Physical distancing on public transport in Mumbai, India: Policy and planning implications for unlock and post-pandemic period

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A B S T R A C T

COVID-19 outbreak affected the daily lives of people around the globe, and authorities proposed numerous interventions to make activity participation and traveling safer during the pandemic period. This study investigates the potential implication of such interventions on executing physical distancing on public transport in Mumbai, India. The study reviews the demand-supply gap of public transport during the pre-pandemic and pandemic period and evaluates the challenges in practicing physical distancing with the short-term interventions, such as lockdown guidelines at different phases and long-term interventions, such as flexible work arrangements, on public transport. The study findings indicate that physical distancing on public transport is difficult to achieve at peak hours, even with the very high travel restrictions and lockdown measures, unless flexible work arrangements are implemented. The flexible work arrangements, such as staggered working hours and work from home, can significantly reduce peak-hour demand and total excess demand without altering the supply pattern. The study can guide in constituting transport and broader policy decisions, including developing low-risk public transport for the post-pandemic period.

1. Introduction

The novel Coronavirus Disease (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has rapidly spread worldwide. The World Health Organization (WHO) declared this contagious disease a pandemic on March 11, 2020 (WHO, 2020a). The countries around the globe took preventive actions to limit the number of cases and slow the spread by restricting travel and out-of-home activity participation. The travel restrictions may delay the dissemination, but it cannot be considered an isolated intervention to rapidly contain the disease (Mateus et al., 2014). The high restrictive environment persisted for several weeks and months, and it created a massive change in the daily lives of people and affected the economy drastically (Budd and Ison, 2020; Mogaji, 2020). As a result, although the active COVID-19 cases did not reach zero, several countries started to relax the restrictions or lift lockdown measures. However, the recommendations included with the easing of restriction suggest not following pre-pandemic normality but strictly practicing respiratory and hand hygiene along with physical distancing (widely known as social distancing) to avoid/decrease physical contact between individuals, especially at public places (WHO, 2020b). Physical distancing is keeping

a distance of at least 1 m between each individual and avoiding spending time in crowded areas or groups, and it may help in breaking the chain of COVID-19 transmission (WHO, 2020c).

Public transport is a popular mode of transportation in cities of developing countries, and there is a risk factor attached to public transport use on infectious disease transmission (Cho and Chu, 2011; Troko et al., 2011). When the people are returning to their daily subsistence activity, it is advised to practice physical distancing on public transport and transport stations to reduce the contagious disease transmission (Fletcher et al., 2014). Enforcement of physical distancing demands more space for passengers, and thus, controlling the number of passengers traveling on public transport is the key measure to achieve it (Dzisi and Dei, 2020). However, overcrowding in public transport is a significant issue in developing countries during the pre-pandemic period, especially during peak hours (Pucher et al., 2004; Sahu et al., 2018). A considerable shortage in public transport supply is expected while introducing mandatory physical distancing norms into the public transport service. This effective safety measure may increase the use of private and intermediate public transport on roads. Furthermore, the individuals who can afford private transportation may shift from public transport to private transport for their daily trips (Bucsky, 2020) to

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avoid the risk of disease contraction in shared travel mode during the pandemic period (De Vos, 2020). The increase in on-road vehicles can worsen traffic congestion and air quality in urban areas.

In addition to increasing private vehicle ownership and use, the developing countries may also face transport equity issues due to limited public transport supply during the pandemic. The urban poor cannot afford to access the private and intermediate public transport modes as high traveling costs are associated with these modes. Additionally, the lack of transport accessibility can result in unemployment and poverty, leading to a lack of access to healthy food and poor housing condition. Moreover, poor health and housing condition can make the urban poor more vulnerable to COVID-19. Public transport should be safe (De Vos, 2020) and available for all, including individuals from low-income groups, those without a private vehicle, and specially-abled groups during the pandemic period.

Physical distancing is a decisive measure during the pandemic until a completely effective vaccine against COVID-19 is widely available (Atangana, 2020; Thu et al., 2020). However, implementing physical distancing norms into the current public transport service requires additional measures to balance the supply and demand. The partial travel restrictions, such as restricting non-essential trips like leisure trips, followed by different countries, can reduce the transport demand during the pandemic. Besides, the pandemic period witnessed an increase in the use of Information and Communications Technology (ICT) for completing daily activities, such as work from home (Kramer and Kramer, 2020; Spurk and Straub, 2020), online learning, and online shopping (De Haas et al., 2020), etc., can also reduce the transport demand to some extent. Thus, such practices can reduce the excess demand (the demand above the supply) during peak hours.

The present study explores the potential implication of executing new norms for practicing physical distancing in otherwise crowded public transport in developing countries. In the context of physical distancing as a relevant application, the research frameworks are applied for public transport in Mumbai, India, to provide meaningful insights for decision-makers. This study discusses the challenges in practicing physical distancing on public transport during the current pandemic period, which is compared with the pre-pandemic demand and new demand scenarios. The more policy-oriented branch of the study is investigated through the new demand scenarios.

The upcoming sections are structured as follows. Section 2 briefly discusses the timeline of important events and the travel restrictions enforced during the initial stages of COVID-19 in India and compares transport characteristics among developing cities from Global South. Section 3 elaborates on the data, methodology, and scenarios selected for the study. Section 4 deals with analysis specific to pre-pandemic transport demand. Section 5 presents the impact of partial travel restrictions on public transport physical distancing during the pandemic. Section 6 sets the field for subsequent analysis with new transport demand scenarios that focus on the change in workplace policies. Finally, section 7 outlines the policy implications, and Section 8 concludes. The most relevant research outcomes are shown in Figs. 10 and 11.

2. Travel restrictions and activity participation DURING COVID-19 pandemic

COVID-19 started in December 2019 in Wuhan city of central Hubei province of China (Hui et al., 2020), and India reported its index case on January 30, 2020 (Government of Kerala, 2020). The first three cases were students who returned from Wuhan, and they recovered without spreading the disease. Later from March 2, 2020, new cases were reported from different parts of the country after several people with travel histories to affected countries and their contacts tested positive. The first COVID-19 fatality in India was reported on March 12, 2020 (Ministry of Health and Family Welfare, 2020).

Indian states and union territories declared the COVID-19 outbreak an epidemic during March 2020, and the authorities took various measures to contain the spread of the virus, including the temporary closure of educational and commercial establishments. A complete nationwide lockdown was imposed on March 25, 2020 (Ministry of Home Affairs, 2020), when the cumulative number of cases had crossed 600, and COVID-19 deaths were ten. Fig. 1 illustrates the timeline of critical events of COVID-19 in India as of December 31, 2020 (Ministry of Health and Family Welfare, 2020).

Ministry of Home Affairs, Government of India, issued guidelines and rules on activity participation and travel restrictions for lockdown Phase I (named Lockdown 1.0), which extended for 21 days. Along with the compulsory use of masks and physical distancing, the guidelines and rules imposed included a strict restriction on inter-state and inter-district traveling, closure of gathering places conducting non-essential activities (for example; gym, shopping mall, religious places), night curfew, restrictions based on activity type, age and health condition, and limiting the maximum number of people permitted in vehicles as well as commercial and public places. The complete lockdown affected the daily lives of the 1.2×10^9 Indian citizens in several ways – raising the unemployment level, and economic issues of migrant workers and low-income groups were the primary concern. Although the COVID-19 cases were increasing nationwide, the national and state governments relaxed the restrictions at different stages (Lockdown 2.0, 3.0, and 4.0) to help the people get involved in the essential activities in the new normal conditions. On June 1, 2020, when the COVID-19 cases have surged past 250000, the national Government released an order (Unlock 1.0) to lift travel restrictions imposed previously. The Unlock 1.0 guidelines include relaxations in night curfew and opening religious places, shopping malls, hospitality services, inter-state traveling, domestic flights, and public transports except for metro trains. Following unlock phases (Unlock 2.0, 3.0, 4.0, 5.0, 6.0, and 7.0), relaxed several other restrictions on educational institutes, sports, and physical training facilities, and recreational facilities and revoked the night curfew order.

The civic body of Indian cities and states Government has imposed certain restrictions in addition to the national guidelines for their region, including time window for the opening of places for non-essential activities, the maximum limit for worker strength in Government and private offices, and curfew. Table 1 describes the COVID-19 restrictions in major Indian cities at three phases, and it indicates that most of the restrictions are relaxed since Lockdown 1.0; however, the authorities suggest following age restriction in activity participation (People aged above 65 years and children below 10 years of age are not allowed to travel for non-essential activities), online services and staggered timing for work, education, and commerce. Besides, suburban trains are closed for the general public in some cities like Mumbai and Chennai, even during Unlock 7.0. Several people like informal workers and daily-wagers are affected when the suburban trains are closed since March 2020. However, reopening public transport incorporating COVID-19 guidelines needs an evaluation to propose suitable interventions for the pandemic period.

The share of public transport in the Global South cities indicates that cities highly depend on public transport in daily life (see Table 2). Public transport services owned by public operators in these countries are generally subsidized due to environmental and social benefits (Fearnley and Aarhaug, 2019). Typically, public transport in developing countries is economical and time-saving for people from different socioeconomic backgrounds, and therefore, public transport in most of these cities was overcrowded during peak hours in the pre-pandemic period. Thus, public transport has an important role in providing mobility and accessibility and reduces social exclusion and poverty in society. However, during the pandemic period, public transport is either entirely or partially closed in these cities to reduce the risk of spreading viruses. The official lockdown measures like passenger limit in vehicles, restriction in some activity participation, and the fear of contracting the virus while engaging in outdoor activity reduced activity participation (Google LLC, 2020), public transport usage (Google LLC, 2020), and congestion levels on roads (TomTom, 2020). Nevertheless, providing necessary public
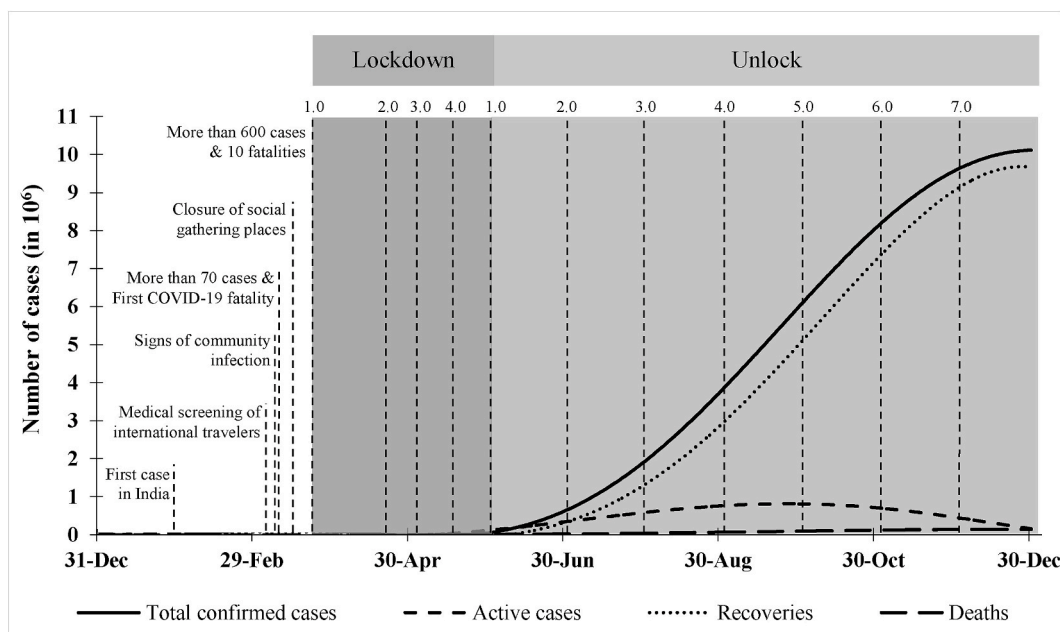
Fig. 1. Timeline of the COVID-19 pandemic in India as of December 31, 2020.

transport access to the general public while maintaining necessary safety regulations during the pandemic is a primary challenge in the urban transport system in developing countries, considering the existing infrastructure and economy. Hence, analyzing the effect of the lockdown measures suggested by the authorities on the current public transport system and finding out the interventions best suited for functioning the public transport could improve the mobility and quality of life in the cities of developing countries during the pandemic period.

