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Analysis and monitoring of post-COVID mobility demand in Rome resulting from the adoption of sustainable mobility measures

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ABSTRACT

The paper describes research activities of monitoring, modeling, and planning of people mobility in Rome during the Covid-19 epidemic period from March to June 2020. The results of data collection for different transport modes (walking, bicycle, car, and transit) are presented and analyzed. A specific focus is provided for the subway mass transit, where 1 m interpersonal distancing is required to prevent the risks for Covid-19 contagion together with the use of masks and gloves. A transport system model has been calibrated on the data collected during the lockdown period –when people's behavior significantly changed because of smart-working adoption and contagion fear– and was applied to predict future mobility scenarios under different assumptions on economic activities restarting. Based on the estimations of passenger loading, a timing policy that differentiates the opening hours of the shops depending on their commercial category was implemented, and an additional bus transit service was introduced to avoid incompatible loads of the subway lines with the required interpersonal distancing.

1. Introduction

The dramatic COVID-19 epidemic is highlighting how health aspects -timely diagnosis and adequate patient care-are crucial for people's lives and is showing as controlling mobility is perhaps equally important for preventing the infection and disease of many other people and avoiding an exponential spread of the virus.

In pandemic situations, people mobility has to monitored to prevent further virus spread; nevertheless, it is equally important to analyze the mobility patterns that are profoundly modified in the spatial and temporal distribution, in the choice of the transport mode, and in the mobility behavior within the mode to plan adequate transport policies.

Planning and management of the mobility system in the epidemic era must take into account two fundamental aspects with which the mobility of people contributes to the spread of the epidemic:

- people mobility in the territory represents the virus' vehicle and allows epidemic spreading from one region to another and from one city to another;
- people gathering on vehicles and in the transport systems as well as in their activity places provides the condition for infection transmission.

However, the pandemic outbreak is imposing strict reductions to the capacity of Public Transport in order to comply with the social distancing requirements. Such a radical change of paradigm requires studying and developing new methods to control the demand for public transport that guarantee accessibility, reduce delays, and ensure safe conditions by limiting the risk of contagion.

The paper describes the activities undertaken by the authors to support the Municipality of Rome in monitoring, modeling, and planning mobility during the lockdown and in the successive phase of the

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progressive reopening of activities and services.

The paper is organized as follows. Section 3 summarizes the policy measures introduced by national and local authorities to regulate the economic activities and the use of public transport introduced to ensure the required social distancing. Section 4 presents an analysis of traffic and mobility data from the end of February (that is, the Pre-COVID period) till the half of June, when all the activities within the Country borders, except schools, have restarted. Section 5 provides a short overview of the methodology applied to recalibrate the system of transport models because of the changes in users' behavior and to the restriction of transit capacity. Section 6 presents the predictive scenarios of the demand for mobility and the impact on the transport system, which are provided in the successive phases of the progressive reopening of activities and services, called Phase 2.

Section 7 introduces the policies that have been devised to plan the reboot of the mobility system that ensures –on the one hand– passengers social distancing and –on the other hand– avoids discomfort and inconvenience to users due to the massive reduction of transit capacity. Finally, Section 8 illustrates the results achieved after the policy implementation and describes the predictive scenarios developed for the full reopening of activities and services, called Phase 3.

2. State of Art

Over the past year, authors have been studying the impact of travel restrictions on the spread of the pandemic. The following are some of these studies.

Oum and Wang (2020) proposed a model for evaluating pandemic policies to find the optimal lockdown and travel restrictions for transmissible viruses. Results obtained from the model application show as persons do not affect the external cost of the infection risks they impose on others and thus government actions are needed to induce individual travel decision makers to internalize this external cost. Fang et al. (2020) computed the causal effect of human mobility restrictions on containing and delaying the spread of pandemic. The results show that the lockdown of Wuhan city played a significant role in decreasing the cases of infection outside Wuhan. Moreover, Liu et al. (2020) investigated the relationships between mobility patterns and the trajectory of the pandemic outside Hubei province, also estimating the impact of local travel restrictions. Results show as synchronized travel restrictions among cities may be effective in controlling the pandemic. Chinazzi et al. (2020) applied a metapopulation disease transmission model to study the impact of travel restrictions on the spread of the pandemic. Results show that the travel restrictions have to be combined with the reduction of transmission in the community to achieve effective results for spreading. Mo et al. (2020) proposed a time-varying weighted PT meeting network to model the spreading of diseases evaluating control policies from the public health side as well as the transportation one. Results show as partial closures of bus routes help in slowing but cannot completely limit the spread of pandemics.

Focusing on the air traffic, Lau et al. (2020) assessed the correlation between domestic air traffic and the number of confirmed COVID-19 cases and determined the growth curves of cases within China before and after lockdown measures. Maneenop and Kotcharin (2020) investigated the impact of the COVID-19 pandemic, specifically three events have been studied such as the first contagion outside China, the outbreak in Italy and the WHO statement on the global pandemic outbreak along with the U.S.A. announcement of a ban on travelers from 26 European countries. Always in the field of aviation, Sanchez et al. (2020) studied the airline seat capacity and airline demand for the first four months of 2020. The data provided background for an assessment of the long-term impact of Covid-19.

Other studies have looked at resilience, Litman (2020) studied how to increase resilience to pandemics and other unexpected economic, social or environmental risks. Author investigated different problems caused by pandemic control suggesting how communities can better prepare for recover from pandemics and other shocks. Teixera and Lopes (2020) studied the operation of subway and bike share systems suggesting insights on how bike sharing and bicycling can support the ongoing transition to a post-coronavirus society. The analysis shows as the bike sharing can improve the resilience of urban transportation systems to disruptive events.

Pluchino et al. (2021) proposed a methodology to assess the a-priori epidemic risk also identifying the higher risk areas. The risk is computed according to the disease hazard, the exposure and the vulnerability of the area. Baldwin et al. (2020) addressed some important questions from an economic point of view. Specifically, they investigated how far and fast the economic damage will spread as well as its severity and duration, the mechanisms of economic contagion, and what governments can do about it.

3. Regulations

3.1. Economic activities

The progressive lockdown imposed by the government authorities (national, regional, and local) and the progressive reopening of the activities that impact on the Rome mobility system are briefly described in Table 1.

3.2. Public transport

To avoid crowding on public transport that could favor the spread of COVID contagion, national and regional authorities required transit companies to apply any measure to ensure a minimum interpersonal distancing of 1 m onboard, at station gates, and in indoor elements of the subway stations and, if this requirement could not be achievable, to ensure that in any case the number of passengers admitted onboard not

Table 1
COVID-19 lockdown timeline in Rome.

Level	Date	Shutdown description
L0	February 23rd, 2020	Strict quarantine (red zones) imposed in towns of northern regions. Traveling to the northern regions is not recommended.
L1	March 4th, 2020	schools are closed while universities open for research purposes only. Social distancing in crowded places is recommended.
L2	March 11th, 2020	Bars, restaurants, and public food courts are closed. Refraining from unnecessary travel is recommended. Social distancing is mandatory. Working in a remote mode is highly suggested, except for unavoidable services. Limited Traffic Zones are disabled (all traffic allowed in the city center).
L3	March 13th, 2020	All public parks and gardens are closed. No outdoor sports activities are allowed. Residents can walk their dogs only nearby homes. Stay home is imposed except for unavoidable needs.
L4	March 22nd, 2020	All "non-essential" shops and activities are closed. Food and drink retailers, banks, chemists, petrol stations, newsagents, as well as other particular categories defined "essential" to support coronavirus emergency are exempted from the ban. Residents are still allowed to shop for food, to go to work (if their job belongs to "essential" categories and it is impossible to do remotely) or to move for unavoidable needs (e.g., support to elderly who are not self-sufficient).
R1	May 4th, 2020	All "non-essential" shops and activities are reopening. Go to work is allowed even if smart-working is still recommended. No more "stay home" rule applies. Outdoor sports activities are allowed. Except for family, social distancing is required.
R2	May 18th, 2020	All retail, recreation, bars, restaurants, and public food courts reopening. Go to work is allowed, but again smart-working is recommended. Public parks open even if social distancing still applies. Schools and universities remain closed.

exceeding one-half of the maximum vehicle capacities, provided that passengers were required to wear protective masks.

In Rome subway, which is the component of the transport system affected by the highest crowding, the trains of the usually most loaded subway line (the Line A) are about 100 m long, have a standard composition of 6 cars, and legal capacity of 1200 passengers.

To ensure a safe interpersonal distancing of 1 m between passengers and enable a free passage to the doors, the maximum passenger load in each car should be reduced to 25 passengers (Fig. 1), which is 150 passengers/train. Given the hourly frequency of 20 trains/hour, this constraint corresponds to a maximum allowed load of 3000 passengers/hour.

A special effort has been conducted by the Mobility Agency of Rome and academicians to analyze mobility data, model the transport system, and develop specific plans to ensure that the strict requirement of 1 m interpersonal distancing was guaranteed without affecting people mobility needs neither during the lockdown nor in Phase 2 when the risk of contagion was still high (Brinchi et al., 2020).

After the heaviest phase of contagion has been passed, the strict requirement of 1 m distancing has been progressively relaxed by the transit company, which ensured in any case, the passenger load did not exceed one half of the train capacity.

4. Mobility monitoring

Different communication technologies are being in use for traffic monitoring, such as GNSS (Fusco et al., 2018), Bluetooth (Carrese et al., 2020), VANET (De Felice et al., 2014); specifically, GNSS onboard equipment supply Floating Car Data (FCD) that enable studying traffic dynamics (Isaenko et al., 2017), drivers' behavior (Colombaroni et al., 2020), travel time (Cipriani et al., 2014), or parking search time (Mannini et al., 2017), or calibration of models to forecast network congestion (Fusco et al., 2013).

Monitoring of mobility has been carried out by exploiting two sources of data: Bluetooth (BT) for pedestrians and cyclists, floating car data for private vehicles, and data of the validations at subways stations for the public transport.

Fig. 2 shows the summary of the percentage change in mobility for private, public, pedestrian, and bicycle modes in the main phases of the process from the lockdown to the present (July 2020) compared to the average values observed in the working days of the first two weeks of February, respectively in terms of trips and vehicles in circulation. During the lockdown, the number of vehicles in circulation decreases by more than 50%, which corresponds to a 70% reduction in journeys and a decrease in mileage of more than 75%. Smaller reductions affect heavy vehicles, while public transport, as well as pedestrian and bicycle mobility, have been reduced by almost 95% in the Lockdown period. In Phase 2, 25% of cars and 13% of trucks have begun to circulate again, leading to a reduction compared to the pre-COVID period of 40% and 25%, respectively. Differently, public transport and non-motorized mobility maintain an extreme reduction compared to the pre-COVID period, of about 85%.

Fig. 3 shows the hourly distribution of the circulating fleet of private vehicles, as it can be observed the peak periods of the morning and afternoon are found, more or less accentuated, in every phase, except for the Lockdown period where the trend seems to have almost no more peaks.

In the following paragraph, the three modes of transport are individually analyzed in the three periods of Lockdown, Phase 2, and Phase 3.

4.1. Pedestrian mobility

Focusing on the pedestrian flows, Fig. 4 describes the results of the analysis of the data collected by Bluetooth in the historic city center and the biggest park in Rome (Villa Borghese), and it shows the variation trend compared to the pre-COVID period.

