income in megacities post-COVID-19 lockdown, there is a considerable decrease in PT and walk trips by lower-income respondents, and the shift is towards private motorized vehicles. This is contrary to the popular belief that lower-income groups are often captive users of PT and NMT modes. A possible explanation is that during such an extraordinary situation, travelers are giving higher preference to safety than affordability, which results in a modal shift towards MTWs by low-income households.

Typically, persons belonging to medium and high-income households are choice riders, and therefore, it is important to analyze the modal shift for such persons. The medium-income respondents have also switched from PT to MTW and IPT modes. Interestingly, the high-income respondents have reportedly also switched from PT to private motorized vehicles, which is a cause of concern for policy-makers, state transport undertakings (STUs), and environmentalists. Thus, it can be inferred from the findings that PT ridership across the income categories have declined. For tier-B cities, the PT, NMT modes are the most preferred travel choice among the lower-income respondents. Important to mention here that a marginal increase in the share of private motorized vehicles, especially the car, is observed among the lower-income respondents. Middle and high-income respondents have an evident shift towards private motorized vehicles, especially the car. Interestingly, IPT modes have to bear the brunt of this pandemic situation since their mode share has decreased across all income categories, and high-income respondents categorically have shunned the IPT modes for their private motorized vehicles.

3.4.1.2. Nature of modal shift. To understand the nature of the travel mode shift in tier-A cities, the respondents were asked about their travel mode preference post-COVID-19 lockdown, and these were compared with their before COVID-19 response. Primary reasons for the change in the travel mode are chances of getting an infection, unavailability of the travel mode, and assumption that the service will be poor when the service resumes. A sizable decrease is observed in the usage of PT. About 50% of PT users reported, they would switch to other travel modes. Most of these respondents, who wished to switch, preferred to use private motorized vehicles (see Fig. 7). For trips made to perform primary activities in tier-A cities, travel modes used for long-distance (>10 km) trips changed significantly; for instance, a significant number of persons shifts from PT to private motorized transport modes. This suggests that longer trips in the transit vehicles increase the exposed duration, which in turn increases the risk of getting infected.

For secondary activities, a marginal increase in walk mode can also be observed, which is justifiable by making trips close to the residence. However, in contrast to the expectations for primary activities, many respondents reported switching from NMT modes to PT. This can be attributed to the lack of safe NMT infrastructure in tier-A cities. Further, a significant drop is observed for secondary activities by IPT modes post-COVID lockdown. The shift is reported towards walk and private motorized vehicles. This drop can also be partly attributed to respondents preferring online shopping post lockdown.

Similarly, in tier-B cities, a sizable increase is reported in the usage of cars as travel modes for carrying out primary and secondary activities (see Fig. 8). In the case of the primary activities, an increase in share for car travel mode is mostly coming from MTW, NMT, modes, and PT. Further, MTW and PT user-base stand constant, which is obvious as they serve captive users in the low and middle-income categories. However, the share of NMT modes, post-COVID-19 lockdown is likely to decline, and the switch is mostly towards PT and car. This shift can be attributed to the lack of safe and spacious NMT infrastructure and, to some extent, now to the fear of getting infected in uncontrolled urban spaces. Lastly, the share of IPT modes has considerably declined post-COVID-19 lockdown, and the shift is distributed equally among private motorized vehicles.
vehicles, PT, and walk travel modes.

3.5. Gender equity in urban mobility

To ensure adequate mobility choices for women in urban cities, it is essential to scrutinize their travel mode choices before and after the outbreak of COVID-19. In tier-A cities, before the outbreak, more than 50% of women respondents preferred PT (27%) and traveling on foot (27%) to cater to their primary activity trips. About 18% of women respondents also used their private cars for work and study trips. However, after the outbreak, although the combined share of PT (22%) and walk (29%) trips among women remained above 50%, a marginal decrease is observed in the PT trips. Also, a considerable increase is observed in the usage of private cars (25%). Similarly, in tier-B cities, before the
outbreak, about 40% of women respondents used their private motorized vehicles (Car: 22% and MTW: 18%) for work and study trips which increased to 32% and 12% respectively post-COVID-19. PT trips also increased slightly from 15% to 17%. Further, a significant decline is visible in the preference of NMT modes after COVID-19 lockdown (i.e., from 24% to 15%). The IPT modes use among women respondents dropped from 14% to 9%. The findings highlight the importance of PT, NMT, and IPT modes to ensure gender equity in both categories of the cities.