Among the Indian states, Maharashtra has reported the highest number of COVID-19 cases in 2020, and the state capital, Mumbai, is the most populated and one of the worst COVID-19 affected Indian cities. The Government of India, Mumbai's civic body, and Public transport authorities have been taking several interventions at different unlocking stages to provide safer public transport for the urban population in Mumbai during the pandemic period. The study chooses to analyze the implication of physical distancing in Mumbai Public Transport under different short-term interventions (guidelines and measures that were relaxed immediately) and long-term interventions (guidelines and measures recommended to continue for a longer period) suggested by different authorities.

3. Data and methodology

3.1. Data collection and data description

The paper focuses on the potential implication of different COVID-19 preventive interventions on the public transport service in Mumbai, a metropolitan city in India, with a large population of about 12.44×10^6 (Census of India, 2011). For the analysis, the study required three kinds of data, pre-pandemic transport demand data, public transport supply data, and COVID-19 preventive guidelines and measures enforced in Mumbai (which was discussed in Table 1).

Data based on a household-level survey conducted in the administrative area of Municipal Corporation of Greater Mumbai is used for the information specific to transport demand. The survey was conducted from April 2016 to July 2016 after resolving the issues specific to wording, question sequence, and respondent biases in the pilot survey questionnaire. The survey captured the respondent's 24-h time use with daily travel information for a working day (any day from Monday to Thursday) and a non-working day (Saturday or Sunday). The study also uses the data on the socioeconomic characteristics of the individual collected from the survey.

Mumbai being a city with nearly 42 percent of the population living in the slum, the survey attempted to obtain the data from the representative sample to reduce sampling bias. A four-stages of the survey which was conducted to reduce sampling bias are; i) identification of the distribution of population in the urban area, ii) random selection of formal and informal (slums, chawls, etc.) housing locations, iii) identification of households within the selected survey locations, and iv) administration of survey for household members. Every individual traveling for personal reasons is considered eligible for the survey participation; therefore, all available members above five years old (school-going) were surveyed. Personal face-to-face interviews, with computer-aided personal interview (CAPI) survey questionnaires, were conducted at household levels to capture the revealed preference data on the daily travel behavior of respondents. Compared to internet/online survey, personal face-to-face interviews is found to be more suitable for revealed information in developing countries since it guarantees high response rate (Rastogi and Rao, 2002). Besides, face-to-face interviews provide more flexibility and reduce the chances of refusal (Richardson et al., 1995). Moreover, face to face interview allows capturing the information from the target population from different behavioral segments while online surveys are inaccessible to illiterate individuals, those who have poor access to phone or internet, etc. The data gathered the information from 1205 individuals and have been previously used for the researches exploring the travel time variation (Thomas *et al.*, 2019), multitasking activities (Varghese and Jana, 2018a), and use of ICT (Varghese and Jana, 2018b) while traveling in different modes.

All the information specific to an individual was removed from the actual data set if found any of these issues; incomplete survey response, format issue, duplicate data, missing trip information, error in the time of travel information. After the necessary data cleaning, 1740 trips of 711 individuals were considered for the analysis, and a total of 3448 mode changes is observed from the total trips. The data show that individuals used multiple modes of transport for completing a single trip. Table 3 shows an overview of the survey sample.

The survey data captured the travel behavior of individuals resided in informal housing settlement (such as slums or chawls), formal housing settlements (such as apartment complexes, Government provided

Table 1

COVID-19 rules and guidelines recommended for major Indian cities during three phases (Phase 1: Lockdown 1.0, Phase 2: Lockdown 4.0, Phase 3: Unlock 6.0).

	Phase	National guideline	Mumbai	Delhi	Bangalore	Chennai	Kolkata
Age restriction	1	People aged above 65 years and children below 10 years of age are not allowed to travel for non-essential activities					
	2						
	3						
Curfew	1	Complete lockdown					
	2	7 PM–7 AM					Nil
	3	Nil	11 PM–6 AM		11 PM–5AM	Nil	
Activity Participation							
Work	1	Few sectors such as healthcare, police, etc., are allowed to travel for work.					
	2	Allowed but advised Staggering of work hours and work from home	Private offices: Not allowed	National guideline		Allowed with only 50% of their workforce	Private offices: Allowed with 50% strength
	3	Allowed but advised Staggering of work hours and other suitable measures	Private offices: Allowed with 30% strength	Employees should work in shifts	Continue working from home	National guideline	
Education facilities	1	Not allowed					
	2	Not allowed for students. Online learning permitted					
	3	Higher classes and higher studies with a limited number of people at a time; encouraged online classes and staggered work hours					
Retail	1	Allowed essential and emergency facilities only					
	2	Allowed	Limitation in time and number of people	Odd-even basis with limitation in the number of people	Limitation in the number of people	Limitation in the number of people	Limitation in time and number of people
	3	Allowed	Limitation in time	National guideline			
Restaurants, recreations and sports facilities	1	Not allowed					
	2	Restaurant: Allowed to take away and food delivery					
		Mall, cinema halls, Gym, & Pool: Not allowed					
		Parks and sports complexes are permitted to open without spectators					
		Mall, cinema halls, Gym, & Pool: Not allowed					
	3	Allowed				Limitation in time	National guideline
Events and gatherings	1	Social, political, and religious functions, gatherings & congregations: Not allowed, and Wedding & funerals: Allowed with limitation number of					
	2	people					
	3	Allowed with limitation number of people					
E-commerce	1	Essential and emergency services					
	2	Allowed all goods except in the Containment Zones					
	3	Allowed					

		National guidelines	Mumbai	Delhi	Bangalore	Chennai	Kolkata
Transport modes							
Private Transport	1	Allowed only for essential and emergency services with passenger limit					
	2	No restriction	Passenger limit	Pillion rider not allowed	National guideline		
	3	Allowed					
Paratransit	1	Not allowed					
	2	No restriction	Allowed with passenger limit				
	3	Allowed					
Public transport	1	Not allowed					
	2	Buses: Allowed	Buses: Allowed with passenger limit				
		Local trains: Allowed for selected population					
		Metro: Not allowed					
	3	Bus & Metro: Allowed	Trains: Allowed for women during non-peak hours	National guideline		Trains: Allowed for the general public during non-peak hours	National guideline
		Trains: Allowed for a certain population (some government workers)					

Note: Data collected from the State and Central government websites and National news websites.

housing, etc.) and slum rehabilitation authority housing (SRA). 46.27 percent of the total number of individuals surveyed resided in informal housing settlements. The value indicates that the data captured the percentage share comparable to the actual population living in the slum (42 percent). The data on employment shows that the percentage of individuals having formal jobs is 41.4 percent, and informal jobs are 16.62 percent. All the jobs untaxed or unmonitored by the Government were categorized as informal jobs in the data set. The Worker Population Rate in Mumbai as per the 4th Annual Employment-Unemployment Survey 2013-14 is nearly 45 percent (Ministry of Labour and Employment, 2014) which is comparable to MCGM (2016) and as per the Employment and Unemployment survey conducted in the 68th round of National Sample Survey during 2011–2012 indicates 49.35 percent (NSSO, 2015). The employment data captured by the survey is observed to be representing the actual population in Mumbai.

The data on household vehicle ownership shows two-wheeler vehicles (with 45.21 percent) are more common than four-wheeler vehicles (with 10.51 percent) in Mumbai city. The two-wheeler is the most

Table 2
Transport condition of 14 cities of the Global South.

City	Public transport share			Public transport on December 2020	Average yearly reduction in congestion level on December 2020
	Share	Data year	References		
Mumbai, India	45	2011	Pai (2011)	Trains closed for the general public	−33.33
Delhi, India	42	2011	Pai (2011)	Open with passenger limit	−26.09
Bangalore, India	35	2011	Pai (2011)	Open with passenger limit	−52.14
Chennai, India	39	2008	Pai (2011)	Trains closed for the general public during peak hours	Not available
Kolkata, India	54	2008	Roychowdhary et al. (2018)	Open with passenger limit	Not available
Mexico City, Mexico	78	2010	Peralta (2008)	Open	−54.55
Sao Paulo, Brazil	36	2012	Informações and Domiciliar (2013)	Limited services	−70.24
Jakarta, Indonesia	36	2009	Nguyen and Hanaoka (2009)	Open with passenger limit	−72.94
Shanghai, China	33	2009	Journeys (2011)	Open	2.99
Manila, Philippines	49	2014	Regidor (2019)	Open with passenger limit	−52.94
Seoul, South Korea	63	2010	Journeys (2011)	Open with high safety measures	Not available
Lima, Peru	62	2004	Transport Council of Lima and Callao, 2005	Open with additional facilities for cyclists and pedestrians	−47.92
Bogota, Colombia	62	2008	Rode et al. (2014)		−21.52
Bangkok, Thailand	30	2009	Nguyen and Hanaoka (2009)	Open	−49.49

Note: Congestion level reduction evaluated from data obtained from TomTom (2020)..

Table 3
Overview of the survey sample.

Characteristics	Statistics
Number of samples	711 people
Gender	Male: 60.76%, Female: 39.24%
Age	Below 10: 2.1%, 10–65: 95.5.27%, Above 65: 2.4%
Housing	Formal settlement:25.18%, Informal settlement:46.27%, Slum Rehabilitation Authority (SRA) houses: 28.55%
Employment	Formal jobs:41.4%, Informal jobs: 16.62%, Studying:15.21%, Homemakers/unemployed:24.65%, Part-time/other: 2.11%
Household private vehicle ownership	Two-wheeler:45.21%, Four-wheeler: 10.51%
Number of trips	1740 trips per day
Number of mode change	3448 mode change per day
Average travel time	34 min 54 s

Table 4
Percentage share of transport mode use in Mumbai.

Trip types	Modes	Percentage of trips	
Public Transport Only	Bus/Train/Metro	11.9	
		11.9	
		30.3	
		1.8	45.5
		1.5	
Public Active Transport	Bus/Train/Metro with Walk/Bicycle	30.3	
		45.5	
Public Intermediate public Transport	Bus/Train/Metro with Autorickshaw/Taxi	1.8	45.5
Other Public Transport	Bus/Train/Metro with Private car/Two-wheeler & Walk/Bicycle & Autorickshaw/Taxi	1.5	
Active Transport Only	Walk/Bicycle	41.9	
Intermediate Public Transport Only	Auto-rickshaw/Taxi	2.5	
Private Transport Only	Private car/Two-wheeler	2.5	
Other	Private car/Two-wheeler & Walk/Bicycle & Autorickshaw/Taxi	7.7	

preferred private mode in Indian cities due to its low initial and maintenance cost and maneuverability on congested roads (Thomas et al., 2019b). With 4.69 household sizes observed in the data, the share of private vehicles per individual is approximately 12 percent. The vehicle ownership observed is relatively close to the vehicle ownership details mentioned in MCGM, 2016 and Subbarao and Rao (2014). The collected demand data indicate that an individual's average trip rate (number of trips per person per day) on a weekday is 2.45 in the pre-pandemic period. Another study on travel patterns in the Mumbai metropolitan region shows the average trip rate as 3.19 (Subbarao and Rao, 2014). The employed people have an average number of daily trips of 2.4, which is lesser than students, home-makers, and unemployed people. The average number of daily trips by individuals below ten years, between 10 and 65 years, and above 65 years of age are 2.27, 2.44, and 2.94. The trips use single and/or multiple modes to reach the destination, averaging 1.98 per trip. Walking is the most used mode of transport by the city's population. While 41.9 percent of the daily trips are made purely in active transport, 45.5 percent of the daily trips use public transport as a single mode of transport or along with other transport modes such as active, private, or intermediate public transport modes (see Table 4). The data indicates that public transport and active

transport play a vital role in Mumbai's urban transport, as observed in other studies from the city (Baker et al., 2005; Subbarao and Rao, 2014)

The data demonstrate that the travel patterns differ among individuals from different housing conditions. Seventy-seven percent of the public transport users reside either in informal settlements or SRA housing. Although vehicle ownership does not vary highly among residents from different housing settlements, the share of private transport and intermediate public transport is more for formal housing residents than for informal and SRA housing residents.

3.1.1. Activity participation and mode-split
Table 5 shows the activity-based travel pattern of the individuals in

Table 5
Percentage share of transport mode use for different kinds of activity participation.