In the lockdown phase, increasing reductions are seen in both L1 (28%) and L2 (78%). The prohibition on L3 has a particular impact on pedestrian mobility, which reduced by 87%, a much larger value

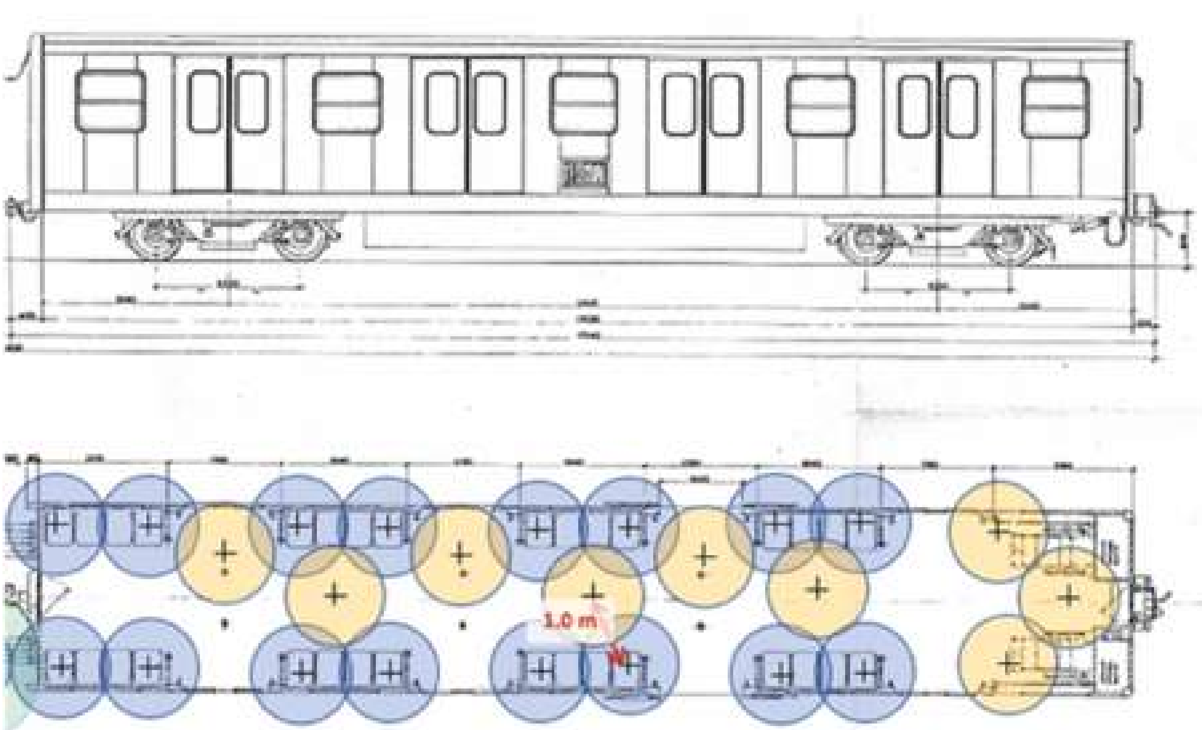

Fig. 1. Allowed positions for seated (in blue) and standing (in yellow) passengers in a subway car to ensure a safe personal distancing of 1 m; in green (only seated) to ensure a safe personal distancing of 2.5 m. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

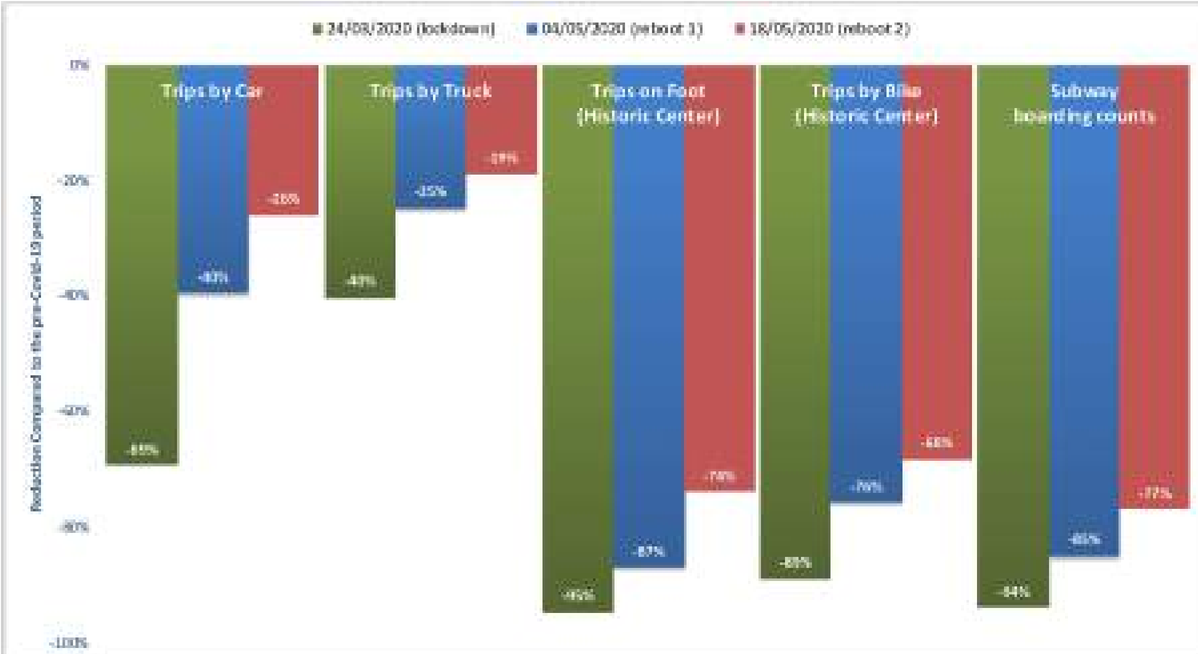

Fig. 2. Reduction of trips and fleets compared to the pre-COVID period.

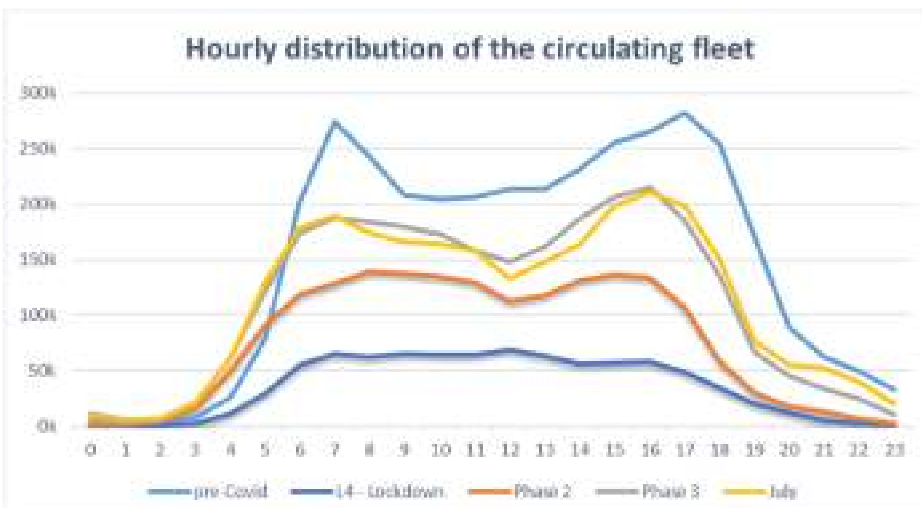

Fig. 3. Hourly distribution of the circulating fleet.

compared to the 10% reduction observed on the same day in the previous week (down in L1). The more restrictive measures of L4 are reflected in the maximum observed reduction in pedestrian movements (93%).

On May 25th, the reduction compared to the pre-COVID period was around 50%.

4.2. Cycling mobility

Fig. 5 shows the comparison between the pedestrian and the bicycle flows. As shown, the trend of the two modes is similar.

4.3. Road mobility

Fig. 6 shows the trend of the number of observed samples of vehicles equipped with GPS as FCD traveling on the network of the study area, from the pre-COVID period until June 2020, while Fig. 7 reports the trend of the daily circulating car and trucks.

Concerning the lockdown period, it can be observed that the differences with the Pre-COVID period are still negligible on L0 when the quarantine only regards the Northern Italian cities. The same can still be observed for heavy traffic in L1; otherwise, light vehicle traffic is affected by the closure of educational institutions. Both categories are characterized by significant reductions following the adoption of social distancing measures and smart-working (L2), although the reduction in heavy traffic is less due to the inevitable need to guarantee logistic supply. On L3 (fleet closures), no further reductions for vehicles are observable, since this measure, imposed to limit recreational gatherings at weekends, is mainly pedestrian-oriented. The adoption of the L4 restrictive measures, which prohibit all non-essential activities, implies a further reduction (except for L3) compared with the reference in the initial phase of the measure, while, from the following week, there was a slight recovery in vehicle traffic.

In Phase 2, both the circulating car fleet and the number of sample

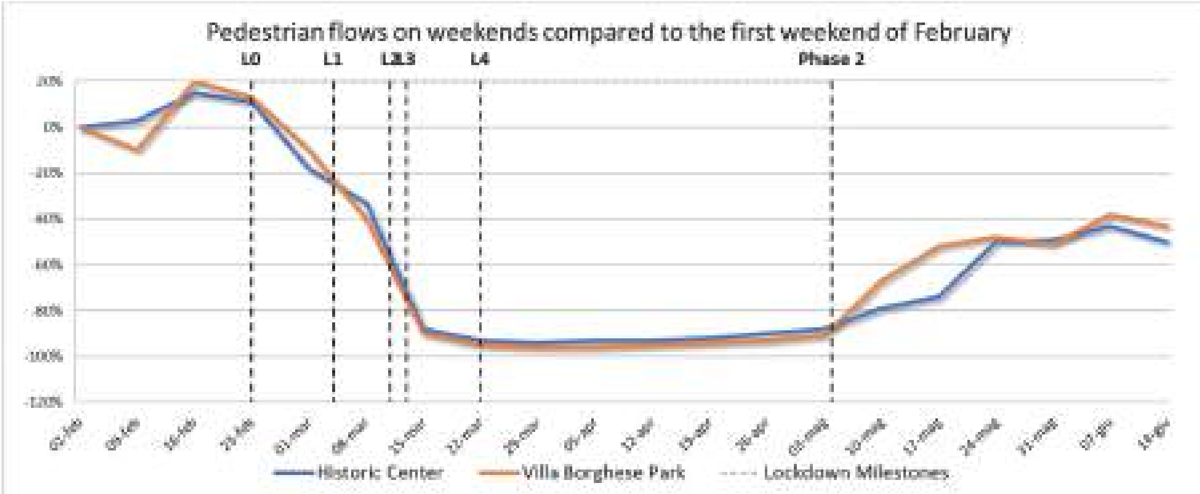

Fig. 4. Monitoring of the sample of BT data for the pedestrian flows on the weekend in the different steps of the progressive milestones of Lockdown and Phase 2.