3.6. Safer and resilient public transport system

After staying indoors for an extended period of the pandemic, people would like to travel for primary as well as for secondary activities. In
tier-A cities, approximately 50% are willing to pay extra for their travel to make it safer using a private car or taxi to avoid the chances of getting an infection, which include significant PT users in these cities. About 50% of the respondents in tier-A cities and 40% in tier-B cities are willing to pay up to 25% of their past expenses on travel. It can be inferred from this response that urban centers are required to prepare themselves to provide safe, disaster-resilient, and affordable transport for all. Along the line, this study attempts to identify the willingness to pay for a safer, faster, and resilient PT system that can attract private motorized vehicle users.

Personal Rapid Transit (PRT) system is an alternative to users who are captive to private motorized vehicles and has the capability of being an effective formal feeder system to conventional PT system (refer to Section 1.7 for details). Such systems have the capabilities to be used as
ongoing pandemic situation. The trend in urban mobility is clearly to activities (i.e., work and study) have been severely impacted by this situation. The resulting modal share and choice model parameters are re-calibrated to match the modal share from the reference study. The resulting modal share and choice model parameters are presented in Table 1. In contrast to the previous calibration, (a) the present study uses the traffic dynamics ‘withHoles’ within MATSim framework, which resembles with the simplified Kinematic Wave Model (Agarwal et al., 2017) and (b) in contrast to a constant speed for PT, the present study sets the PT speed factor in which the travel time by PT between a pair of origin-destination is twice that of the free speed car travel time. In practice, this is more realistic than using a constant speed and a beeline distance factor. For this, the choice model parameters are re-calibrated to match the modal share from the reference study. The resulting modal share and choice model parameters are presented in Table 1.

Further, the scenario is calibrated once again to replicate the post-COVID-19 situation as illustrated in Section 3. About 18% of persons prefer to work from home post-COVID-19. This situation is simulated in

![Fig. 9. Willingness to pay for PRT during normal and emergency situations.](image-url)
the iterations) is achieved at this stage. During the calibration, it is run for 600 iterations, and a convergence (verified by looking at the Table 2

| scenarios          | description                                                                 |
|--------------------|-----------------------------------------------------------------------------|
| Business As Usual  | none                                                                        |
| Bicycle superhighway | In line with (Agarwal et al., 2019a), potential of bicycle share is evaluated (see Section 4.2). |
| Alternate work days | 50% of persons from each zone are going to office alternate days: rest work from home (see Section 4.3.1). |
| Education trips in two-shifts | 50% of persons go school/university/college in morning shift and rest 50% in the afternoon shift (see Section 4.3.2). |
| Discount PT        | Discount PT fare by 10% during N – 1st and N + 1st hours and by 20% during N – 2nd and N + 2nd hour, where N is morning/afternoon peak hour (see Section 4.4). |

5 The worst plan is removed when the maximum number of plans are reached in a person’s choice set. However, to keep the randomness in the choice set, it is ensured that at least one type (i.e., SHP and a plan for each travel mode) of the plan is present in the choice set.

6 Refer to https://developer.here.com/documentation/traffic/. For the present study, v6.2 is used for traffic flow resources. The road types are classified into five categories (i.e., functional classes), of which the top three categories are included in the figure. Bengaluru city is chosen due to its greater coverage.

7 https://www.transportxtra.com/publications/parking-review/new/s/65856/cycleway-prioritisation-tool-developed-by-university-of-leeds.
exposed duration (ii) by polluting significantly higher. Thus, a cycle track physically separated by a green line will reduce the exposure significantly.

Though the crowdsourced tools are helpful in identifying the spatial-distribution of the streets, which has high potential to have a bicycle track in terms of the congestion levels, road safety, and air pollution exposure; however, a sophisticated tool like ‘Rapid Cycleway Prioritization Tool’ can be used which considers other input parameters.

4.3. Staggering of primary activities

As depicted in the survey (see Section 3.4), the travel preferences for primary activities (e.g., work, education) has the edge over secondary activities. During the lockdown period, work/study-from-home in many sectors become feasible as well as gained popularity, which seemed infeasible in the before-COVID-19 situation. With this, the need for travel is reduced. Note that the 18% persons are already staying home to work or to study (see Section 4.1). Therefore, to reduce the travel demand in the mid-long term, the following two policies are recommended. The potential of these policies is shown using the MATSim Patna model. The results are then compared with the Business as usual scenario. Thus, the following scenarios are considered.