	Return to Home	Work/education	Retail and recreation	Grocery shopping, hospitals, repairs, bill payment	Other	Total
Total	48.32	32.86	8.03	7.63	3.16	100
Active Transport						
Walk	55.2	49.8	56.3	66.2	68.8	54.8
Bicycle	8.7	5.5	19.5	9.1	4.6	8.4
Public transport						
Train	16.6	20.9	9.7	10.3	7.3	16.7
Bus	11.6	15.0	4.3	4.2	12.8	11.6
Metro	0.6	0.9	0.7	0.8	0.9	0.7
Private Transport						
Four-wheeler	0.4	0.7	0.4	0.4	0.0	0.5
Two-wheeler	1.9	2.9	1.1	0.8	0.0	2.0
Intermediate Public Transport						
Auto Rickshaw	4.3	3.7	6.9	5.7	5.6	4.5
Cab/Taxi	0.7	0.7	1.1	2.7	0.0	0.8

Greater Mumbai, represented through the percentage share of different modes used by Mumbai's population. The table displays walking is the most used mode of transport for completing all kinds of activities. Public transport, especially trains and buses, is the second most used mode of transport for activities except for leisure trips. Among the different activities, mandatory trips such as work and school trips have the highest share of public transport and private vehicles and the lowest share for walking. Maintenance trips such as grocery shopping depend more on active transport and intermediate public transport modes than mandatory trips. Leisure trips and other trips such as visiting religious places, which are less recommended during the pandemic period, also show more active transport and intermediate public transport modes than mandatory trips. The average time taken for traveling in a day is 34.9 min. The average daily time for traveling is highest for Mandatory trips (36.54 min) and lowest for Maintenance trips (32.67 min). The mode-specific activity participation data for Mumbai is not described in any other recent studies and, therefore, could not be compared to justify the observation.

The study considers four types of data from the travel diary of weekday trips for the demand estimation: (i) Purpose of travel (such as work trip, school trips, essential shopping trips, etc.), (ii) Modes selected for each trip, (iii) Travel time taken in each mode, and iv) Time of traveling in each mode used for every trip. The overall transport demand in Mumbai is estimated from the obtained demand structure prepared using survey data.

The suburban rail system, metro trains, and public bus system (named BEST) are the available public transport modes in the city. Every day, more than 7.3×10^6 and 3.7×10^6 passengers use the suburban rail system and public bus system (Cropper and Bhattacharya, 2012). Two kinds of information, collected from the official websites of public transport operators, used to compute the public transport supply curve for a weekday include (i) the public transport route and schedule data and (ii) the capacity of different public transport vehicles (IRCTC, 2019; Mumbai Best City Bus, 2019; Reliance Mumbai Metro, 2020).

3.2. Methodology

To implement physical distancing inside public transport, the transport operator must decide the maximum occupancy of the public transport modes to provide a minimum distance between two individuals. This study analyses the challenges of physical distancing on public transport at two new levels of transport supply patterns based on its occupancy; namely, Physical distancing level 1 (PD1) with 50 percent of seating occupancy (sitting only) and Physical distancing level 2 (PD2) with 50 percent total occupancy (sitting and standing), which are compared against Business as usual (BAU) supply pattern with cent percent total occupancy in public transport that was existed in the pre-pandemic period. Physical distancing level 1 would be a more preferred option during the high-risk pandemic condition.

The present study proposes a two-stage analysis to find the implication of different interventions for physical distancing on public transport, and it uses the travel supply and demand data of public transport in the city. The first stage analyses the impact on physical distancing during the phase-wise easing of lockdown. Each phase relaxes the travel restrictions in the city, and the second stage is a scenario analysis that focuses on long-term intervention for safer transportation during the pandemic and post-pandemic periods. Fig. 2 shows the methodology framework of the study.

The scenario analysis uses the assumptions related to flexible work policies. Thus, the study emphasizes the impact of the short-term interventions, such as lockdown guidelines at different phases, and long-term interventions, such as flexible work arrangements, on public transport physical distancing. The pre-pandemic demand, the transport demand that existed before the COVID-19 pandemic with no restriction or regulation on passenger movement, represents the baseline scenario to compare all the alternative scenarios. The study considers the interventions implemented by the Government of India or practiced by the Indian population during the pandemic period to reduce disease dissemination. The analysis evaluates the excess demand (the demand above the supply) for public transport daily while practicing physical distancing under different assumptions. Table 6 provides a basic description of the supply and demand levels that are selected for the study.

The paper presents two main directions of research. Firstly, the analysis gauges whether physical distancing on public transport is a plausible solution in developing countries with the current transport supply and demand during the pandemic. Secondly, the analysis investigates whether new policies which are not forcefully restricting activity participation (such as flexible work arrangements) be considered a pertinent policy to solve the transport issue prevailing from the pre-pandemic period.

4. Public transport demand during pre-pandemic period

4.1. Transport demand on a weekday

Fig. 3 illustrates the 24-h transport demand pattern of trips completed on public transport modes and all modes. The demand curve is expressed in terms of the percentage share of travelers among the total population in Mumbai. Although walking is the predominant mode of transport in Mumbai, public transport modes (train and bus) dominate walk trips during certain peak hours. Three major peaks in public transport demand are observed between 9.00 AM to 10.00 AM, 2.00 PM and 2.30 PM, and 4.00 PM to 5.00 PM. The evening peak has a high percentage of travelers than the morning peak due to participating in different activities, such as returning home, shopping, and socializing. The highest peak of train and bus travelers is between 4.00 PM and 5.00 PM, while the highest peak of the day is between 5.00 PM to 5.30 PM.
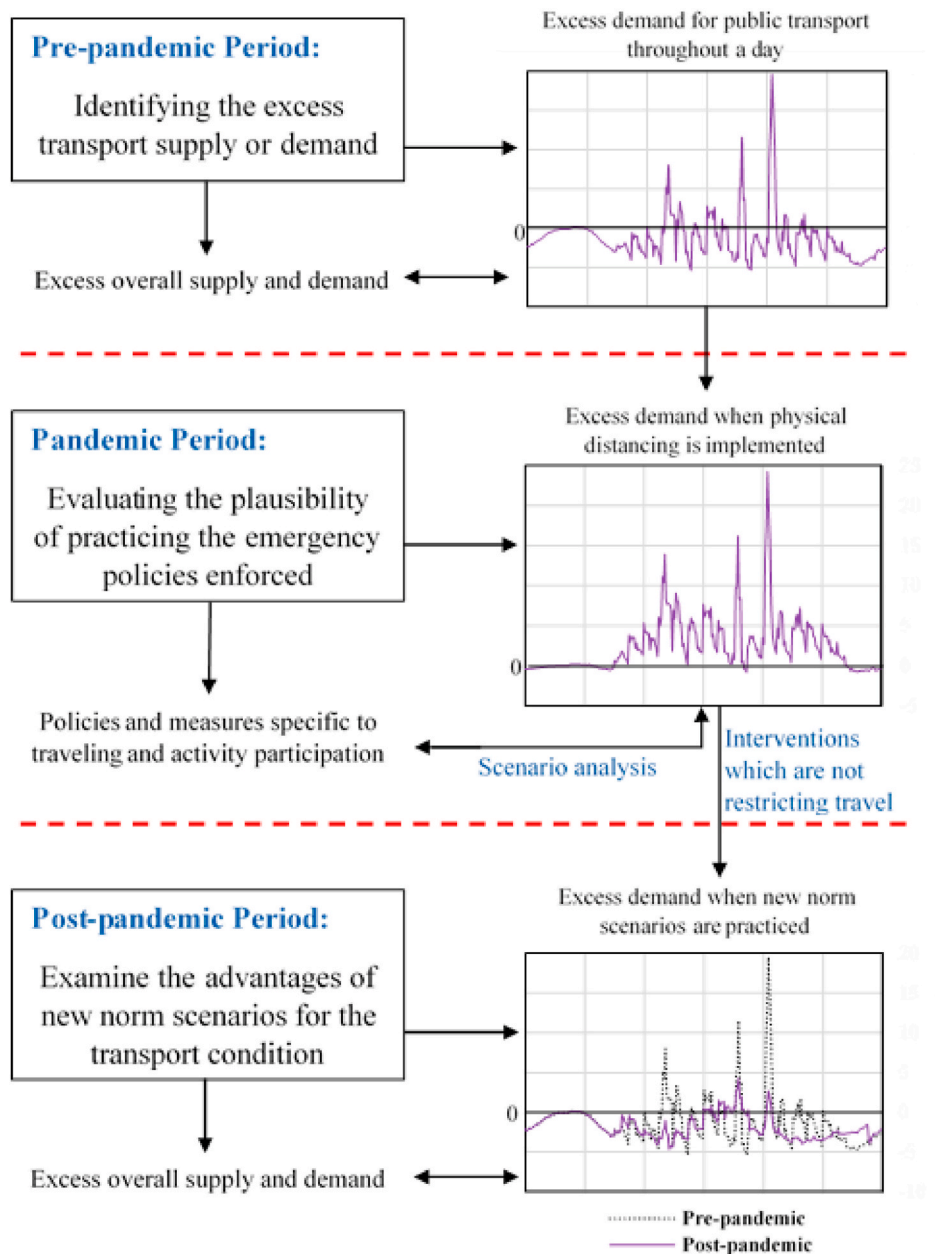
Fig. 2. Methodology framework.

Table 6
Supply and demand levels selected for the analysis.

Supply levels	Description
Business as usual (BAU)	100 percent total occupancy (Sitting and standing)
Physical distancing level 1 (PD1)	50 percent of seating occupancy (Sitting only)
Physical distancing level 2 (PD2)	50 percent total occupancy (Sitting and standing)

Demand levels[a]	Description
Pre-pandemic demand	No restriction or regulation on passenger transport
Phase-wise easing of lockdown	Phase-wise relaxation of the restriction on passenger transport. Total number of phases: 4
Long term interventions	New passenger transport demand through flexible work policies. Total number of scenarios: 3

[a] Note: All demand levels are analyzed with three transport supply levels; BAU, PD1 and PD2.

Public transport users are reduced to less than 5% after 7.00 PM. At 10.00 PM, the total number of travelers is reduced further to less than 2%. The minor share of train use is observed between midnight to early morning (01.00 AM–06.00 AM).

4.2. Physical distancing on public transport with pre-pandemic demand

Fig. 4 displays the city's pre-pandemic demand pattern along with the three public transport supply patterns considered for the study, and demand is observed to be less than the BAU supply during certain peak hours. Fig. 5 provides a more detailed illustration in terms of excess demand for public transport with the pre-pandemic demand at different public transport supply patterns.

BAU supply condition reveals excess demand or crowding in public transport during peak hours (9 AM–10.30 AM, 2 PM–2.30 PM, and 4 PM–5 PM). The supply of public transport is expected to be less than the demand most of the time throughout the day if physical distancing is enforced (implementing transport supply patterns PD1 or PD2) and no
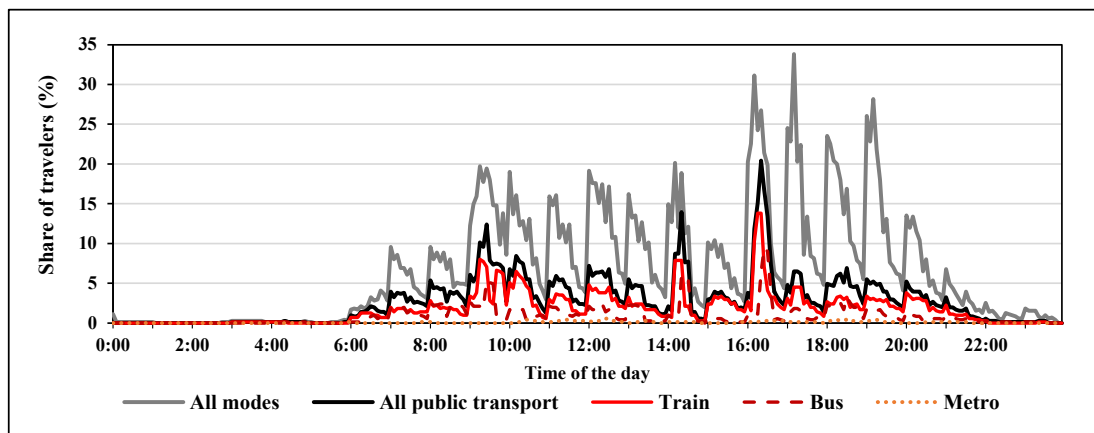
Fig. 3. 24-hour travel demand pattern based on the survey data from 2016 (in percentage).
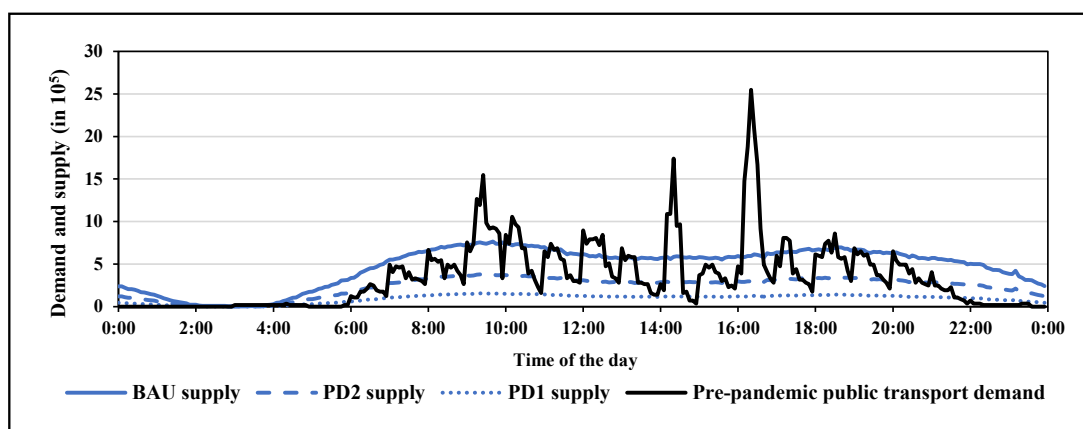

Fig. 4. Public transport supply levels and pre-pandemic demand based on the survey data from 2016.

restriction for travel and participation in out-of-home activities is imposed (Pre-pandemic demand).