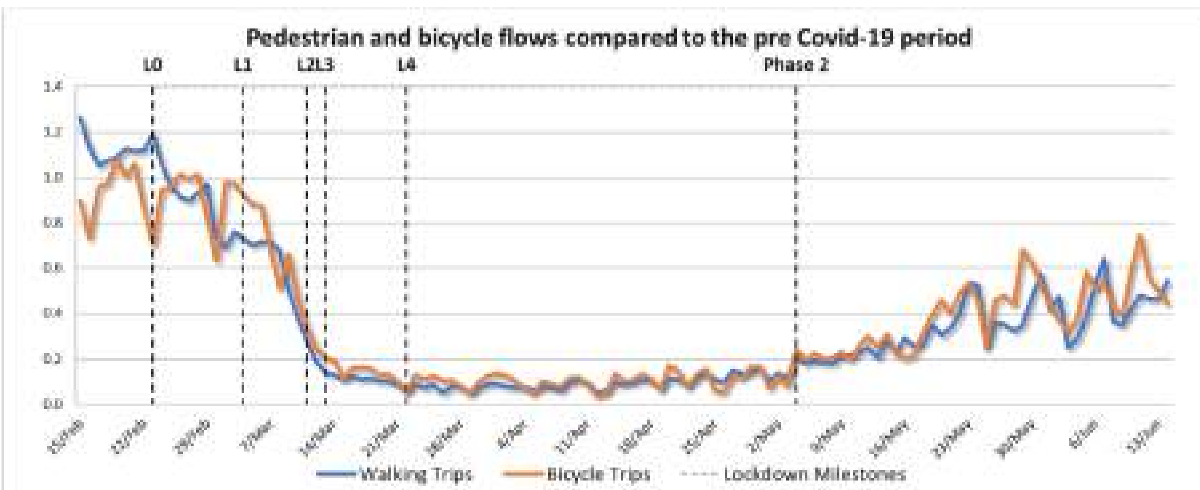

Fig. 5. Monitoring of the sample of BT data for pedestrian and bicycle in the different steps of the progressive milestones of Lockdown and Phase2.

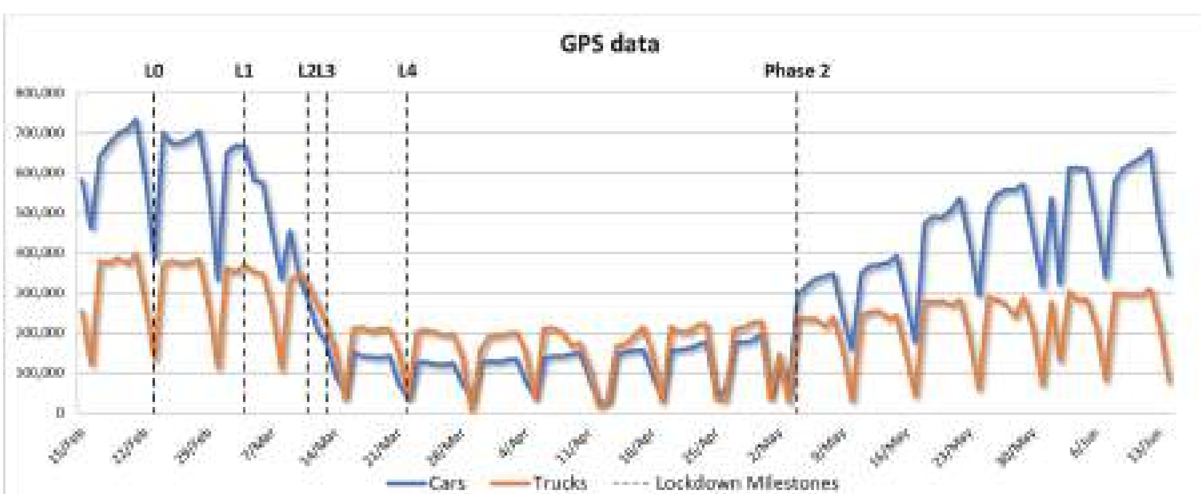

Fig. 6. Monitoring of the sample of FCD vehicles on the network in the different steps of the progressive milestones of Lockdown and Phase 2.

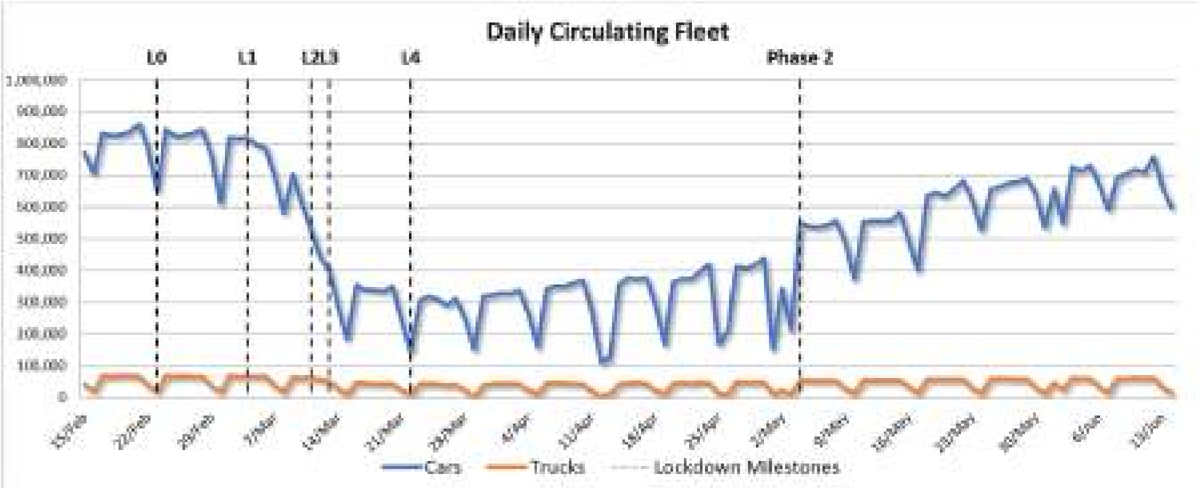

Fig. 7. Daily circulating fleets in the different steps of the progressive milestones of Lockdown and Phase 2.

GPS data, representing an estimate of the total distance traveled, increase again, reaching a value very close to the beginning of Phase 1, where only measure L1 was introduced.

4.4. *Public transport mobility*

Fig. 8 shows the trend of the number of validations at the turnstiles of the subway lines from the pre-COVID period to mid-June, where Phase 3 begins.

As shown, the ridership is around 85% and 80% of the pre-COVID ridership in the first periods of lockdown, falling to 25% in L2 and L3 and finally falling to 6% in the last Lockdown period. In Phase 2, differently from the road mobility, the public transport does not resume its regular ridership; this is partly due to the respect of the physical distancing that reduces the capacity on public transport both to the fear of contagion. However, public transport supply has been guaranteed with an increase in the frequencies of the lines to guarantee the efficiency and effectiveness of the service.

The analysis of the variation of the subway users in correspondence with the progressive closure of the activities has also allowed identifying, even in an approximate way, the user quota corresponding to the different categories of people affected by the closure of the different types of activities, identified in Fig. 9 such as students, smart workers, classic ("non-smart") workers, necessary (but not essential) workers, essential workers. There is also a share of users, sensitive to the risk of contagion (defined as "scared" in the figure), who abandoned public transport before the introduction of the school closure measure when information on forms began to circulate of contagion in increasing diffusion in Northern Italy.

The categorization of users, other than providing interesting information on different components of transit users, has also made it possible to make a coarse forecast on-demand at the beginning of Phase 2, based on the trend observed during the progressive tightening of the lockdown.

5. Transport models

5.1. *Transport system model*

The system of transport models used for traffic predictions is based on a well-consolidated set of models used since the 90s by the Transport Agency of Rome (RSM - Roma Servizi per la Mobilità), which has been adapted to reproduce mobility choices of users in the COVID-19 pandemic.

The functional architecture of the modeling system is shown in Fig. 10. It allows simulating the traffic of passengers and freight on the road network as well as the passengers on public transport as a result of modeling the interaction between demand and supply. For a given

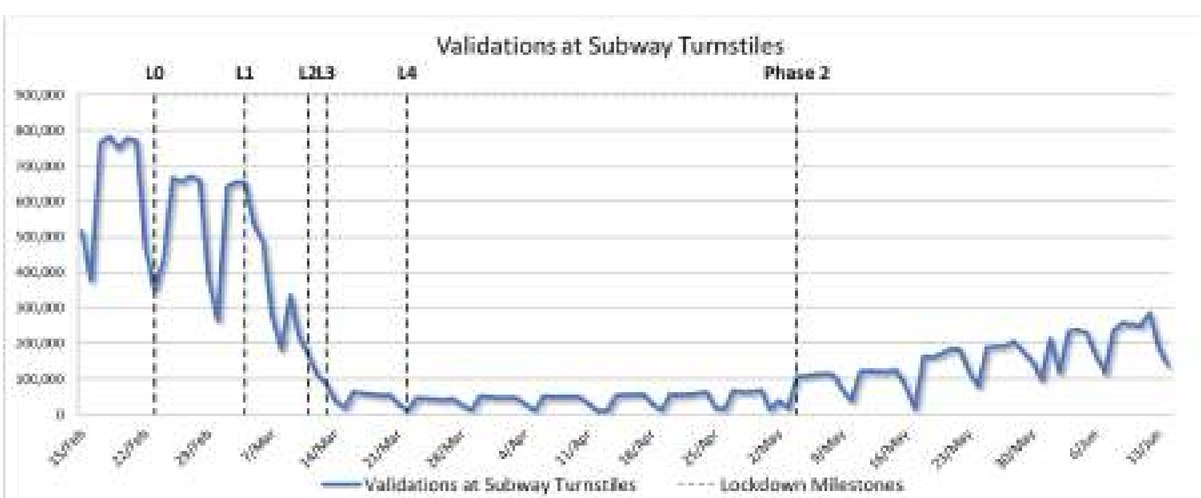

Fig. 8. Validations trends at subway stations in the different steps of the progressive milestones of Lockdown and Phase2.