4.4. Alternate work days

In the absence of any alternatives, work-from-home (WFH) has become essential during the lockdown period, and it is likely to continue for a short period of time. This provides a great opportunity to reduce the travel demand in the long-term and make it a new-normal. Therefore, a policy can be made such that a person comes to the office on alternate days and WFH on the rest of the days (i.e., travel only on three days in a week, e.g., Mon. Wed. Fri.). Clearly, the share of the employees who can work remotely is higher in a few industries (e.g., IT, education, etc.), and lower in some other industries (e.g., construction, manufacturing, etc.). To demonstrate the effect of alternate working days, the Patna MATSim model is used (see Section 4.1). For simplicity, it is assumed that in every ward of Patna city, roughly 50% of the work activities are performed remotely, i.e., 50% fewer work trips. Fig. 11 shows the change in the total urban traffic volume (in PCU) with respect to business as usual. The values are scaled up to represent traffic corresponding to 100% population. Clearly, a substantial reduction in the traffic can be observed on almost all streets of Patna. This leads to a reduction in the congestion externalities, i.e., for urban travelers, total delays for bicycle, car, and motorbike travel modes are reduced by 20.8%, 9.6%, and 14.8%, respectively. Further, the total travel time by bicycle, car, motorbike, PT and walk modes reduces by 18.5%, 8.0%, 11.9%, 28.7%, 29.3% respectively, which is not only directly contributing to saving in the equivalent value of time but also reduces the exposure to air pollution (Agarwal and Kaddoura, 2019), and exposure for getting the infection. Further, due to capacity relief, about 4200 additional bicycle trips (about 2.5% of total trips) are observed.

4.5. Education in two-shifts

Due to the involvement of vulnerable age groups, lesser priority, and higher chances of getting infections, the education sector is among one of the last segments, which still has not able to reopen after the

![Fig. 10. Speed profiles for Bengaluru.](image)

![Fig. 11. Change in traffic volume (in PCU) of urban travelers for a typical weekday; scaled to 100% population. OpenStreetMap© is used as background map.](image)
disruption caused due to COVID-19. Instructors and students across the globe are compelled to switch to online teaching and to learn from their homes in the wake of the pandemic. In contrast to office work, it is assumed that physical presence is important in the education sector due to various practical/fieldwork/experiments. At the same time, physical distancing is required, which is impractical for bigger class sizes and limited infrastructure. Therefore, a policy is proposed in which all educational institutions work in two shifts (morning and afternoon). A possible mechanism is to start the first shift of the school/college/university early in the morning and the next shift in the afternoon. The typical study duration can be limited to up to 6 h, i.e., additional hours can be spent studying online. For school students, it would be better to call senior students early in the morning, whereas younger students (up to class 5 or so) in the afternoon section. For colleges/institutions, every class can be split into two shifts; if required, the shifts can be reversed in alternative weeks.

To investigate the impact of this policy, it is implemented in the Patna MATSim model. For this, the departure time of every alternative educational trip in every zone (ward) is shifted to a random time in the morning departure window, and the rest of the students depart for a study trip at a random time in the afternoon departure window. The study duration of an agent is limited to 6 h. Comparing the simulation results with the business as usual scenario, it is found that due to capacity relief, the bicycle and motorbike trips increased by 3.1% and 3.2% of the total trips, respectively; these are mostly transit riders or persons who were walking. Even after an increase in the traffic (i.e., travel modes which are simulated on the network, e.g., bicycle, car, motorbike), a marginal reduction in the average trip time of all modes except PT and an insignificant increase in PT is observed. The changes in the total delay for bicycle, car, and motorbike modes with respect to BAU are −22.5%, −5.6%, and +1.8%, respectively. Clearly, this will result in an overall gain in the system welfare.