The finding highlights that the physical distancing on public transport is not practical to follow with the pre-pandemic demand. Therefore, implementing a new policy to control transport demand or restriction on travel and participation in out-of-home activities could reduce the excess demand and encourage physical distancing in the existing public transport system.

5. Public transport demand during pandemic period: phase-wise easing of travel restrictions

Public transport services, retail, recreations, workplaces, educational institutes, etc., were closed in Mumbai on March 23, 2020, when the nationwide lockdown was imposed to prevent virus spread. Facilities opened gradually, and Fig. 6 shows the percentage change in activity participation during the pandemic period until December 2020 in Mumbai, India. Out-of-home activity participation has increased since the Unlock period, and currently, bus and metro services are functioning for the general public. However, the suburban train service, used by 80 lakh people daily in the pre-pandemic period, is still closed to the general public. Moreover, vehicle ownership and congestion level in Mumbai are rising during the unlock period. This section discusses the pragmatism of physical distance in public transport during a pandemic when travel restrictions are executed.

Four phases are considered to analyze the implication of phase-wise easing of lockdown or travel restriction, increasing relaxation in the restriction on passenger transport and out-of-home activity. Travel

restrictions for phases one to three are framed considering the lockdown and unlock guidelines issued by the Maharashtra State Government and Ministry of Home Affairs, Government of India (see Table 7). Phase 1 follows the guidelines for Lockdown 1.0; Phase 2 follows the guidelines for Lockdown 4.0; Phase 3 follows Unlock 6.0, and Phase 4 rules are assumed for the study. Travel behavior of Mumbai citizens during pandemic identified from Google's COVID-19 Community Mobility Reports (see Fig. 6) is referred for assuming the participation share percentage for certain activities. The restrictions on essential and non-essential trips and night curfew for out-of-home activities reduces with each phase.

About 53 percent of workers in Mumbai are salaried employees (Ministry of Labour and Employment, 2014) whose work can be accomplished through work from home to some extent during the pandemic. About 40 percent of workers are self-employed. The rest of the workers are contract workers or casual laborers. Besides, Mumbai people use ICT to complete several other activities, including online shopping, online educations, and telemedicine. The analysis uses the pre-pandemic transport demand information to identify the public transport demand during the phase-wise unlocking period, such as i) socioeconomic characteristics (such as age, vehicle ownership, and job type) ii) activity participation and mode use, and iii) time of travel.

Excess demand for public transport during the phase-wise easing of restriction is identified and analyzed in this section. Three scenarios of phase-wise easing of restrictions are selected, which include:

Scenario 1: Phase-wise easing of travel restrictions considering the change in activity participation.

Scenario 2: Phase-wise easing of travel restrictions considering the
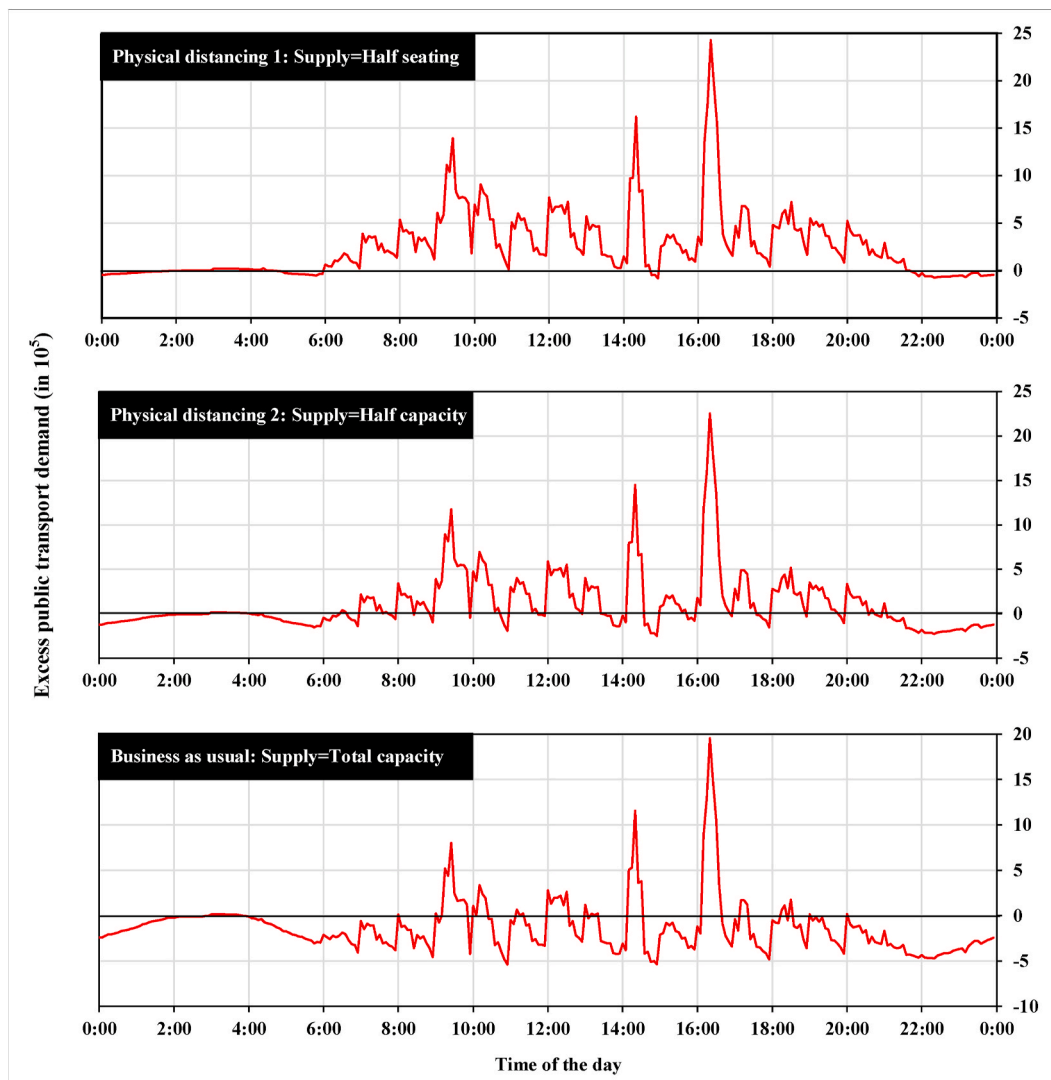
Fig. 5. Excess demand for public transport during the pre-pandemic period.

change in activity participation and mode shifting behavior.

Scenario 3: Phase-wise easing of travel restrictions considering the change in activity participation, mode shifting behavior, and public transport supply limit.

5.1. Scenario 1: Phase-wise easing of travel restrictions considering the change in activity participation

Scenario 1 assesses the excess demand for public transport during the phase-wise easing of restriction at three supply levels discussed in Table 6. Travel restrictions specific to public transportation have not been considered for this scenario. Fig. 7 shows the excess demand for public transport during the phase-wise easing of restriction considering the change in activity participation.

The analysis illustrates that the overcrowding in public transport can be reduced significantly in the BAU supply pattern with phase 1 and phase 2 travel restrictions. However, with a strict physical distancing norm in public transport, such as only 50 percent of seat occupancy is allowed for use in public transport (PD1), the supply will be less than the demand for almost every hour for all phases except phase 1. For phase 1 with the PD1 supply pattern, the excess demand is not observed during some non-peak hours. However, when 50 percent of total occupancy (PD2) is allowed, demand does not exceed the supply for phase 1 and phase 2, except during afternoon and evening peak hours.

5.2. Scenario 2: Phase-wise easing of travel restrictions considering the change in activity participation and mode shifting behavior

Scenario 2 assumes that the private vehicle owners can shift from public transport to private transport, considering that would be a safer transport decision during the pandemic period (see Fig. 8). A drastic difference in the excess demand pattern is observed with this assumption. The result explicates that better achievement of the physical distancing norms in public transport is possible when trip-makers shift from public transport to private transport for their daily trips. Peak time demand can be reduced majorly through this mode shift. The highest difference in phase 1 due to the mode shift is 488206 during 4.20 PM, which is around 20 percent of the scenario 1 phase 1 excess demand during that time. However, during.

5.3. Scenario 2: Phase-wise easing of travel restrictions considering the change in activity participation and mode shifting behavior

Scenario 2 assumes that the private vehicle owners can shift from public transport to private transport, considering that would be a safer transport decision during the pandemic period (see Fig. 8). A drastic difference in the excess demand pattern is observed with this assumption. The result explicates that better achievement of the physical distancing norms in public transport is possible when trip-makers shift
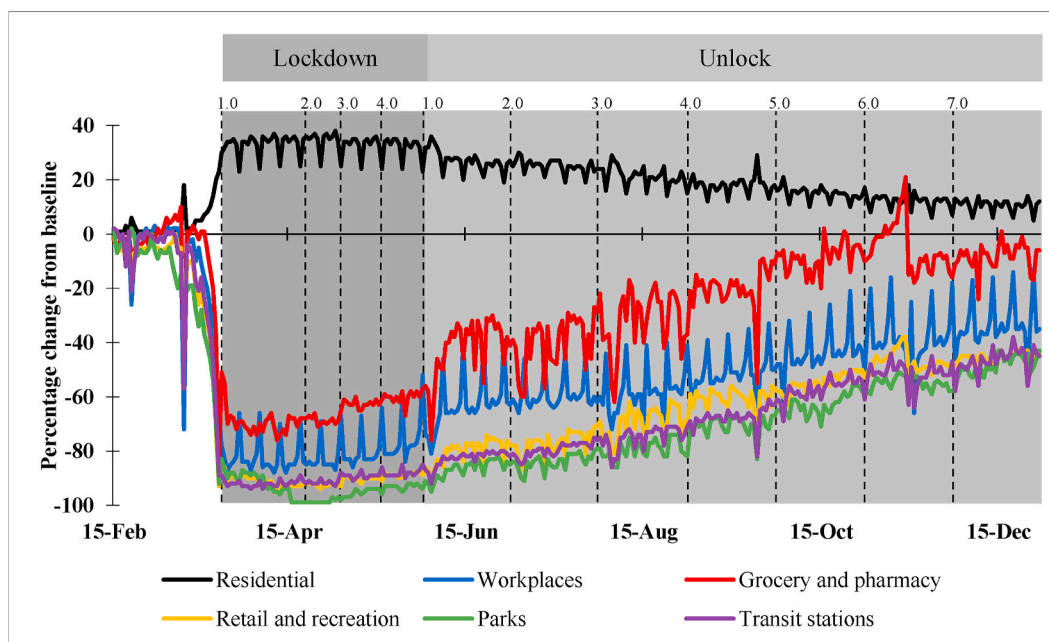
Fig. 6. Activity Participation during COVID-19 pandemic in Mumbai, India as of December 31, 2020. Authors' rendering based on Google COVID-19 Community Mobility Reports.