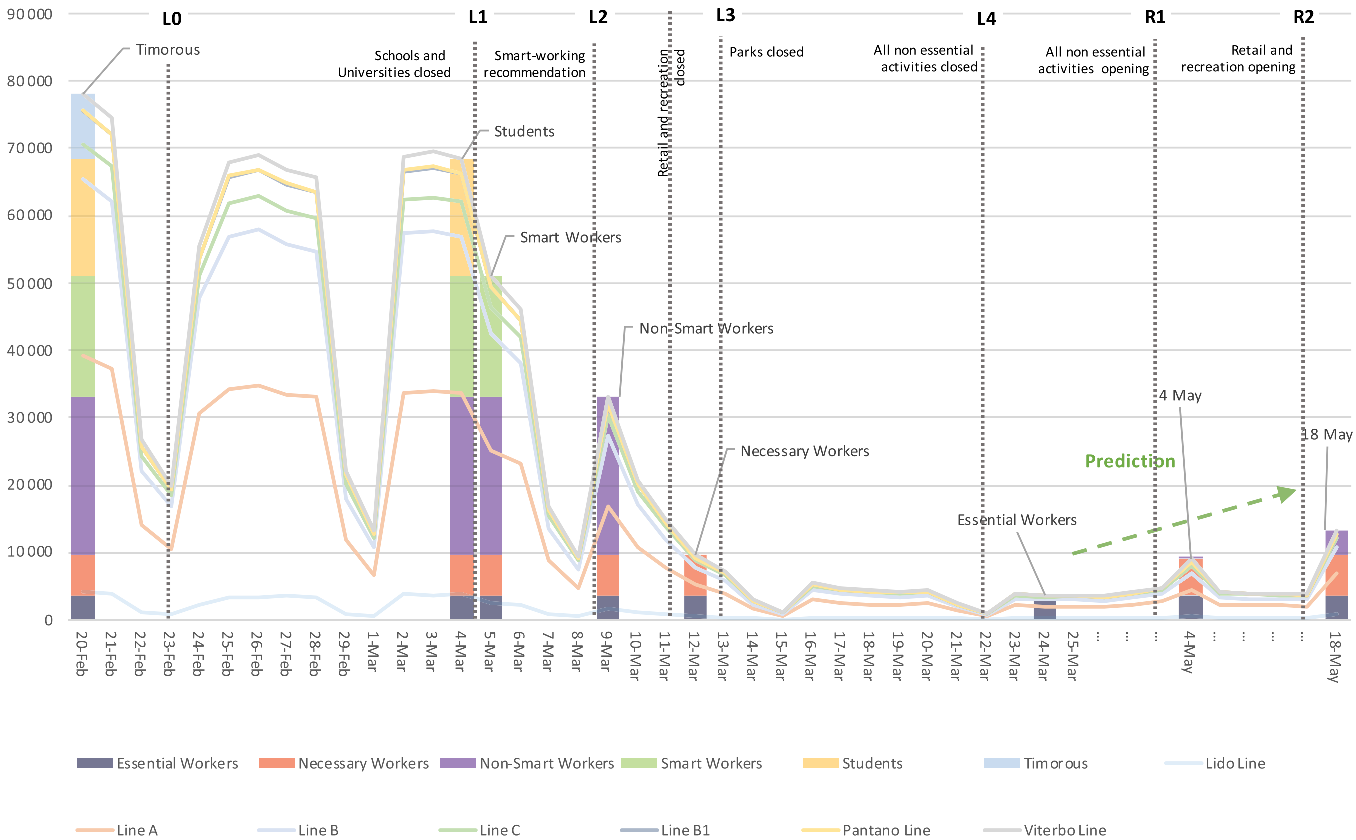

Fig. 9. Number of passengers in the subway system in the morning peak hours in the different steps of the progressive milestones of Lockdown and Phase 2.

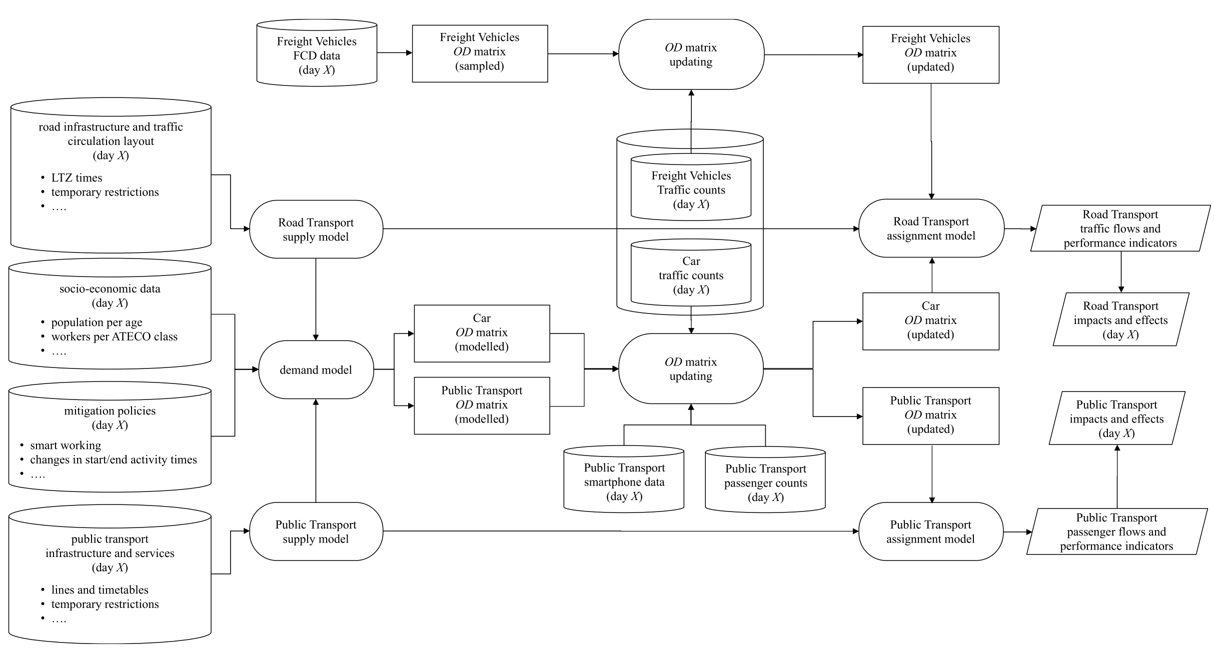

Fig. 10. Transport models: functional architecture.

scenario (e.g., day X), such a system of models considers as input socio-economic data (e.g., population), mitigation policies (e.g., smart working), as well as road and public transport networks and services.

From the modeling point of view, on the supply side, the multimodal transport network is represented by two different supply models: the former allows to reproduce road network performances for passenger cars and freight vehicles (private transport), which share the same infrastructures; the latter allows to represent different public transport services (regional trains, subway, tram and bus lines) with their features (e.g., frequency).

On the demand side, passenger demand is estimated by using multi-step demand models based on a system of generation, distribution, and modal choice models characterized by four different trip purposes (work, school, University, and others) and four-mode alternatives (pedestrian, motorbike, private car, and public transport). Freight demand is obtained by an initial sampled O-D matrix, which is currently updated by traffic counts.

The Origin-Destination (O-D) matrices per mode carried out by using such a system of models are updated by using all traffic data available, including Floating Car Data, smartphone data, and subway counts at entering gates.

For a better reproduction of the demand in a never-proven scenario, such as that simulating the mobility in the COVID era, the above demand matrices are subject to a further adjustment by using a "pivot" technique aiming at "locking" the demand forecast of a scenario in the COVID era (C) to that carried out by models calibrated for the pre-COVID (P) scenario (see Fig. 11). For a given O-D pair *od*, the formulation of the pivoting for the demand estimation can be expressed as:

$$d_{od}^{C} = d_{od}^{P} * \frac{MP_{od}^{C}}{MP_{od}^{P}}$$

where

d_{od}^{C} is the pivoting result, i.e., the "pivoted" demand forecasted for the COVID scenario (C);
d_{od}^{P} is the pre-COVID (P) "adjusted" demand;
MP_{od}^{C} is the demand estimated by applying the demand model to the COVID (C) scenario;
MP_{od}^{P} is the demand estimated by applying the demand model to the pre-COVID (P) scenario.

Once the OD matrices per mode are ready to be assigned to the transport networks, the demand-supply interaction (assignment) is simulated by using probabilistic path choice models for the road assignment and by using the well-known hyperpath choice model for public transport. The theoretical framework of the assignment is specified by using an equilibrium formulation within a static approach. Given the assignment results, traffic flows and network performances, as well as passengers boarding public transport lines, are used to calculate performance indicators useful for the assessment and the design, as described in the sections below.

5.2. Model adjustment

Much effort has been made for the estimation of transit demand on the Subway system, being passengers of such transport mode highly vulnerable due to possible exposure to COVID infection risk. Precisely, the demand for the forecast scenario has been estimated as in the following flow-chart: starting with the reference Pre-COVID scenario where passengers' boarding counts are available, the reference demand has been initially "adjusted" with such counts in order to correct the model estimation; then, such adjustment has been transferred to the future scenario by pivoting the forecasted demand so that also the final "pivoted" transit demand is forecasted taking into account correction to model errors. Inputs to forecast scenario are:

- Decision-making variables to be defined by the local authority such as, for any type of activity:
  •smart working rates
  •opening hours
- System variables specific to Phase 2 scenario such as:
  •modal split value as resulting from the new mobility structure and reflecting new travel behavior of the demand affected by COVID risk

6. Mobility predictive scenarios for phase 2

As the number of infections and hospitalized people decreased, the Italian Government planned to reopen economic activities and enable the inter-urban mobility progressively in two steps, on May 4th and May 18th. In these scenarios, keeping interpersonal distancing is crucial to prevent the epidemy spread-out. The public transport system is one of the riskiest sites because of the intense personal interaction on board, at the station gates, and in the connecting elements like corridors and stairs. Thus, forecasting the demand for mobility in the reopening scenarios is very important to predict possible critical conditions and plan suitable actions to prevent both unsafe people aggregation and undesirable queues and waiting times at the entrance of transit stations.

On a broader scale, tracing the inter-urban mobility is essential to prevent the contagion diffusion from one town or one region to another.

Finally, the study of mobility in the different scenarios is useful to understand the behavior of different user categories, their spatial distribution, and their mobility preferences.

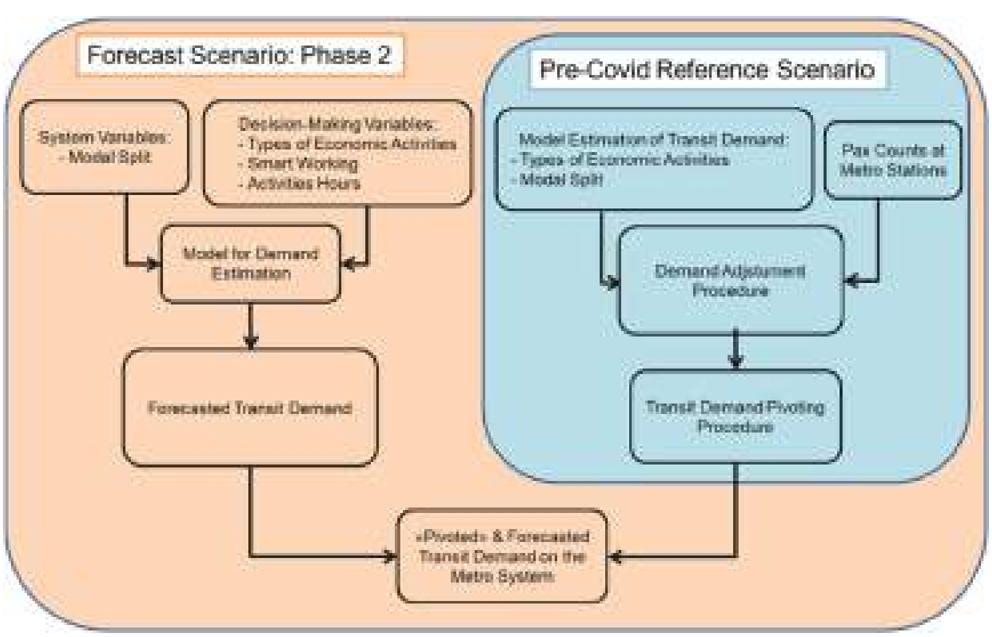

Fig. 11. Flow chart of the demand estimation for the forecast scenario.

The application of the recalibrated mobility for different assumptions on the progressive reopening of activities and services provides predictive scenarios for the demand for mobility.

Specifically, through the load forecasts on public transport lines in the different time interval as well as the access demand to the stops, it is possible to identify the probable criticality and provide for any necessary corrective action. The scenarios take into account all monitoring data available, the distribution over time of the business hours planned by the local authorities, and the hypotheses on the percentages of Smart Working updated through the consultation of stakeholders (e.g., Mobility Managers).

6.1. First step of phase 2 (R1)

Since the transport model described in section 4.1 was calibrated in standard conditions when all economic activities were active, three main factors that affect mobility behavior in a contagion scenario have to be considered to apply to predict the mobility in the reopening phases: the share of smart-working, the share of mobility due to other purposes than work, and the modal shift from public to private transport because of the fear for the contagion.