4.6. Discounting public transit

In the current crisis, imposed due to pandemic COVID-19, it is appropriate to say that public transport (PT) is the first casualty among the travel options in urban mobility systems. Given the requirements of physical distancing in outdoor settings, not only the PT ridership will take a severe hit, but it is also evident that existing PT infrastructure will fall short in meeting the demand while ensuring any level of physical distancing (Suman et al., 2020). With the perception of getting an infection in the closed public spaces, travelers are likely to avoid PT during post-COVID-19 situations too. For instance, in megacities, the PT share is likely to drop from 30.8% to 19.6% for primary activity trips and, similarly, from 16.8% to 8.4% for secondary activity trips, respectively (see Section 3.4). However, PT is a sustainable mode of transportation, the backbone of the dense urban cities and lifeline for many urban poor, and therefore, it is apt to implement the policies to improve the public transit ridership.

With the aforementioned discussion, the present study would like to propose a public transit discounting scheme for the mid-term to attract the travelers of private motorized vehicles and to shift the existing users from peak hours to off-peak hours (i.e., spreading the peak). The concept of spreading the travel demand by means of various tolling schemes is demonstrated by Arnott et al. (1993) using Vickrey’s model. Kaddoura and Nagel (2019) propose a first-best congestion pricing approach which is applied to Vickrey’s model and a real-world case study. Using the proposed pricing scheme, the area between cumulative arrival and departure curves of Vickrey’s bottleneck model became negligible, i.e., insignificant delays. However, such first-best pricing schemes are impractical, and second-best pricing schemes are advised for real-world implementations. On a similar line, this section exploits and illustrates the impact of discounting the public transit fare on the modal share and peak spreading.

The discounting of PT is investigated with the help of the Patna simulation model. Based on the number of persons en route using PT, the peak hours in the model are from 07:00 to 10:00 and 15:00–18:00; these are denoted by $T$. Therefore, up to 1 h before and after the peak hours (i.e., $T - T$ and $(T + T + 1)$, the PT fare is discounted by $d\%$ and up to 2 h before and after the peak hours (i.e., $T - 2$ and $T - 1$ and $T + 1$, $T + 2$), the discount is $2d\%$. The PT fare remain unchanged for rest of the day.

In this scenario, different values of discounting factor ($d$) are used. For each value of $d$, a simulation is run for 200 iterations. In order to provide the flexibility to react, a time allocation mutation strategy is used. In this, 10% of agents change the departure time randomly within the 2 h range. In order to compare from the same base, BAU is rerun using the same set of strategies. The modal share for different values of discounting factor is shown in Fig. 12. Clearly, as the discount increases, the share of public transit increases, which is coming primarily from the motorbike. Since the car is predominantly used by the high-income group, the share of the car remains almost constant. It is noteworthy that compared to the simulation scenario, the increase in the PT share will become significant in the real-world implementation because of the capacity constraints of the transit vehicles, which is not part of the current simulation model.

5. Discussion

The present study examined the impact of the COVID-19 outbreak on travel choices and subsequent mobility-shift of individuals with respect to their primary and secondary-activity-based trips before, during, and after the lockdown period in the Indian context. Further, the study attempted to identify the need and willingness to pay for a safer, faster, and resilient PT system that can provide handholding to the conventional PT system in normal and emergency situations and attract private motorized vehicle users. Finally, the study evaluated a set of medium to long-term policies that have the potential to reduce the negative transport externalities and pave the way for sustainable and disaster-resilient communities as the lockdowns are eased.

5.1. Extended evidences on impact of COVID-19 on mobility shift

The findings of the present study highlight the change in travel behavior and shift towards private travel modes, which are consistent with those presented in other Indian studies (e.g., TERI, 2020; ASSOCHAM, 2020; Bhaduri et al., 2020; Das et al., 2021) and other countries (Abdullah et al., 2020; Harrington and Hadjiconstantinou, 2020; Eisenmann et al., 2021; de Haas et al., 2020; Aloï et al., 2020). For instance: (a) in Kolkata, the modal share of private cars has increased by 10% during the COVID-19 outbreak (b) in Bengaluru, 50% of PT users are likely to shift to private vehicles (TERI, 2020).