Table 7
Travel restrictions during four phases.

	Phase 1	Phase 2	Phase 3	Phase 4*
Age restriction (except for essential and health purposes)	<10 & >65	<10 & >65	<10 & >65	<10 & >65
Office work trips (53% Work trips)	10%	15%	50%	100%
Non-office work trips (47% Work trips)	5%	50%	100%	100%
Educational and Non-essential trips	0%	0%	20%	50% between 5am and 9pm
Non-essential trips	0%	10%	50%	50% between 5am and 9pm
Grocery shopping and other essential trips*	40% between 9am and 5pm	50% between 7am and 7pm	90% between 5am and 9pm	100% between 5am and 9pm
Medical trips*	40%	50%	90%	100%

Note: '*' indicates assumed condition while other conditions consider guidelines issued by authorities.

from public transport to private transport for their daily trips. Peak time demand can be reduced majorly through this mode shift. The highest difference in phase 1 due to the mode shift is 488206 during 4.20 PM, which is around 20 percent of the scenario 1 phase 1 excess demand during that time. However, during phase 4, this mode shift behavior can worsen the traffic congestion prevailing in the city.

The analysis highlights the vast gap in public transport supply-demand during the pandemic period while practicing physical distancing. Even with travel restrictions and mode-shift towards private vehicles during the pandemic period, the existing public transport service in the city cannot meet the transport demand if it has to follow strict physical distancing norms.

5.4. Scenario 3: Phase-wise easing of travel restrictions considering the change in activity participation, mode shifting behavior, and public transport supply limit

Scenario 3 evaluates the excess demand for public transport during the phase-wise easing of restriction considering the change in activity participation, mode shifting behavior, and public transport supply limit. Travel restrictions specific to public transportation instructed by different authorities are included along with other activity-specific restrictions for evaluating the excess demand. Table 8 describes the public transport supply-based travel restrictions incorporated for analysis. One limitation of the study is that this analysis does not incorporate the number of public transport vehicles allowed to run during different phases of the unlock period. Train users without access to private transport options may shift to bus service when the entry is restricted in train for the general public. The analysis takes three assumptions; i) restricted train users without a private vehicle will shift to the bus, ii) the number of services and their timing is the same as the pre-pandemic supply for all public transport services if they are open except for Phase 2 train service, and iii) there is zero excess supply or demand for the train during Phase 2.

Fig. 9 shows the graph representing excess demand for public transport during the unlock period considering the change in activity participation, mode shifting behavior, and public transport supply limit. The excess demand for public transport is more when the public transport service is limited or closed during the unlock period (Phase 1 and 2). The overcrowding in the train can be controlled with restricted access during peak hours as implemented in Phases 2 and 3. However, overall demand for public transport will not reduce significantly from Scenario 2 as most train users without access to private transport will prefer shifting to bus service when the access to train service is restricted, thus increasing the demand for bus service. Besides, the time taken for traveling by bus is more compared to train, thus increasing the demand for public transport at a time.

Physical distancing in public transport is not attainable with the transport demand and supply restrictions selected for Scenario 3. Closing or reducing the level of public transport service cannot limit the transmission of the virus if the public transport is functioning without physical distancing norms. The result indicates that strict
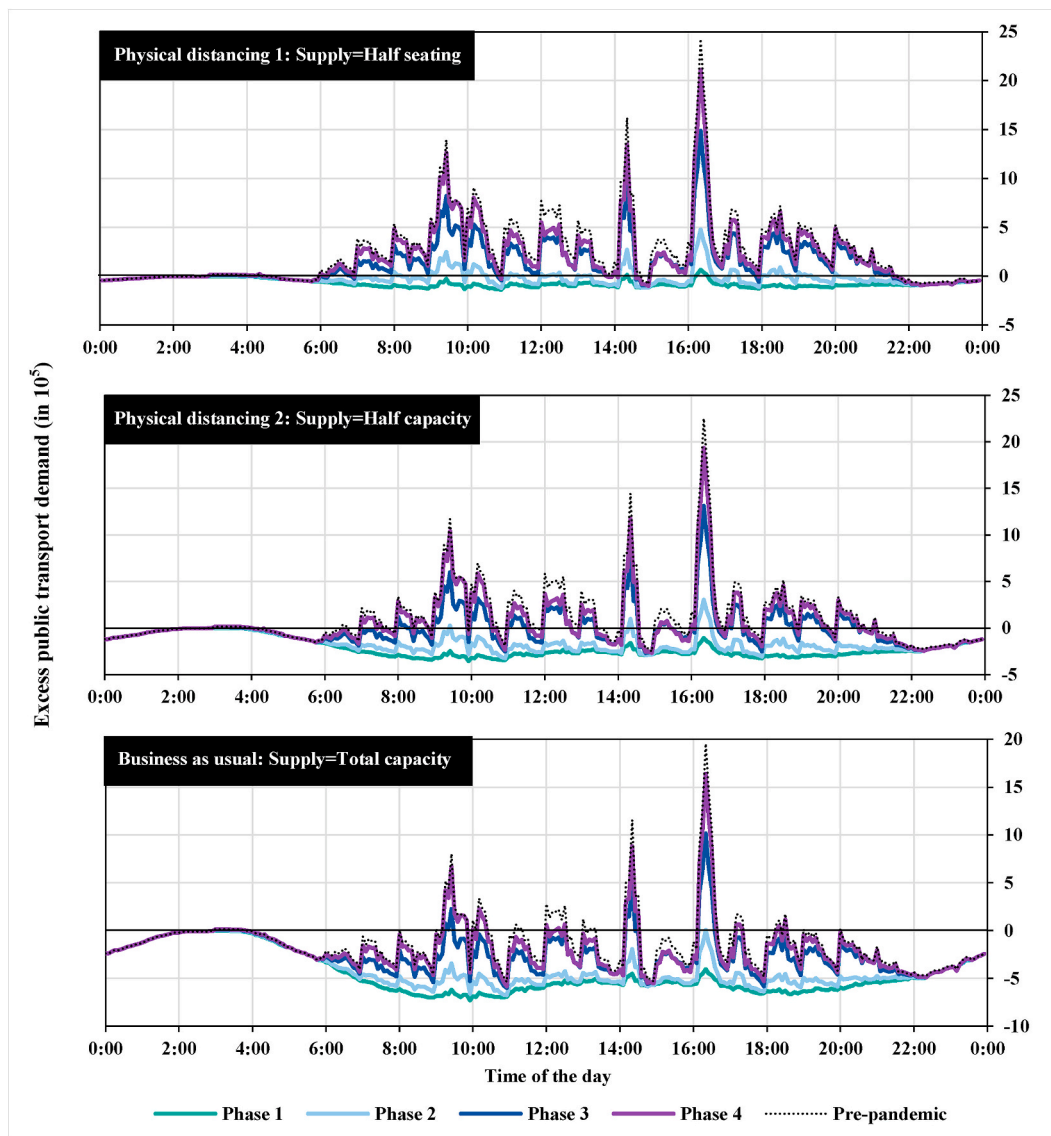
Fig. 7. Excess demand for public transport during the unlocking period considering the change in activity participation.

implementation of physical distancing norms (PD1) will result in very high demand for public transport. Peak hour restriction to all public transport use can reduce the excess demand during peak hours, and people may prefer traveling for non-essential activities during non-peak hours. However, large total excess demand due to limited public transport supply will make physical distancing difficult.

6. New public transport demand from long-term interventions

A scenario analysis that looks into a long-term intervention to change passenger travel patterns through flexible work policies is analyzed in this section. Three scenarios selected for the study include:

Scenario 1: Introducing compulsory work from home policy for office workers,

Scenario 2: Implementing staggered work hours for the offices, and.

Scenario 3: Analysing the combinational effect of staggered work hours and work from home policy and potentially changing the travel behavior of other trips due to the trip chaining effect.

Assumptions for each scenario are discussed in Table 9. The analysis uses the pre-pandemic transport demand information to identify the public transport demand for each of the scenarios, which includes i) socioeconomic characteristics (job type), ii) activity participation and

mode use, and iii) time of travel. Fig. 10 shows the comparison between the excess demand for public transport at the BAU supply condition for the sub-scenarios of each scenario.

6.1. Scenario 1: Compulsory work from home policy

Work and returning home from work trips have the highest share in a city's travel pattern. Moreover, Mumbai city has a large proportion of the population using public transport for work-related trips. The pandemic has shown that work from home is a possible alternative for several office jobs, and thus, introducing compulsory work from the home policy can reduce the overall demand for public transport. Several advantages, such as reducing travel time and travel expenses, more quality time with family and kids, and flexible working hours, are attached to this option of work from home. However, a complete work-from-home job has certain limitations: less social interaction with colleagues, clients, physiological disadvantages of not meeting people, etc. Considering both the benefits and drawbacks, Scenario 1 analyses how a weekly one-day (Sub-scenario 1.1) and two-day (Sub-scenario 1.2) compulsory work from home culture change the transport demand in the city.

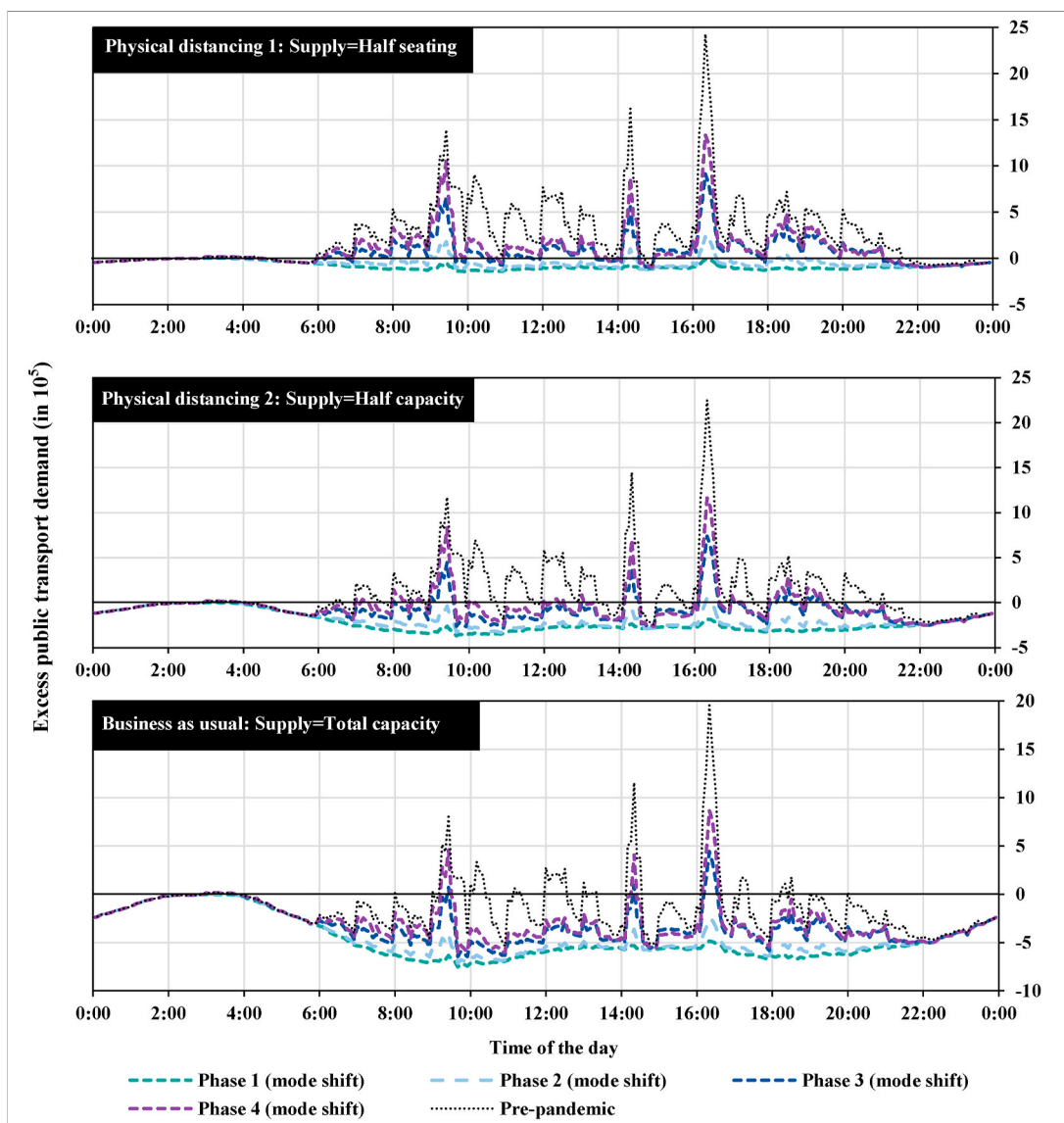Scenario 1 result shows the one- or two-day compulsory work from

Fig. 8. Excess demand for public transport during the unlocking period considering the change in activity participation and mode shifting behavior.