By observing the reduction of passengers on the subway system after the introduction of lockdown measure L1, the share of smart-workers was estimated around 35% of the workers who used the subway before the lockdown. However, the expected reduction of mobility demand at the beginning of Phase 2 is even higher because not all economic activities were allowed to restart. For example, bars and restaurants were enabled to supply home deliveries, but indoor service was not allowed; clothing stores could reopen only in the second step of Phase 2, on May 18th.

Thus, the estimations of the smart-working share for the two steps of Phase 2 were assumed based on the Government's decrees examination, stakeholders' consultation, and the available surveys. Knowing the number of employees in the town of Rome for every economic category, the corresponding potential mobility demand for work purpose was estimated for the two steps of Phase 2. In the first step, on May 4th, it was expected that the potential mobility demand for work would reduce from 1.2 million to about 510,000 trips (that is, the 42% of the Pre-COVID period). In Phase 3, on May 18th, it was expected that restarting all retail activities would have added about 83,000 trips, leading to approximately 593,000 potential trips during the whole day.

Because of the lack of time to carry out specific behavioral surveys, a small panel survey was made to introduce reasonable assumptions on mobility reduction for different trip purposes. The results are shown in Fig. 12. As a whole, predictions for the Phase 2 were that the people mobility would reduce in the peak hour from about 470,000 to 204,000 trips/hour (that is, the 43% of the Pre-COVID period).

According to the transport model described in Section 4.1, about 155,000 trips occur in the peak hour on public transport in standard conditions. Based on the abovementioned assumptions on smart-working and the observations of the trends of road traffic and public transport passengers during the lockdown period, they are expected to reduce to 33,000 trips, about 21% of the Pre-COVID period, in the first step of Phase 2 (May 4th) and to increase to 41,000 in the second step (May 18th).

6.2. Second step of phase 2 (R2)

After the first step of activities reboot (R1) on May 4th, it will be possible to verify the goodness of preliminary predictions based on simple analogy reasoning and panel survey assumptions and adjust the transport model by using the traffic counts.

Fig. 13 shows the ridership of the subway lines and urban railways in the pre-COVID scenario, corresponding to a total demand of about 155.000 trips in the morning peak hour.

The matrix demand resulting from the forecasted modeling procedure for the step R1 of Phase 2, without any assumption on change in the users' behavior, is approximately 58.730 trips.

Fig. 14 shows the ridership of subway lines and urban railways in Phase 2 under the assumption that the modal split is around 30% for the PT, as in the Pre-COVID period. The sections with the volume exceeding the capacity according to the social distancing are highlighted in red.

A sensitivity analysis highlighted that, in the hypothesis of restarting activities and Smart Working's share, the social distancing on the meters is respected up to a modal distribution of demand on the TP equal to 15%.

Once the counts at the turnstile are available at the beginning of Phase 2, the correction procedure can be applied directly to the model, and it is estimated its evolution (trend).

The demand resulted in a total number of 45.855 trips.

In Fig. 15 the comparison between simulated and detected boarding passengers on subway lines and railways, applying the matrix demand adjustment procedure, is reported. It can also be seen as a validation test of the modeling system in terms of reproduction of the mobility choices of users in the COVID-19 pandemic. As it can be observed, the R^2 is about 0.99, and the slope of the regression line is very close to 1.

In Fig. 16 and Fig. 17, the load profiles simulated for the Phase 2 Scenario are reported for the most crowded subway lines, e.g., subway line A towards Battistini and subway line B towards Laurentina. As it can be observed, towards Battistini, the maximum load of subway line A is found between San Giovanni and Termini, and it is about 3.000 passengers per hour. In contrast, the maximum load for the simulated profile of subway line B towards Laurentina is found at Tiburtina station, which is an interchange terminal, and it is about 1.500 passengers per hour.

The results of the demand assignment to transit network highlighted that the maximum load onboard and the maximum number of passengers on the platforms in the first step R1 of Phase 2 (2300 and 520 passengers/hour, respectively, on the most loaded subway line) were expected to comply with the interpersonal distancing of 1m required by

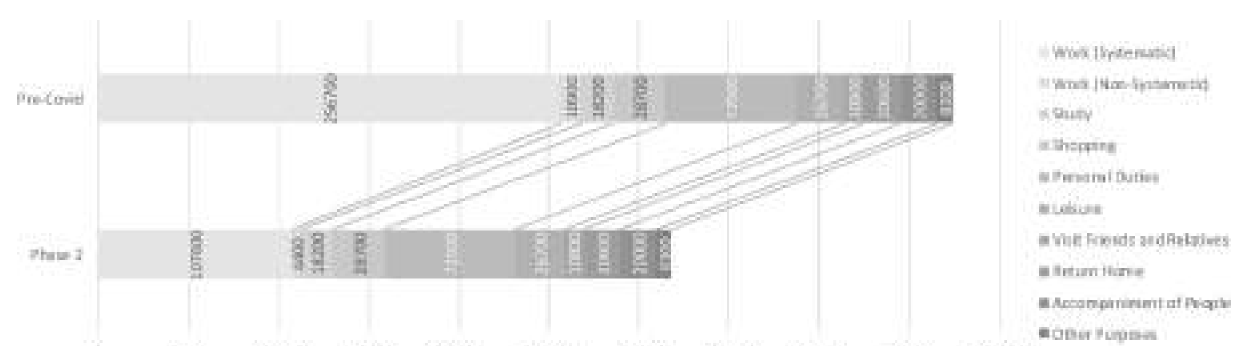

Fig. 12. Number of employees in the Subway area of Rome and assumptions on the reduction of potential mobility demand for different economic categories.

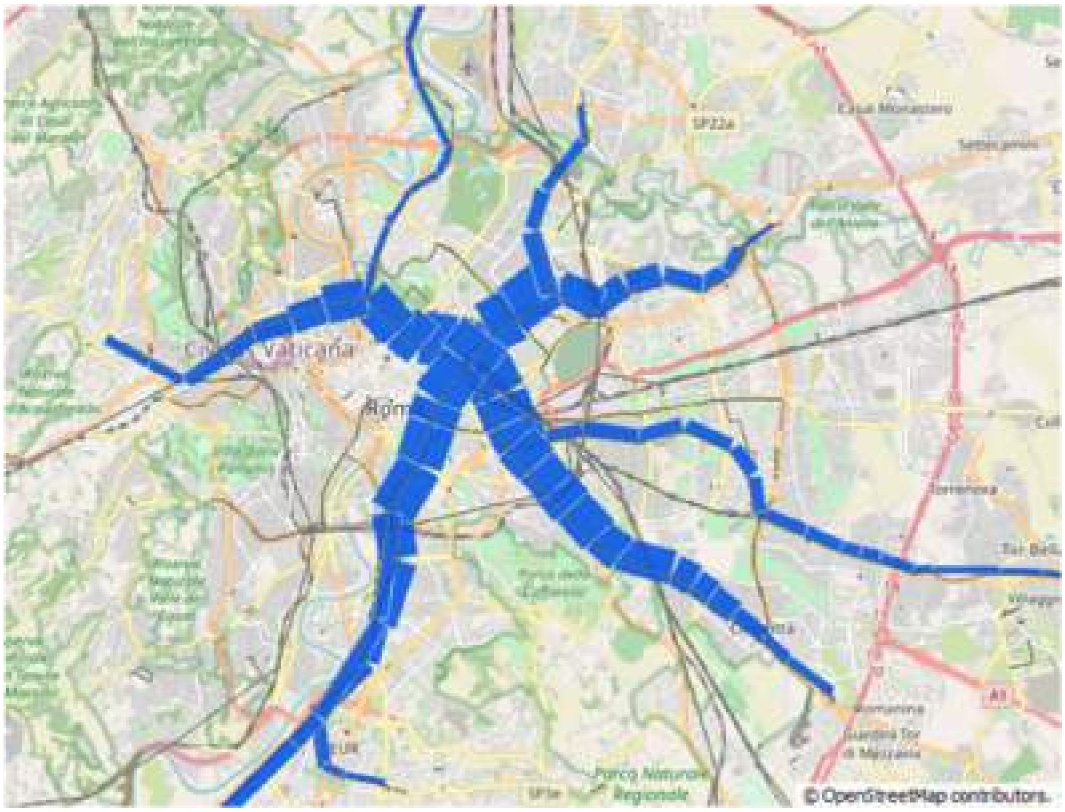

Fig. 13. Simulation results of PT (subway and railways lines)- pre-COVID Scenario.

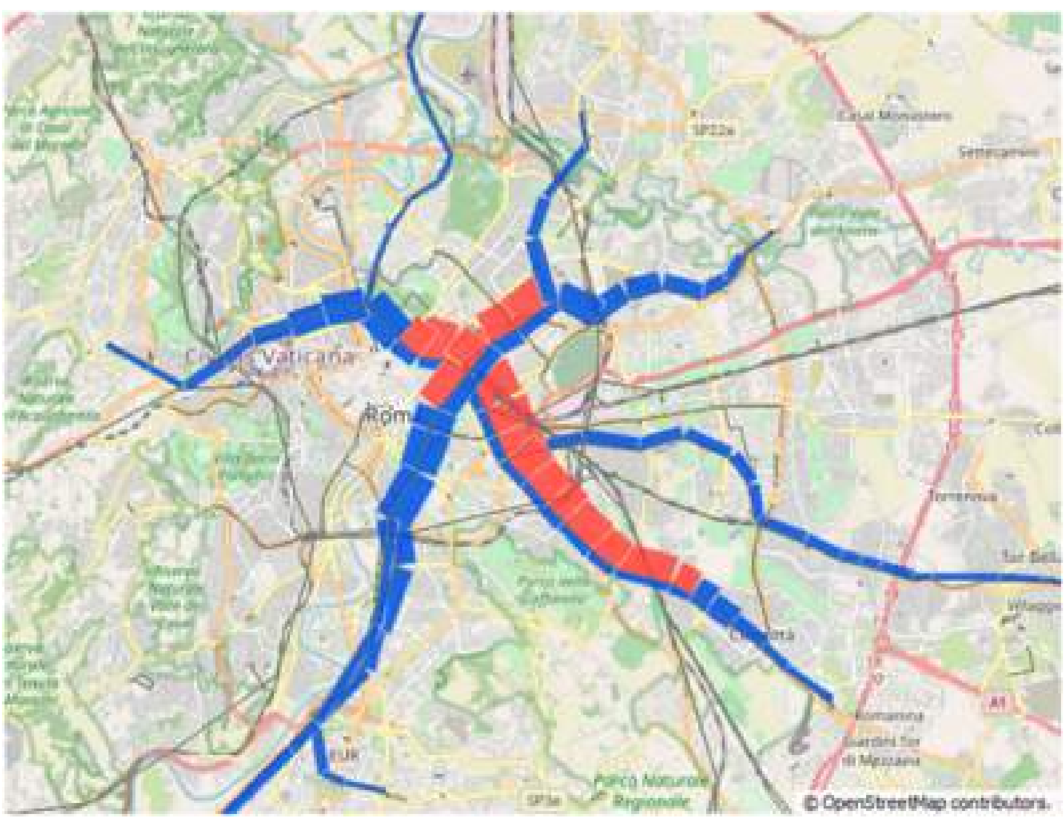

Fig. 14. Simulation results of PT (subway and railways lines)- Phase 2 Scenario (modal split 30%).