Similar shifts from PT to private and NMT alternatives are found across the globe Abdullah et al. (2020). For instance, (a) in the UK, only half of PT commuters are likely to continue using it Harrington and Hadjiconstantinou (2020), (b) in Germany, PT ridership declined during the restricted lockdown period while the private car became more common (Eisenmann et al., 2021) (c) in the Netherlands, de Haas et al. (2020) found that the share of walk trips has increased two-fold, whereas a decrease in all other transport modes was observed. Government authorities and PT operators discouraged the PT, and consequently, a sharp drop in PT ridership was observed. In a nutshell, fewer trips and a significant shift from PT to a private mode of transport and some to active transport are expected. The cause of shift to the active mode of transport, primarily in Europe, is attributed to many factors, such as (a) a better infrastructure for NMT (b) lifestyle and habitual factors (c) curtailment of longer trips to shorter (d) unoccupied road space during travel restrictions (e) strong policy initiatives for bicycle lanes (f) health campaigns, etc. Clearly, a higher share of non-motorized transport is favorable; however, a significant shift from PT to private transport is offsetting its benefits and thus, highlights the need of a disaster-resilient transit system.
5.2. Challenges to public transport

The Coronavirus pandemic has disrupted the public transport most, i.e., the PT ridership has decreased by 70–90% in China, Iran, US, UK (UITP, 2020a). Similar trends, probably to a lesser extent, are likely to continue in the post-COVID-19 situation. On similar lines, PT which is the lifeline of many Indian cities were the worst hit and was suspended except for essential services during the COVID-19 induced lockdown. The findings from a bus operators’ survey reveal that only 1–2% of normal services were operational. About 81% of the operators reported no ridership at all, and the rest witnessed a 90% reduction in ridership (UITP, 2020b). The staggering decline in ridership after resuming the service could be attributed to the fear psychosis, which has got implanted in the minds of the commuters about catching the viral infection and hence preferring to use private modes of transport (like two-wheelers and cars) for travel. The operator’s survey lists challenges related to operational and service delivery, financial management, crew management, and fleet management.

5.3. Policy prescriptions for urban cities

5.3.1. Short-term policies

It is evident from the present study findings that the number of trips will reduce, and private vehicles will be the first choice of urban travelers in the short to medium term as the lockdown restrictions are eased. To counter the challenges posed by the contagious virus and sustain the services in short to long-term, at first, the authorities can attempt to promote ‘work/study from home’, staggering of primary activities, peak spreading (see Section 4.3), crowd management by restricting capacity, to keep the travel demand at a lower level and thus reducing the chances of getting the infection. This will also somewhat reduce the load on the public transport system if physical distance is to be maintained while the travel restrictions are lifted. This is applicable to both tier A and B cities. Fleet expansion is also suggested in some studies (Suman et al., 2020) for managing the PT demand, which might be more suitable to Tier A cities. In short to mid-term, restoring public trust and increasing footfalls should be the focus. The findings of the present study with respect to staggering peak demand by incentivizing travelers will be instrumental for the stakeholders, given that a mid-term modal shift toward the use of private vehicles will increase traffic congestion and make it more difficult to achieve environmental targets. The negative effects can be more intensive for Tier A cities. Further, globally governments are providing specific fiscal packages to revive PT ridership and fight the challenges faced by the transit operators (see Section 5.2). Similarly, bailout packages for PT systems and associated reforms need to begin immediately in India, primarily for tier A cities.

It is imperative that road spaces are reallocated to promote active travel in Indian cities (Tier A and B). The above policy intervention is justified since the proportion of workers who travel a distance of less than 5 km is almost 70% for both rural and urban districts (Census of India, 2011). Across the globe, dedicated infrastructure for cycle and walk is provided given the chances of post-crisis surge in traffic (ITF, 2020). This is likely to be suited for tier B cities for a majority of trips and considerable trips in tier A cities.

5.3.1.1. Long-term policies

The uneven and dynamic changes in travel demand and supply are likely to continue while the travel restrictions are lifted. However, the impact on urban mobility can remain for a longer period. The concept of work-from-home has become more common, which was hard to implement before. In order to reduce the need for travel, work-from-home should be continued to be encouraged, primarily for tier A cities, which is dominated by many big IT industries. In addition to this, the travel demand can be further controlled by staggering work hours and peak spreading. In tier A cities, a multi-centric development approach should be followed, which reduces the need for travel or restrict the trip lengths. This is likely for the secondary activities (e.g., leisure, sports, shopping, etc.) in the medium-long term. As advised in many studies before and after COVID-19, in the long-term, sustainable modes of transport should be promoted, which would lead to a reduction in congestion, air, and noise pollution, etc. For this, a share of existing road space can be allotted to non-motorized transport modes in both tiers A and B cities. In the short-medium term, it can be done using temporary measures, but for the long-term, better infrastructure facilities should be provided for pedestrians as well as for cyclists. Physical segregation, green environment, smooth
ride, lighting, cleaner streets are a few desired properties of such infrastructure. The authorities can try to run campaigns/road-shows to educate the commuters about the health benefits of cycling (Agarwal, 2021) and walking. In short, the policies should strongly be person-oriented to promote the use of non-motorized transport.