Table 8
Public transport supply-based travel restrictions.

	Phase 1	Phase 2	Phase 3	Phase 4*
Bus	Closed	Reopened	Open	Open
Train	Closed	Open for essential workers (Government employees)	Phase 2 guidelines + Open for women & dabbawallas (tiffin box suppliers) during non-peak hours (11 AM - 3 PM and 7 PM till midnight)	Phase 3 guidelines + Open for all during non-peak hours (11 AM - 3 PM and 7 PM till midnight)
Metro	Closed	Closed	Reopened	Open

Note: '*' indicates assumed condition based on suggestions from different authorities while other conditions consider guidelines issued by authorities.

home policy for office workers cannot curb the public transport supply and demand gap prevailing in the city (see Fig. 9). However, the peak hour demand can be reduced through changing work policies. The maximum demand reduction is obtained at morning peak hours, which is around 0.4×10^6 people when two weekly days of compulsory work-

from-home policy are introduced.

6.2. Scenario 2: Staggered working hours

The public transport demand-supply relation during the pre-pandemic period and phase-wise easing of travel restriction highlighted the excess demand for public transport. Nevertheless, the excess demand curve indicated that demand is less than the supply during non-peak hours, especially with BAU and PD2 supply patterns (see Fig. 8). Besides, scenario 1 demonstrates that a flexible working arrangement positively affects peak-hour transport demand reduction. These finding related to the excess public transport supply leads to the second scenario for the long-term intervention. Scenario 2 tests the impact of staggered working hours on public transport demand. The general working hours in Indian offices are between 8 AM and 10 AM and ending time between 4 PM and 7 PM. However, there are specific office jobs, like Information technology jobs, which have multiple time shifts. The scenario considers the staggering working hours for all office-based jobs, and four sub-scenarios with different time intervals for work starting and ending time are assumed. Sub-scenarios 2.3 and 2.4 consider the intermediate peak hour in demand for designing the office hour window.
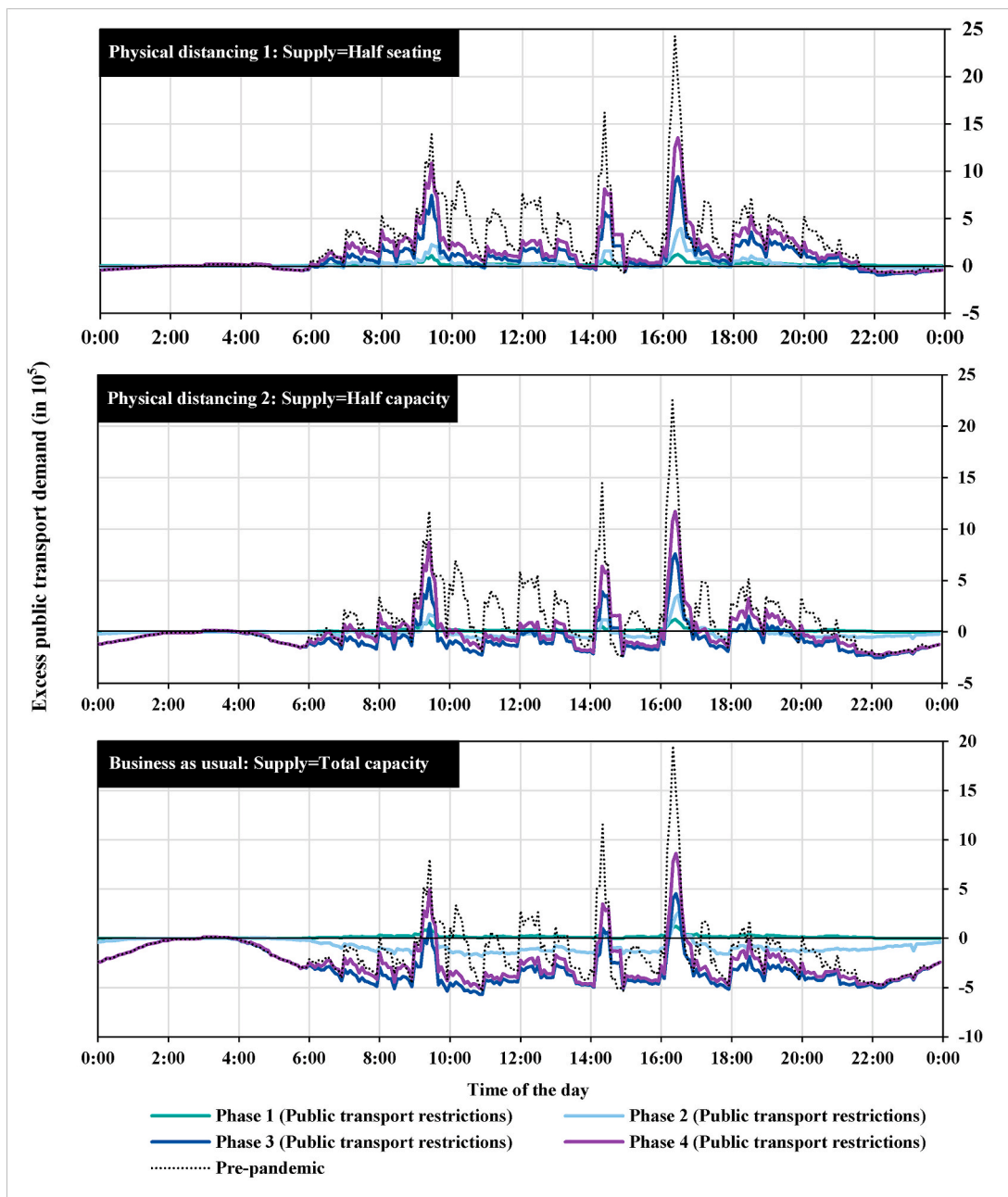
Fig. 9. Excess demand for public transport during the unlocking period considering the change in activity participation, mode shifting behavior, and public transport supply limit.

Scenario 2 result shows a substantial difference in peak hour public transport demand for all sub-scenarios, indicating that the flexible working arrangement can transform the city's transport condition. Moreover, this scenario indicates that both the crowding and overall excess supply of public transport can be reduced without any alteration in the level of service and schedule of public transport supply. However, the three peak transport characteristic of the city limits the reduction in demand during the intermediate peak hour (2.00 PM–2.30 PM), thus making it the highest peak of the day in the new transport demand. The maximum difference in demand among sub-scenarios is observed closer to this intermediate peak hour. The best sub-scenario among four different staggered work hours, which has minimum overall excess demand and lowest peak demand, is sub-scenario 2.4 with maximum window (office start time 6.30 AM-3 PM and office end time 1.30 PM–11.00 PM).

6.3. Scenario 3: Combined compulsory work from home policy and staggered working hours with their impact on other trips

The trip chain-effect linking work, and non-work trips, is a common phenomenon in a working day. The pre-pandemic travel pattern indicates that 4 percent of non-work trips are connected with going to work trips, and about 30 percent of non-work trips are connected with work to home trips. Scenario 3 considers this effect into account while combining it with the best sub-scenarios of scenarios 1 and 2. The travel demand for non-work activities linked with work trips is also considered staggered between the assumed time intervals. Scenario 3, which considers the best-staggered work hours, weekly two-day compulsory work from home policy, and staggered non-essential trips, proves again that the crowding in public transport can be significantly reduced and distributed within the day by adopting the changes in work policy. The
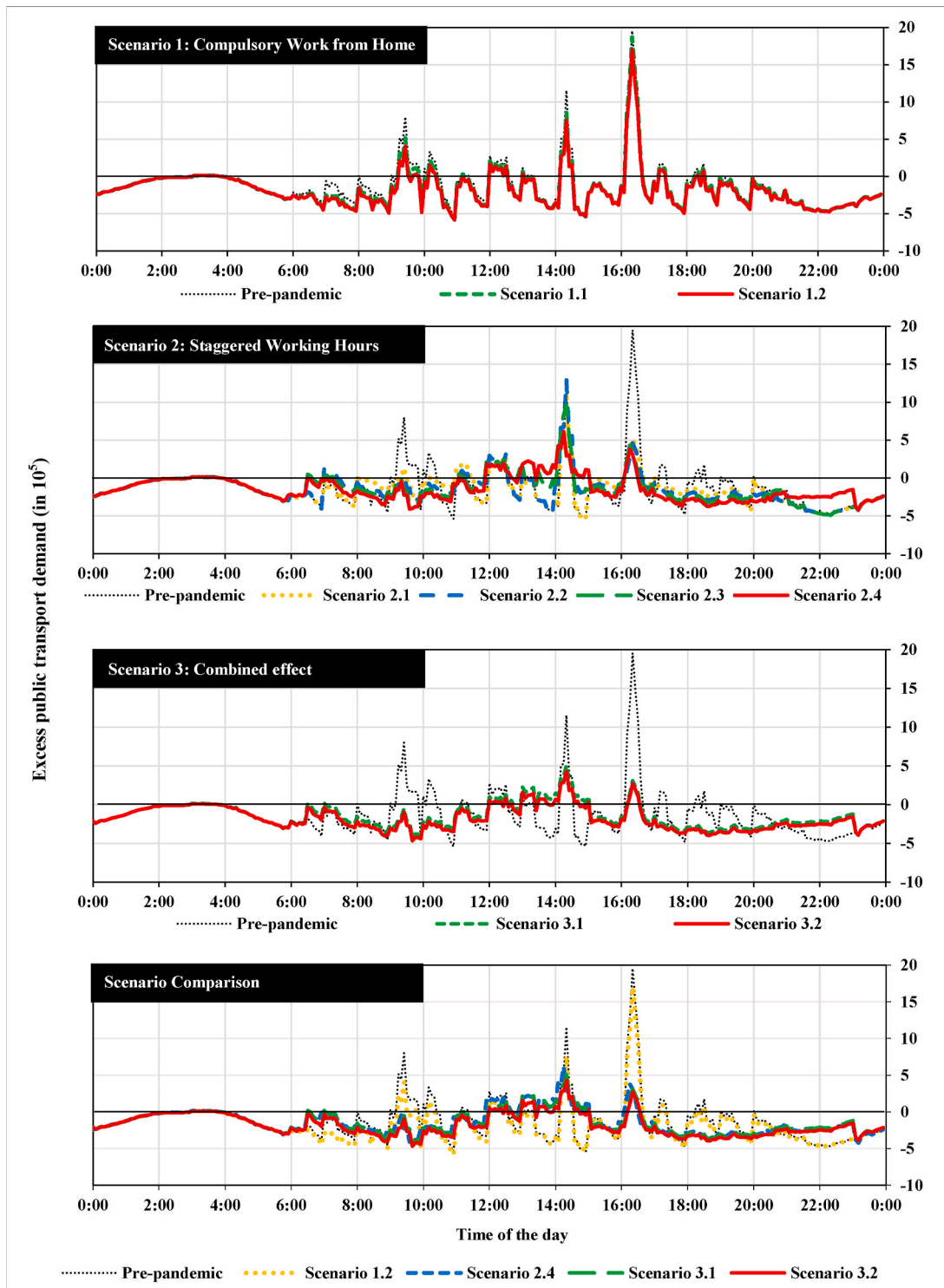
Fig. 10. Excess demand for public transport with flexible work policies (Supply = Total capacity).

best sub-scenario, which can reduce overall excess demand and supply in public transport at different supply conditions, is sub-scenario 3.2 (see Fig. 10). Besides, the sub-scenarios of scenario 3 highlight the difference in transport demand has reduced drastically compared to sub-scenario 2.3 and 2.4 of scenario 2, which have the same staggered working time window, especially between 2 PM and 3 PM. The non-work trips linked with work trips are high in number during this time, which will also have staggered characteristics when they perform staggered working hours.