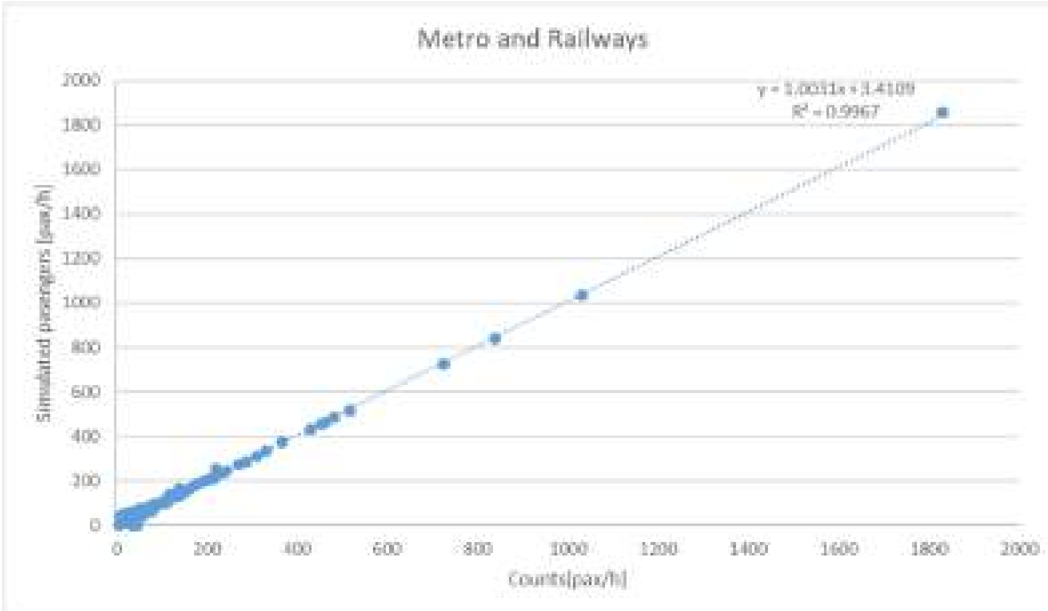

Fig. 15. Comparison between simulated and detected boarding passengers on subway lines and railways – Phase 2.

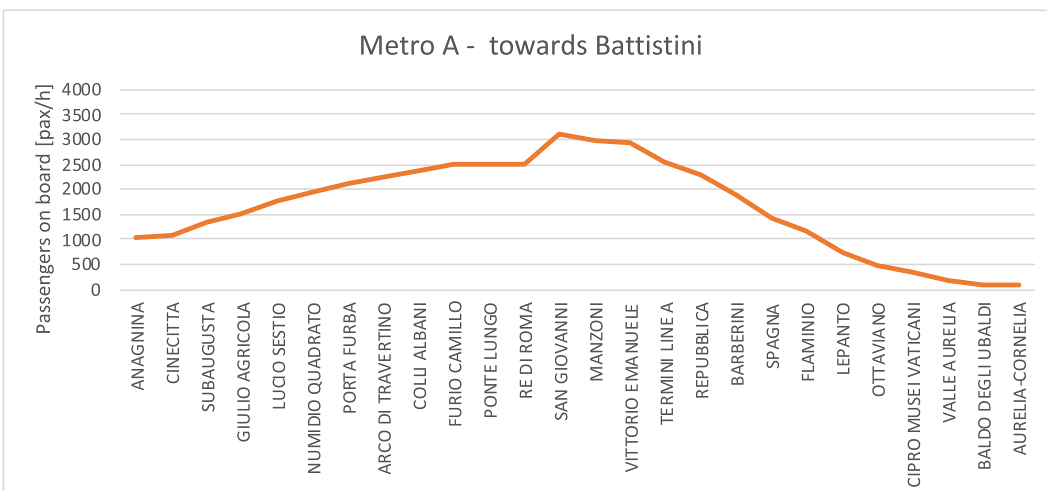

Fig. 16. Load profile of Subway Line A – direction Battistini – Phase 2.

the authority. However, the even small increase of transport demand due to the reopening of retail trades predicted in the second step R2 of Phase 2 would have implied a maximum load on board of about 3000 passengers/hour, corresponding to 150 passengers/train, which would have exceeded the distancing requirement. Thus, additional policies for mobility containment were planned.

7. Policy definition

7.1. Public transport access control

To ensure the safe distancing on the platform, special signs were placed on the floor, spaced 1m from each other along a line corresponding to the whole length of the train, which is 100 m. Given the frequency of 20 train/hour, a maximum number of 2000 passengers can be admitted at each station.

Although the expected average hourly O-D demand resulting from transit assignment complies with the distancing constraint, because of random fluctuations, demand may exceed the safe train capacity temporarily.

A metering control was applied at every subway station to avoid even temporary unsafe distancing. Based on the forecasts of demand at each station and the estimated passenger load along each subway line provided by the transport model, the transit company estimated the maximum number of passengers per minute to be admitted to each station and committed staff to correspondingly limiting the flow of passengers at the entrance gates of subway stations.

7.2. Road traffic regulation

In order to flatten the demand curve on Public Transport and support social distancing, especially on Subway lines, all Limited Traffic Zones (LTZ) of Rome (Cipriani et al., 2018) have been opened to private cars since L2 (see Table 1). At the first stage, as in L4, only “essential” workers have been allowed to move; this regulation policy has been linked to free-of-charge parking in the whole city. Then, at the restart of activities, LTZs have still been opened, but parking fares have been restored. Although traffic in the city center reached the pre-COVID level,

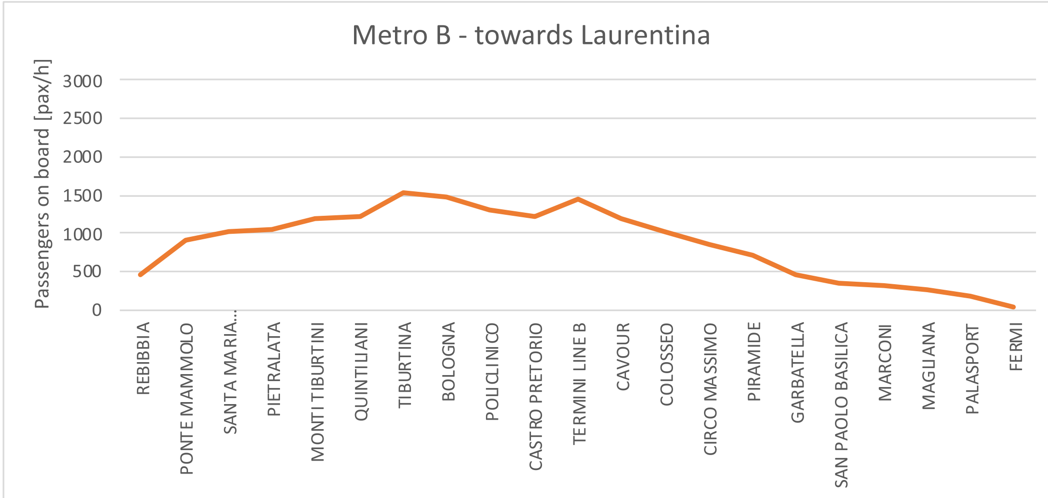

Fig. 17. Load profile of Subway Line B – direction Laurentina – Phase 2.

by aiming at fostering the restart of commercial activities in the city center, the above conditions (LTZs open) still apply.

7.3. Timing of commercial activities

As described in Section 5, smart-working policies and limitations of commercial activities planned in the first step of Phase 2 were sufficient to ensure safe distancing on the public transport system. However, reopening of retail trades planned in the second step of Phase 2 would produce an even limited demand increase that would imply a maximum load on the subway lines of about 3000 passengers/hour, which is precisely corresponding to the maximum admissible load. To mitigate the demand in the rush hours, the Municipality of Rome, supported by the consulting group at the three Universities, planned a timing policy for commercial activities that differentiate the opening hours depending on the specific commercial category. Namely, neighborhood food shops and small food retails (that contribute for about 20,000 employees) have to open before 8:00 and close by 15:00 or later than 19:00; craft workshops and mid-size trades (that contribute for about 35,000 employees) have to open from 9:30 to 10:00 and close from 18:00 to 19:00; no-food shops, Internet points, and hairdressers and beauticians (that account for about 51,000 employees) have to open from 11:00 to 11:30 and close after 19:30.

7.4. Additional public transport services

The forecast scenarios have shown that the reopening of the activities scheduled for May 18th (Phase 2 R2), although distributed throughout the day and mitigated by the use of Smart Working, may lead to an increase in demand on public transport, which would exceed the reduced capacity of the transport system.

To contain long waiting times of the users due to the limited number of users admitted to the stations, the Municipality of Rome introduced an extraordinary service of 70 buses at the three main subway terminals. It was initially organized on four lines and subsequently extended to 6 lines, after a first trial period. The schematic layout of the supplemental bus network of supporting the subway lines is shown in Fig. 18.

8. Results

8.1. Observed transit crowding in the second step of phase 2 (R2)

Table 2 reports a focus on the number of passengers in the subway lines during the day May 4th and May 18th (108,219 and 163,810, respectively) and in the peak hours (8711 and 13,360, respectively) and a comparison with a pre-COVID day (February 20th) and the last day before the lockdown of many economic activities (March 11th). By focusing on the peak hour, the maximum number of passengers in the most loaded line (Line A) is 3764 on May 4th and 6017 on May 18th. The results confirmed that the policy measures introduced were successful in limiting crowding on the transit system under the risk level.

It is interesting to notice that the total number of passengers (156,408) who entered the subway lines on May 18th, the first day of reopening, and on March 11th (159,963), the day before closing, are very similar to each other (−2%), as the analysis of passenger categories led to foresee.

Furthermore, the analysis of passenger distribution over the daytime that is shown in Fig. 19 highlights that, due to the shift in the hours of activities, the hourly distribution changes significantly: on May 18th, the number of entering passengers in the peak period is lower that on March 11th, both in the morning (−15%) and in the afternoon (−12%).

8.2. Predicted metro passengers in phase 3

In Phase 3, because of the observed decline of contagion spreading consequent to the lockdown, the 50% capacity limitation required by the regional rule was considered as admissible in the subway system, where all passengers are obliged wearing protective masks and gloves. With the aim of predicting if this limit is compatible with the increase of demand due to the progressive confidence of the users in the public transport and the increase of traditional in-office working, three scenarios have been proposed and analyzed with different assumptions about the reduction of smart-working, increase of inter-regional trips, and increase of passengers' confidence in the use of public transport. Specifically, in Scenario A, the demand is about 111,000 trips; in Scenario B, the demand is about 102,500 trips; finally, in Scenario B1/B2 the demand is about 94,500 trips.