For tier A cities, public transport is considered as the lifeline of urban mobility. However, it is also considered as a transport mode used by the ‘urban poor’. This is a major concern, primarily in low-medium economies across the globe. However, the development of a safe, rapid, and comfortable public transportation infrastructure will change the lifestyle as well as habits of the users. The tier A cities need the hierarchy of transit system, i.e., mass transport (e.g., Metro/MRT/RRT, etc.), which is complemented by low-medium performance transit system (e.g., LRT, BRT). The latter is eventually supplemented by the feeder services (e.g., regular bus). On the other hand, the development of the PT system in tier B cities can start with medium performance transit system while considering the need and introduction of a high-performing transit system in the future. Given the possibility of such a disaster, the PT system is required to be resilient to disasters. This study exhibits the possibility of using a PRT during such situations, particularly in tier A cities. Under normal circumstances, the PRT can function as a feeder to the medium-performance transit system and increase accessibility and eventually increase the ridership.

5.4. Policy evaluation

It is evident from the global scenario and the subsequent wave of infection spread that we are in a long haul. To avert the negative impacts of the COVID-19 pandemic on travel behavior, the present study aimed to present and evaluate a set of policies ranging from medium to long-term. The policies recommended in the present study are congruent with those prescribed by the Government of India (GoI), wherein the cities/states/union territories (UTs) are expected to adopt strategies in a phased manner for providing urban transport services that encompass short term, i.e., within six months, medium term, i.e., within one year and long term, i.e., 1–3 years. The above proposed three-pronged approach issued in the aftermath of pandemic encourages for the revival of non-motorized Transport (NMT) for trips of length lesser than 5 km, reopening of the PT system adhering to physical distancing norms as well as providing proper sanitization protocols (including within the transit system and its access locations) and leveraging the Intelligent Transportation System (ITS) in PT operations (MoHUA, 2020).

As the lockdown eases and the unlock phenomenon begins, it is pertinent that travel demand is moderated so that COVID appropriate behavior and norms remain intact. The present study’s findings reveal that ‘Work-from-Home (WFH)’ has emerged as the new-normal for working individuals and students, teachers. Moreover, the Confederation of Indian Industry (CII) has announced that more than one million employees working in Information Technology (IT) industries are expected to work from home even after the lockdown is lifted. Another promising policy presented in this study is the ‘Staggering of Workdays’ so that COVID safety protocols can be followed swiftly. The GoI and banking sector in India has also prescribed these measures for their employees in the pandemic situation (MoHPW, 2020). A similar approach is being adopted by many in organizations, institutions, colleges, etc., to provide the essential services as well as maintaining the safety of the employees. The lockdown in India has impacted 247 million children in elementary/secondary schools due to closure of 1.5 million schools (UNICEF, accessed May 15, 2021). The report indicated that only a quarter of children has access to digital services and proper internet connectivity, which was essential for online-teaching or study at home. In such cases, the proposed policy for running the educational institutions in two shifts seems worthy in-practice. The same is also recommended in the SOP by the Ministry of Home Affairs, GoI (MoHA, 2020). The proposed policies from simulation experiments are presented for a scenario of Patna in India; however, these policies are generic and transferable to other cities, where a similar situation persists.

6. Conclusions

This is the first attempt in India, which evaluated the impact of COVID-19 using a survey tool and integrated the findings in a simulation experiment to investigate a set of policies ensuring resumption of PT services and continuity of urban travel. It is evident from the survey findings that the COVID-19 pandemic has had a profound impact on travel behavior and the choices of the individual to satisfy their travel needs. The survey data reveals that predominantly, private motorized transport is used for trips made to perform primary activities (e.g., work, study), which are shorter than 5 km in Tier A and B cities.