6.4. Physical distancing with new transport demand

The results from scenario analysis illustrate that overall and peak time excess demand have reduced significantly from the baseline scenario (pre-pandemic demand), and virtuous results can be achieved by altering the existing work policies. The finding demonstrates the staggered work hours have a significant impact on public transport demand. Fig. 11 displays the impact of the phase-wise restriction on public transport demand in the future if the best scenario 3.2 is implemented.
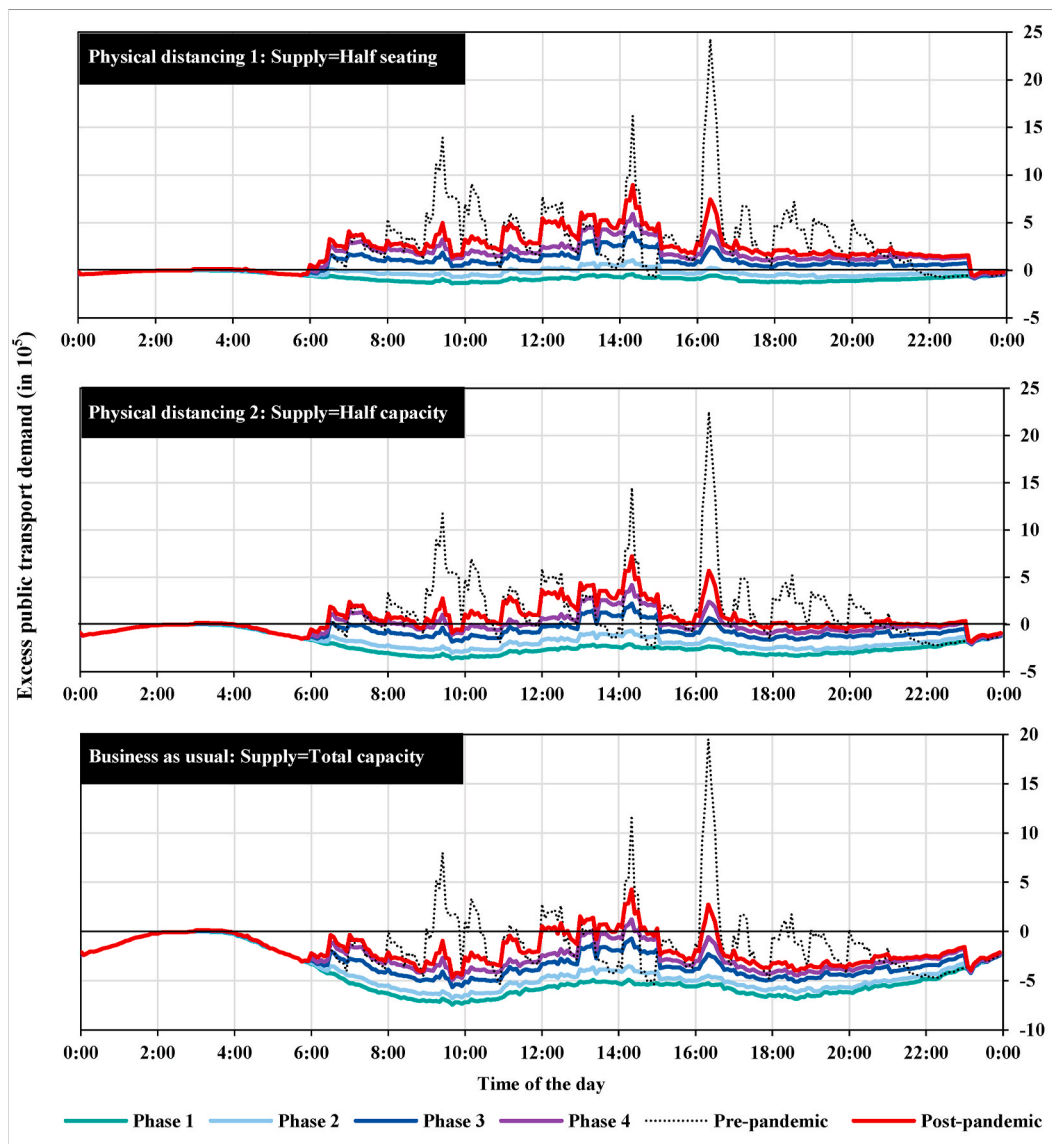
Fig. 11. Excess demand for public transport during physical distancing with flexible work policies.

Table 9
Scenarios for long-term intervention.

		Sub-scenario 1	Sub-scenario 2	Sub-scenario 3	Sub-scenario 4
Scenario 1: Work from home (WFH)					
Number of days with compulsory WFH every week		1	2	Nil	Nil
Scenario 2: Staggered office hours					
Start time		8am–11.30am	7am-12.30pm	6.30am-1pm	6.30am-3pm
End time		3pm–7.30pm	2pm–8.30pm	1.30pm–9.00pm	1.30pm–11.00pm
Scenario 3: Combinational effects					
Staggered office hours	Start time	6.30am-3pm	6.30am-3pm	Nil	Nil
	End time	1.30pm–11.00pm	1.30pm–11.00pm		
Staggered non-work trips[a]		11.30am–12.00am	11.30am–12.00am		
Two days compulsory WFH every week		Nil	Yes		

[a] Staggered non-work trips – About 30% of non-work trips (obtained from travel diary will have a time-shift effect as a result of staggered office hours.

The travel restriction assumptions follow the same conditions used for the Phase-wise easing of travel restrictions considering the change in activity participation during the unlocking period (see Table 7). The analysis shows that the strict physical distancing with occupancy equivalent to half seating capacity (PD1) during a pandemic situation can be practiced with the new demand pattern while phase 1 restrictions are executed. However, excess demand during some peak hours with a maximum count of 639 can be reduced if encouraged personal vehicles during the pandemic situation, as discussed in section 5.2. Physical distancing with occupancy equivalent to half capacity (PD2) can be practiced with the new demand pattern while phase 1, 2, and 3 restrictions are executed except during noon and evening peak hours.

7. Discussion of policy implications

The challenges in the urban transport system have increased and changed radically since the beginning of the pandemic condition. During the pre-pandemic period, providing safer, inclusive, low energy consuming, and low-emission transport was the primary sustainable transportation goal. However, the pandemic situation demanded the immediate reform of safety standards in the transportation system. Physical distancing and hygiene in transport modes are the highest mandate authorities enforce to control the COVID-19 dissemination.

7.1. Public transportation in the pre-pandemic period

The pre-pandemic public transport demand and supply data of Mumbai illustrate that the total supply is higher than the demand by about 36×10^6, while the total excess demand is 16×10^6 indicating that the demand is more than supply at several instances of time intervals (see Fig. 3). The demand-supply relation establishes the overcrowding effect on public transportation during peak hours. With more than 5×10^5 excess demand, the major peak hours are observed between 9 AM-10.30 AM, 2 PM–2.30 PM, and 4 PM-5 PM. The total excess supply indicates the possibility of reducing the crowding in public transport without altering the BAU supply pattern or level of service and schedule through a new demand pattern.

7.2. Public transportation in the pandemic period

Public transportation faces more challenges during the pandemic among the different transportation modes, especially in developing countries. Implementing physical distancing, and maintaining hygiene and safety standards in public transport stations, in addition to public transport, is the primary challenge. The transport operators would have to keep additional staff and security to enforce physical distancing, encourage respiratory and hand hygiene, and clean the surfaces. Secondly, providing access to all passengers in need is another challenge that becomes complex when the capacity of each vehicle is to be reduced significantly due to physical distancing norms. The final and third kind of challenge is the financial burden due to the high operating cost required for maintaining a high degree of safety measures for limited occupancy. Public transport in Mumbai was at a financial loss in the pre-pandemic period (Cropper and Bhattacharya, 2012). Both the public transport services in the city, BEST (Eeshanpriya, 2019) and suburban train services (The Economic Times, 2018), are functioning under financial loss. Traditionally, public transport targets social, environmental, and economic benefits (Stjernborg and Mattisson, 2016). The primary role of public transport in low-income and high population density cities is to provide better mobility and access to opportunities and overcome poverty and social exclusion (Starkey and Hine, 2014); thus, generally, the public transport system's profit in such cities is low
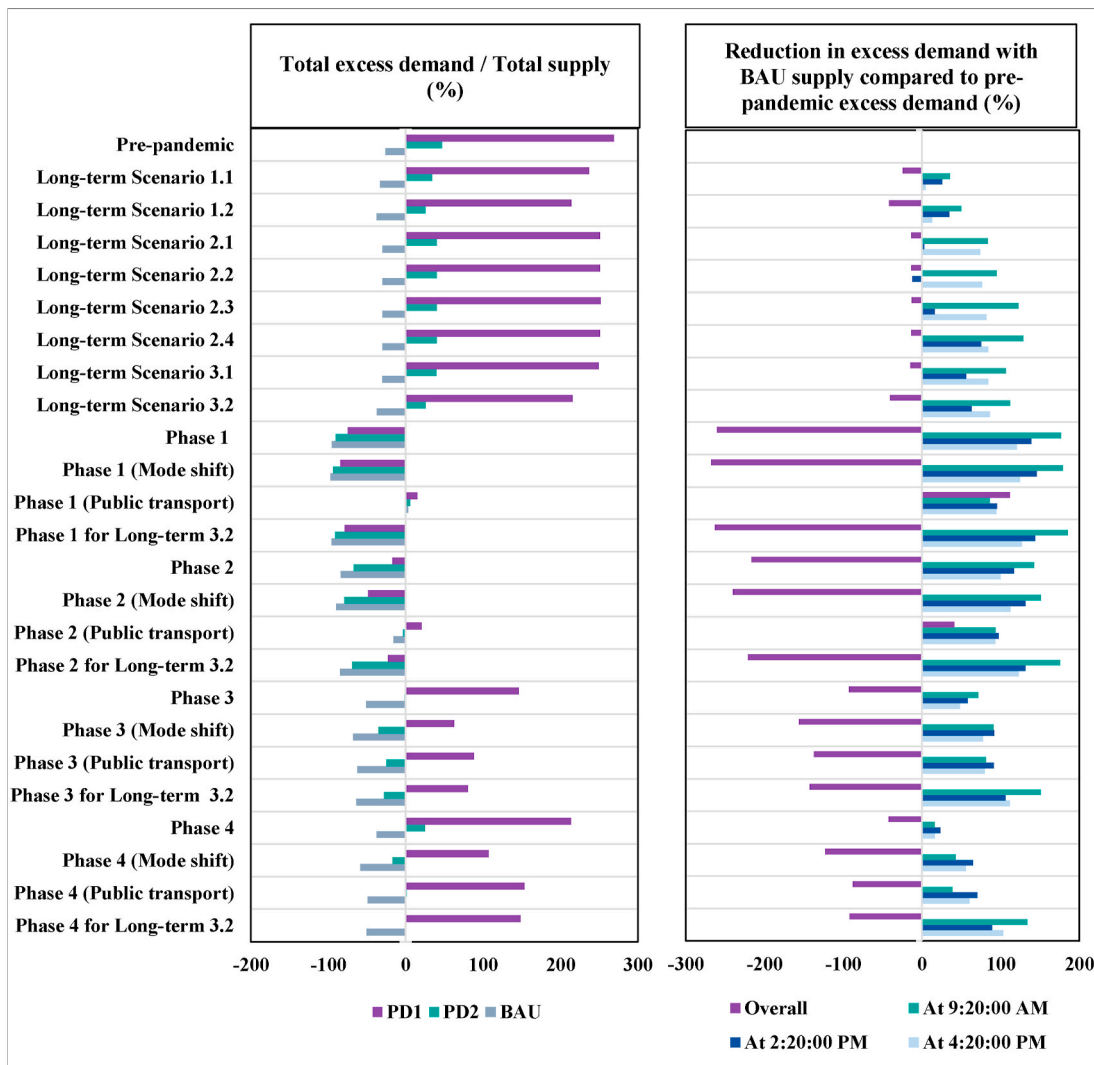

Fig. 12. Comparison of excess demands for public transport at different transport demand and supply conditions.

or null. The provision of safer and continuous public transport services for the general public incorporating physical distancing norms creates an additional financial burden on the subsidized transport system (Advancing Public Transport, 2020). However, reopening safer public transport considering the health-related impact of following physical distancing norms will have social benefits by providing access to opportunities for all socioeconomic groups, especially the lower-income group affected by the lockdown of services. This paper estimates the demand-supply gap of public transport while practicing physical distancing and identifies the measures that can be implemented to plummet the effect of these challenges in public transportation during pandemics.