8.2.1. Phase 3: Scenario A

In Fig. 20 and Fig. 21, the load profile of line A of the subway is shown in both directions of travel. As it can be observed, towards Battistini, the maximum load is found between San Giovanni and Termini (about 8.000 passengers per hour), the load is increased of about 1.5 times (about 4800 passengers per hour more) compared to Phase 2 Scenario; in the opposite direction, the maximum load (about 4500 passengers per hour) is at Flaminio station, where there is the terminal of several tram and railway lines, here the load is increased of about two times (about 3.100 passengers per hour more) compared to Phase 2

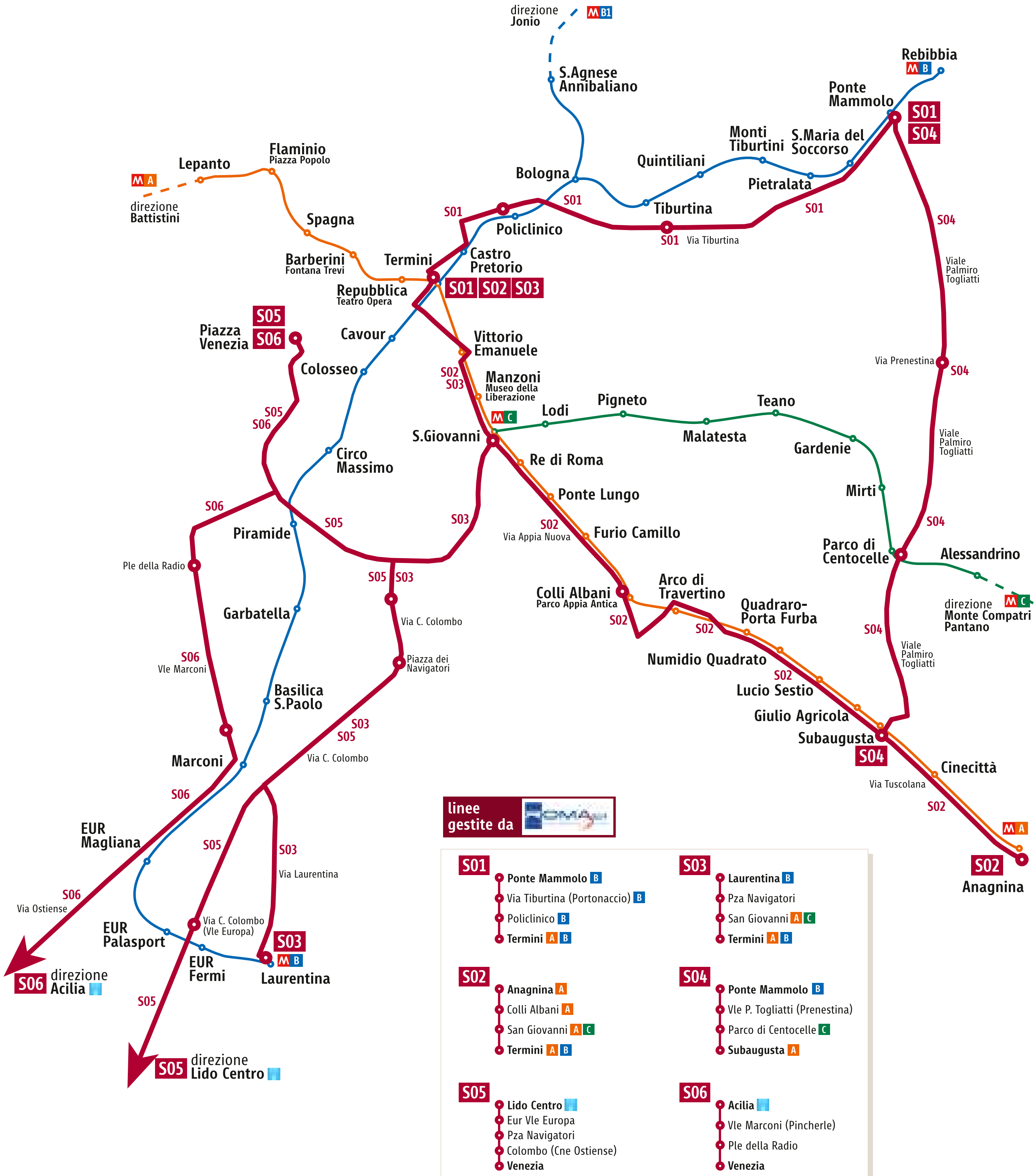

Fig. 18. Map of the four supplemental bus lines introduced to reduce the excess of demand on the subway lines.

Scenario.

In Fig. 22 and Fig. 23, the load profile of line B of the subway is shown in both directions of travel. As it can be observed, towards Laurentina, the maximum load is found at Termini (about 5000 passengers per hour) and at Tiburtina station, which is also an interchange terminal and it is about 4500 passengers per hour, increased of more than two times (about 3200 passengers per hour more) with respect to Phase 2 Scenario; moreover, also, in the opposite direction, the maximum load (about 4500 passengers per hour) is at Termini station, about three times more (3.300 passengers per hour more) than Phase 2 Scenario.

Fig. 24 and Fig. 25 show the load profile of line C. As it can be observed, in both directions, the maximum load is at Malatesta station, about 3000 passengers per hours towards San Giovanni station, about 1.4 times more (1700 passengers per hour more) than Phase 2 Scenario.

Fig. 26 and Fig. 27 show the load profile of line B (line B1) in both directions of travel. As it can be observed, towards Laurentina, the maximum load is found at Termini station, and it is about 3000 passengers per hours; thus, the load is increased of about two times (about

Table 2
Number of passengers in the subway lines in the day and the morning peak hours in selected relevant days.

	Daily Passengers					Peak Hour Passengers (8:00–9:00)				
	20-Feb	11-Mar	23-Mar	4-May	18-May	20-Feb	11-Mar	23-Mar	4-May	18-May
Lido Line	30,621	7679	2262	7382	10,105	4182	733	197	607	827
Line A	370,986	75,331	20,468	45,984	76,372	35,034	7063	1905	3764	6017
Line B	262,362	48,204	12,665	30,723	45,031	26,201	4179	985	2531	3950
Line B1	34,377	7025	1467	3646	5456	4971	710	133	298	440
Line C	49,237	21,724	7815	15,927	19,444	5155	1695	546	1125	1466
Pantano Line	903	228	44	100	187	85	11	2	7	16
Viterbo Line	23,944	6052	1696	4457	7215	2427	503	162	379	644
Total	*772,430*	*166,243*	*46,417*	*108,219*	*163,810*	*78,055*	*14,894*	*3930*	*8711*	*13,360*

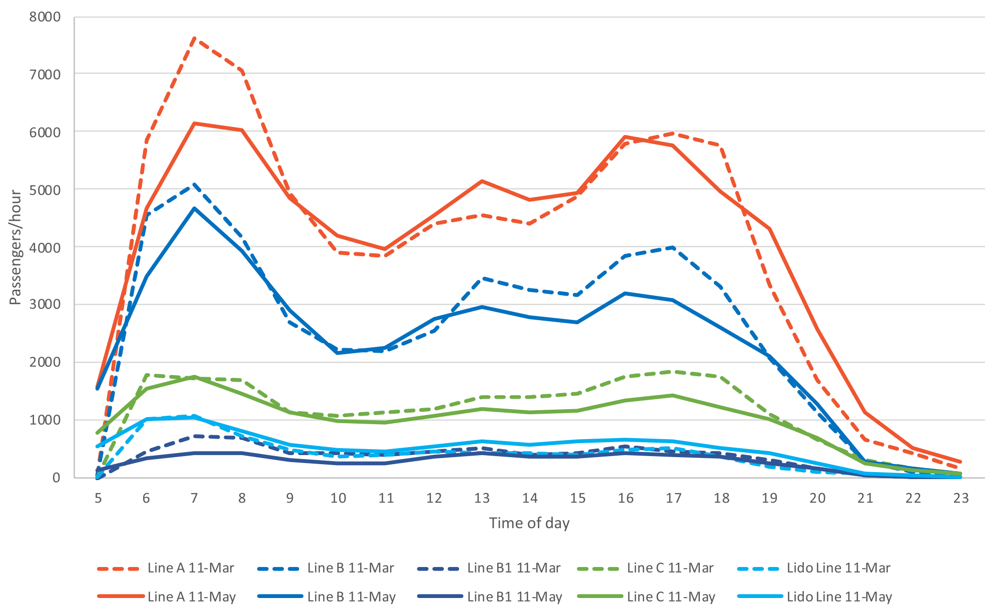

Fig. 19. Passengers per hour on subway lines on May 18th.

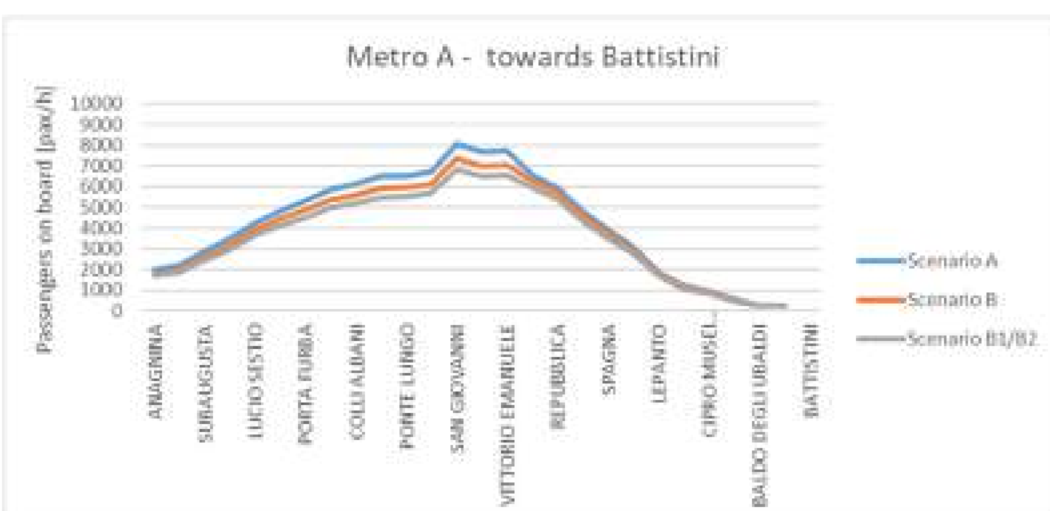

Fig. 20. Load profile of Subway Line A – direction Battistini – Phase 3.

2100 passengers per hour more) with respect to Phase 2 Scenario; moreover, also, in the opposite direction the maximum load (about 3000 passengers per hours) is found between Termini station, where the load is increased of about 2.5 times (about 2000 passengers per hour more) with respect to Phase 2 Scenario.

8.2.2. Phase 3: Scenario B

Concerning the second Scenario of Phase 3, illustrated in Figs. 20 and 21, the maximum load towards Battistini is found between San Giovanni and Termini (about 7.300 passengers per hour, around the 10% lower than Scenario A). In contrast, in the opposite direction, the maximum

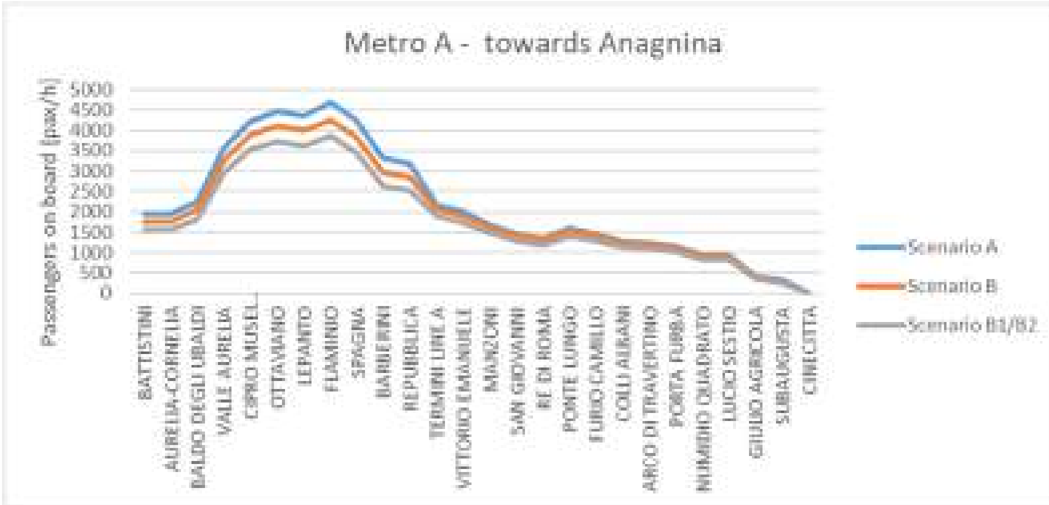

Fig. 21. Load profile of Subway Line A – direction Anagnina – Phase 3.