Approximately 66% of persons started working remotely in Tier A cities, of which about 44% persons were already in their hometown, which indicates huge intra-city/state trips immediately after lifting the ban of the travel. In tier-A cities, about 50% of public transport (PT) users reported, they would switch to other travel modes. Most of these respondents who wished to switch preferred to use private motorized vehicles. The primary reasons for the change in the travel mode are the chances of getting the infection, unavailability of the travel mode. Further, a significant drop is observed for secondary activities by intermediate public transport (IPT) modes post-COVID lockdown in tier-A cities. The shift is reported towards walk and private motorized vehicles. Plausibly, this drop is partly attributed to the reduction in travel (e.g., online shopping/deliveries). The findings also highlight the importance of PT, non-motorized transport (NMT), and intermediate public transport (IPT) modes to ensure gender equity in both categories of the cities. The active mode of travel (walking and bicycling) surged as the most resilient and the least contagion risk travel option among the respondents in both Tier A and B cities, especially for secondary activity trips.

A longer recovery period of mass transportation systems to normalcy is likely to shift urban cities towards car-dependency or private motorized transport modes in the absence of alternate safe and disaster-resilient mobility options. About 50% respondents in Tier-A and 40% in Tier-B are willing to pay up to 1.25 times of their past expenses to make travel safer using a private car or taxi to avoid the chances of getting an infection. The findings reveal that demand as well as the willingness to pay extra for a safer, faster, cleaner, comfortable, and most importantly, resilient PT exists. In the mid-run, due to the necessity of physical distancing, the existing transit fleet is unlikely to serve the travel demand even after increasing the frequency to the maximum possible level. Therefore, it is pragmatic that investments are made in the active travel modes (NMT) for a sustainable and resilient future. Additionally, a longer duration of physical distancing and/or isolation, home quarantine may lead to depression and anxiety issues, which further impels the investment in the NMT infrastructure as well as in the promotion of active mode of transport.

The present study also demonstrates the potential of a few transport policies using the MATSim model of Patna, India. In order to evaluate the choice model parameters, the simulation model was re-calibrated using the modal share of Tier-B cities from the survey data. The first policy exhibits that the provision of bicycle superhighways will push the bicycle share from 31% to approximately 44%. To reduce congestion, improve air quality, and resume the primary activities with a cautious approach, a staggering of primary activities (work, study) post-COVID is proposed as a travel demand management strategy. Results from simulation experiments for the staggering of primary activities demonstrates the reduction in the congestion externalities, i.e., for urban travelers, total delay for bicycle, car, and motorbike travel modes is reduced by 20.8%, 9.6%, and 14.8% respectively. Further, the total travel time by bicycle, car, motorbike, PT and walk modes reduces by 18.5%, 8.0%, 11.9%, 28.7%, 29.3% respectively, which is not only directly contributing to saving in the equivalent value of time but also reduces the exposure to air pollution and exposure for getting the infection. Further,
the simulation for educational activities in two shifts (within a day) reveals that, due to capacity relief, the bicycle and motorbike trips increased by 3.1% and 3.2% of the total trips respectively; also the share in densely populated cities is crucial not only for urban-poor (with no access to private vehicles), essential workers for their daily travel but also for maintaining sustainability in growing cities. In the mid-run, to attract ridership in PT, incentives strategy in the form of reduction of fare in simulation reveals that as the discount increases, the share of PT increases, which is coming primarily from the motorbike. Since car share is very low and predominantly used by the high-income group, its share remains almost constant in the model. However, compared to the simulation scenario, the increase in the PT share will become prominent in the real-world policy implementation. Further, it is recommended that such strategies should be evaluated in the business continuity plans for every transport operator in hazardous/emergency situations.

To summarize, the present study illustrates a few major issues every city might face in the near- or far-future due to the COVID-19 disruption. The policies like staggering of primary activities, discounting PT fare, use of the bicycle-sharing systems, etc., are likely to be effective in the short-to-mid-term only. For the long-term, the focus must be on erecting the infrastructure to make transport integrated, sustainable, and resilient. Additionally, self-sustainable neighborhoods should be encouraged to reduce the trip lengths substantially or need of private motorized transport for various secondary activities.

Author contribution

Conception and design of the work: A. Agarwal; literature review: A. Agarwal, A. Thombe; questionnaire preparation: A. Agarwal, A. Thombe; survey data analysis: A. Thombe; simulation preparation, experiments: A. Agarwal and manuscript draft preparation: A. Thombe, A. Agarwal. All authors read and approved the final manuscript.

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