Fig. 12 compares the excess demands for public transport at different transport demand conditions. The positive value of excess demand indicates that the demand is higher than the supply, and the negative value indicates supply in excess. As discussed in section 7.1, the overall demand is lesser than the supply, while three major peaks observed in the demand pattern have very high excess demand during those hours. Fig. 11 also demonstrates the overall and peak hour reduction of excess demand for public transport with BAU supply patterns at different demand conditions.

The maximum occupancy in public transport might need to be reduced to half the capacity of the seats (PD1 supply pattern) provided in the public transport to practice effective physical distancing during the high-risk pandemic period. The result indicates that with the pre-pandemic demand pattern, the overall demand would be larger than the overall supply if very high travel restrictions and lockdown measures (Phase 1) are not implemented. The phase 1 restrictions suggest limiting the daily subsistence activity, such as work trips, to a large extent, along with non-essential activities. Nevertheless, physical distancing on public transport is difficult to be achieved at peak hours even with the phase 1 guidelines and rules unless the physical distancing is strictly enforced inside public transport. By enforcing strict restrictions on public transport, not all citizens willing to use public transport will have the opportunity to access it considering the excess demand, and there will be a substantial financial loss for operators for providing the same level of service for a lesser number of passengers. A less strict physical distancing norm with the maximum occupancy in public transport reduced to half the total capacity of public transport (PD2 supply pattern) can provide access to more people; however, the authorities would still have to restrict a large population using public transport during peak hours. Thus, the public transport physical distancing norms during the pandemic period would fail to satisfy the needs of passengers and operators considering the pre-pandemic transport demand pattern with or without travel restrictions.

Motor vehicle use had reduced significantly during the initial lockdown period, thus, reducing traffic congestion and carbon emission (Meng et al., 2020). However, private vehicle ownership and personal vehicle use are increasing day by day when people return to their daily work lives. Contradicting the 'use less car' principle propagated in the last decade, 'use a private vehicle for safer travel' became the recommendation by several city authorities. The study confirms that the strict physical distancing (PD1 supply pattern) becomes more comfortable to be implemented for a relaxed level of restriction on work trips (Phase 2) when the private vehicle owners shift their travel on public transport to private vehicles. Although the excess demand for public transport is positive during the mode-shift scenario, peak hour excess demand reduction is significant. In developing countries like India, commuters without access to private modes might avoid crowded public transport by choosing intermediate public transport if they are apprehensive about safety in public transport. The increase in motor vehicle use on the road can worsen the traffic congestion, air quality, and transport quality to a dangerous level, especially when the travel restriction is more relaxed (Phase 3 and Phase 4). Scenario 3 of phase-wise easing of travel restriction also shows that reducing the public transport supply will increase the excess demand for public transport, increasing the use and

ownership of private vehicle ownership in India. The city authorities will have to take different measures to control the adverse effects of the large use of vehicles with low passenger car units during the pandemic period. The measures to reduce on-road vehicles can include improving the safety and inclusivity of public transport and active transport infrastructure.

The pre-pandemic public transport demand and supply relation of Mumbai establish the scope for restructuring the transport demand pattern as a substantial excess supply is available. Also, the demand and supply relation during the phase-wise relaxation of travel restriction indicates the significant influence of altering the work trip demand on the excess demand pattern of public transport. The restrictions and safety measures affected the work-life of several people in the world. People employed in informal and temporary jobs are believed to be affected mostly due to the pandemic situation (Kramer and Kramer, 2020). However, the introduction of flexible working arrangements provided an opportunity to continue work even during the pandemic period for both formal and informal employers in different ways. The work-from-home option enabled people with formal and office jobs to continue their job without traveling. Besides, industries, shops, and offices adopted staggered work hours in order to maintain physical distancing in the workplace.

The study combines the scope for restructuring demand patterns, the huge share of work trips on public transport use, and the concept of flexible work arrangements for identifying the strategies to practice safer traveling on public transport without altering the level of supply and schedule. The flexible work policies, such as staggered working hours and work from home, can significantly reduce overall peak hour demand, as discussed in section 6. The result highlights that imposing physical distancing becomes practical with a certain level of travel restriction in the urban areas if policy reforms are introduced at the earliest. The deployment of staggered working hours can reduce peak hour traffic congestion, and work from home can decrease the overall transport demand and, thus, improve the quality of traveling and air quality.

Further, to encourage less gathering in the public transport stations and inside public transport and reduce extra time spent for out-of-home activities and traveling, transport operators and city authorities can plan new mobile-based applications. New mobile-based applications can update the citizens on real-time information, such as a micro-geography of real-time density that can provide information on the level of crowding in public transport stations or the information about vacant seats available in public transport.

7.3. Transportation in the post-pandemic period

Public transportation might face even more challenges during the post-pandemic period. The high degree of anxiety concerning hygiene can make public transport unattractive in the post-pandemic period (Beck and Hensher, 2020). People have shifted from public transport to two-wheeler and four-wheeler vehicles for their daily transportation during the pandemic period. The travel behaviors build during the pandemic period can get bide to the post-pandemic period, which will become a great challenge in the future. Along with developing policies to reduce vehicle ownership and promoting new technologies like electric vehicles, the measures to encourage sustainable transport options like public transport and active transport need immediate attention.

To rebuild the trust in public transport, the transport authorities and operators need to solve the over-crowding issue that persisted in the pre-pandemic period. The pandemic has reinforced the thought that traveling is unnecessary for several activities previously possible only through traveling out of the home. Thus, various kinds of trips can be avoided without compromising the desired output. The work trips have witnessed a major change in nature during the pandemic period. The study analyses the impact of reforming work policies on public transport

demand and excess demand. In addition to the economic and personal benefits, the introduction of flexible working arrangements also benefits transportation by reducing traffic congestion and public transport overcrowding. Flexible work arrangements, such as staggered working hours and work from home policy, can significantly reduce the peak hour demand with the BAU supply pattern (see Fig. 11). Moreover, the flexible working arrangement can make non-work trips staggered as it depends on the work trip timing, reducing the peak hour transport demand. The new transport demand pattern, obtained through long-term interventions, can transform public transport into a safer, more inclusive, and cost-recovering transport system in the post-pandemic period.

The policymakers, employers, and researchers shall evaluate the work-related 'trial and error' experiments conducted during the pandemic at different workplaces to build future work-related policies that can provide better productivity and quality of life while decreasing resource use. Assessment of flexible work arrangements can help identify the type of jobs suitable for work from home and staggered work hours, and arrangements and infrastructures required for employees for productive working.

The pandemic also prompted the urban planners and city authorities worldwide to appraise the active transport infrastructure in the urban areas. The active mode had the highest mode share in Mumbai during the pre-pandemic period. The data determines that walking is the predominant active mode, and the majority of the active mode users are individuals with low socioeconomic conditions and those without access to private vehicles. Authorities can encourage citizens from all socioeconomic conditions to use active modes by improving the infrastructure for walking and bicycling and providing awareness on the advantages of using active transport for short trips. The city might need to develop a bike-sharing system, dedicated bicycle lanes, and integrated active transport infrastructure with public transport to attract more people towards sustainable transportation.

8. Conclusions

The current COVID-19 pandemic altered the standard way of living, activity participation, and traveling in a drastic way that the world had not planned. Until the outbreak of the COVID-19, the countries around the world were determined to achieve sustainable transportation goals at the earliest; however, the pandemic situation demanded immediate reform in the travel pattern and transportation infrastructures. The peak hour crowding in public transport that existed in the pre-pandemic period makes physical distancing a difficult norm to be followed. However, restricting people from accessing the cheaper transport mode will increase higher private vehicle dependency and social deprivation in developing countries. Besides, the uncertainty of how long the pandemic may continue demands intelligent and long-term interventions over temporary interventions such as the closure of places and transport systems. The study evaluates the supply-demand gap and impact of short-term and long-term policy measures taken during the pandemic period on public transportation.

The paper projected the excess demand (demand above the supply) for public transport in Mumbai, India, during the pandemic and post-pandemic periods. The major aim of the study was not to estimate the precise demand during the pandemic situation. Instead, it attempts to identify the drawbacks in the current transport system and the policies implemented during the pandemic and propose solutions to reduce the crowding in public transport, thus enabling the physical distancing norm to be easier to implement. The paper presents several significant applications specific to safer public transportation, activity participation, and peak hour travel demand. The major applications are discussed below, along with the findings from the study:

i. Identifying the excess transport supply or demand in the city: The demand-supply analysis of public transportation shows the overall supply (total supply of public transport in a day) is higher than the overall demand (total demand for public transport in a day), indicating there is an excess supply of public transportation in the pre-pandemic period. However, during the peak hours, the excess demand is causing over-crowding in the public transport. The study suggests that no additional or alteration in the level of service and schedule in public transport supply, which will increase the congestion and financial burden, is necessary to reduce the crowding. Rather innovative interventions to alter the demand pattern need to be focused, such as distributing the demand with policy measures specific to activity participation will reduce the peak hour demand.

ii. Evaluating the plausibility of practicing the policies enforced by the authorities during the pandemic on public transport: Although there is a need to implement special measures and policies during the pandemics for public health, an evaluation is necessary to find out the applicability of those measures. Evaluation of the emergency policies can guide in formulating better policies and strategies for the later stages of the COVID-19 pandemics and any unusual scenarios in the future. This study estimates the effect of pandemic policies on public transportation and identifies that physical distancing is impractical to be followed on public transport in Mumbai without reducing or distributing the peak-hour demand. Physical distancing can be feasible with enforcing measures such as travel restrictions for non-essential trips, incorporating flexible working arrangements for all possible employments, and encouraging the use of online services and private modes.

iii. Examines the advantages of new norm scenarios for the transport condition of the city in the post-pandemic period: Although immediate interventions are essential to make traveling safer during the pandemic period, the study advises concentrating on long-term interventions, which can also solve the pre-pandemic transport issues. Another benefit of the approach is that the investments and planning for the pandemic period can also be utilized efficiently for the post-pandemic period. The paper identifies some measures and recommendations from the Government, such as work from home and staggered work hours, during the pandemic can help reduce the peak hour demand, over-crowding, and traffic congestion, even in general the post-pandemic period. Besides, the paper suggests examining other new-norm scenarios, such as the use of online/door-to-door services, on the change in transport conditions and their possible implication for the post-pandemic period.

The study highlights the need for analyzing and re-evaluating the present transport systems and policy governance for pandemic and non-pandemic situations. Developing new transport and broader policy decisions and incorporating strategies specific to work and online services will help build less-risk public transport for the pandemic and post-pandemic era. Besides, such strategies may also reduce the traffic congestion caused due to the increased dependence on private vehicle use during the pandemic. Policymakers, researchers, and employers need to look more into the prospects of flexible arrangements for all kinds of mandatory activities such as work and education and door-to-door services—moreover, the requirements for bringing such policy in the act.

It should be noted that there are some limitations associated with this study. The study estimates the demand based on the travel behavior data from the pre-pandemic period. Although it gives a rough estimate of the excess demand during the pandemics, survey data on activity participation and travel behavior of people collected during the pandemic period can help forecast a more precise transport demand pattern at different levels of restrictions. However, the data used for the study can be considered a good source available in providing the information necessary to evaluate the suitability of the COVID-19 guidelines and measures because of challenges in instrumenting a face-to-face survey

during the pandemic period and the risk of sample bias in the online survey. The more practical way to collect travel information during pandemics is through online surveys and app-based tracking. However, obtaining data representing people from different socioeconomic groups is challenging for developing countries with less mobile and internet penetration. Another limitation of the study is that it analyses the impact of policies and measures implemented in Mumbai during the pandemics; it does not consider the effect of general travel determinants of transport choice behavior such as built environment, weather, etc. and change in travel patterns in terms of travel purpose, time and cost. Understanding the level of satisfaction with the current changes in activity participation and preferences for the post-pandemic period can help conduct more empirical analysis and bring more depth to future research. Additional studies could include investigating the effect of new norms in essential and non-essential activities during the pandemic period on the overall travel behavior and carbon emission. Lastly, future studies on the policy reforms for post-pandemic travel in developing countries need to investigate the inclusivity of measures taken for people's safety and comfort.

Author statement

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