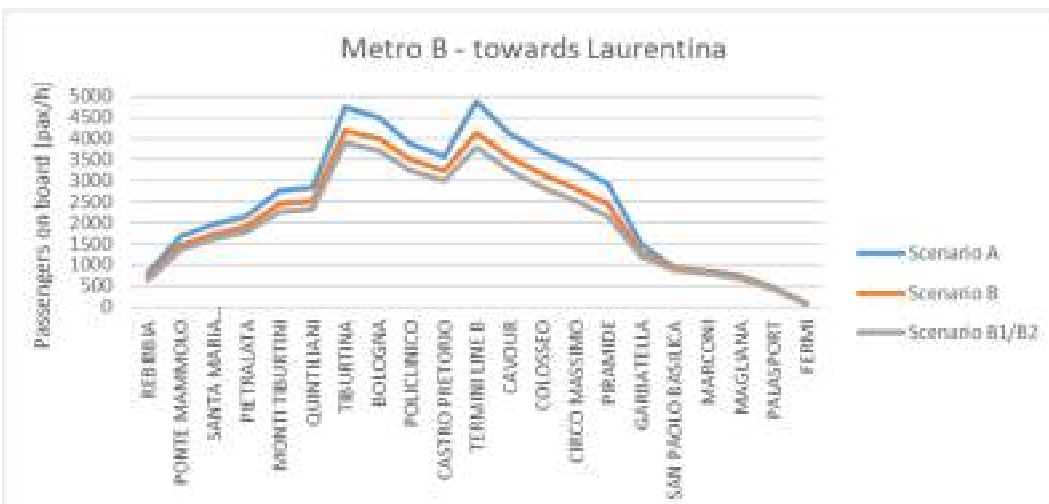

Fig. 22. Load profile of Subway Line B – direction Laurentina – Phase 3.

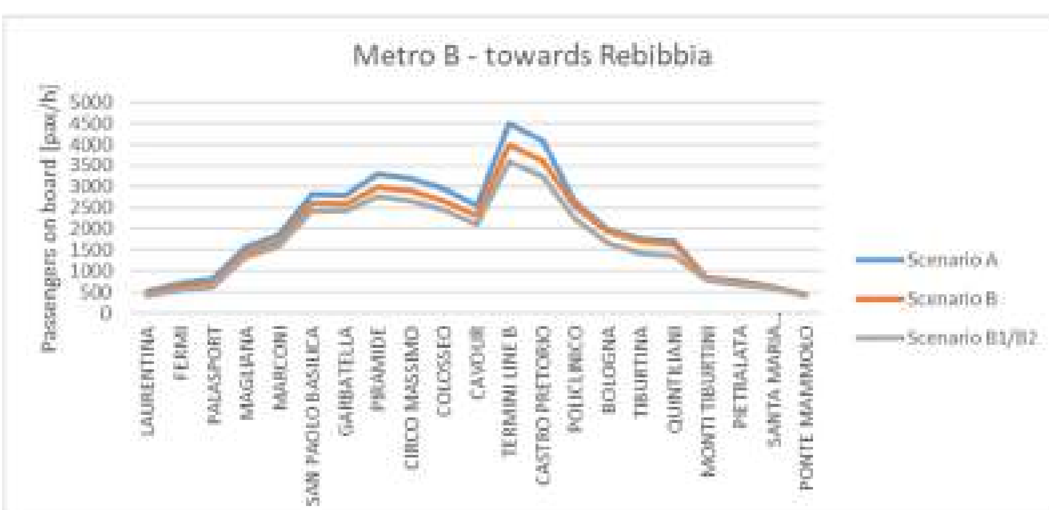

Fig. 23. Load profile of Subway Line B – direction Rebibbia – Phase 3.

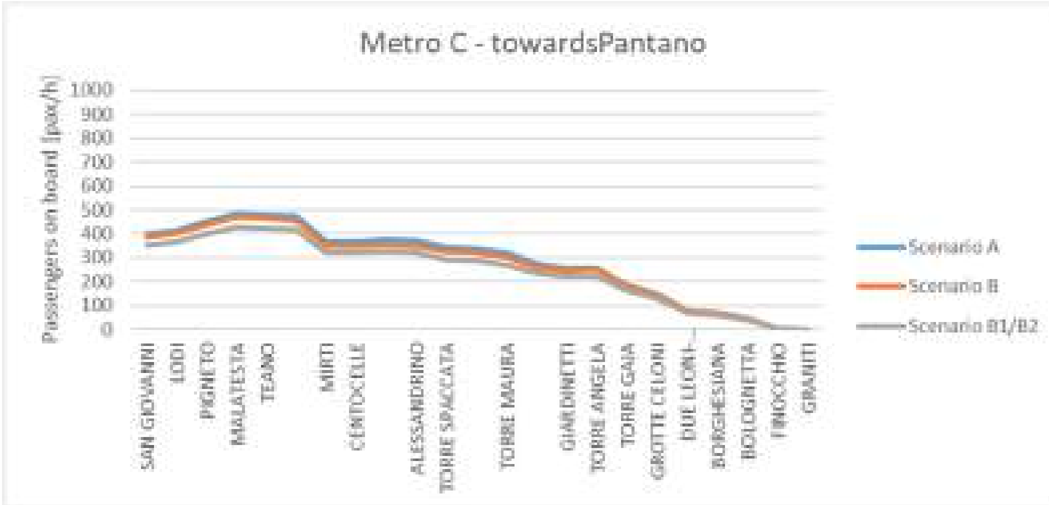

Fig. 24. Load profile of Subway Line C – direction Pantano – Phase 3.

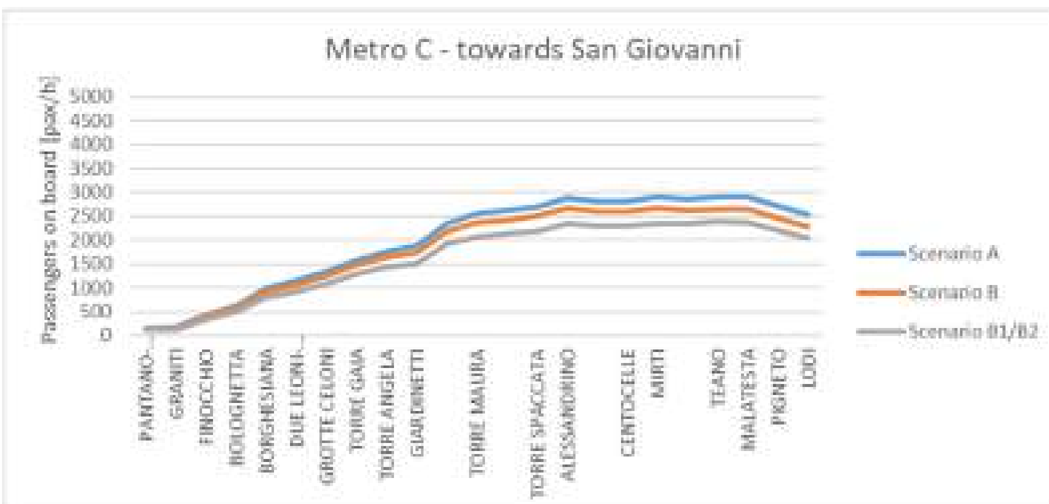

Fig. 25. Load profile of Subway Line C – direction San Giovanni – Phase 3.

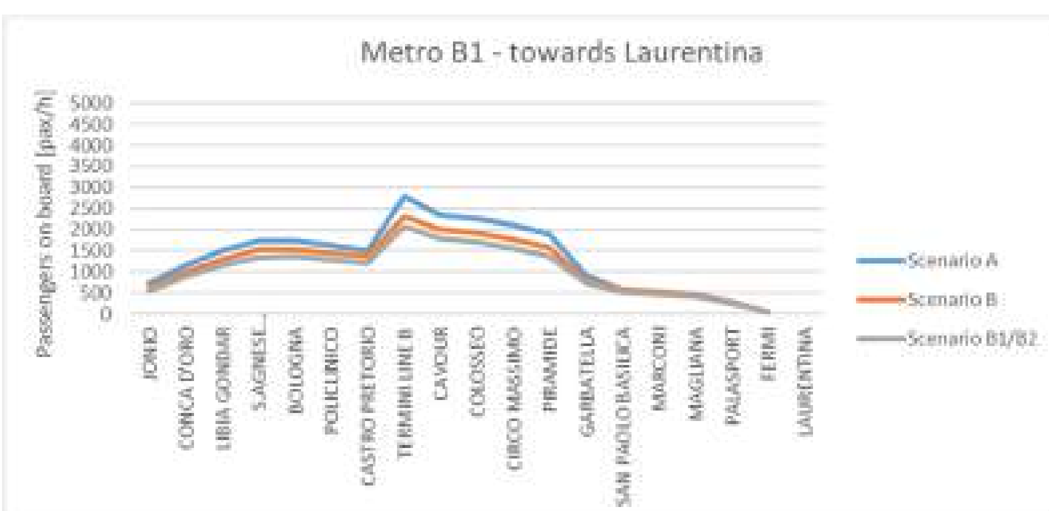

Fig. 26. Load profile of Subway Line B1 – direction Laurentina – Phase 3.

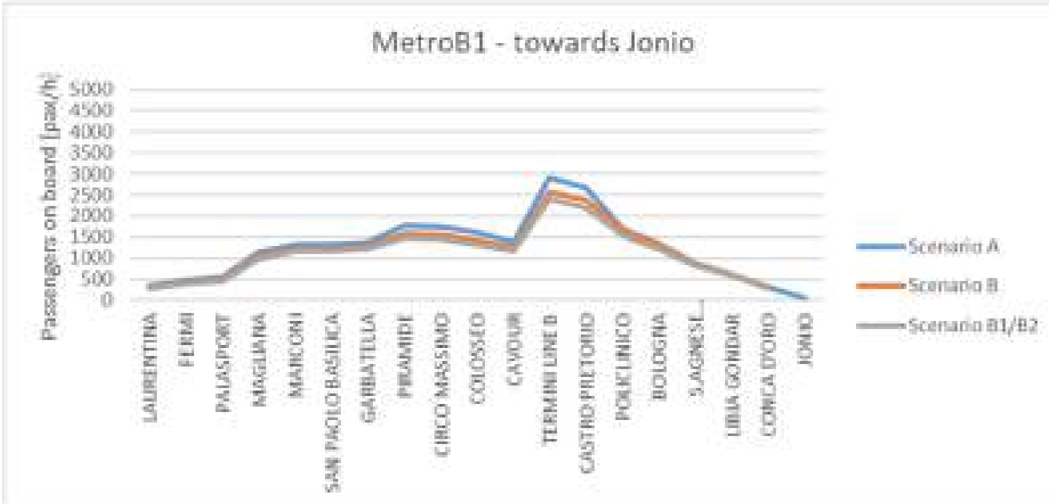

Fig. 27. Load profile of Subway Line B1– direction Jonio – Phase 3.

load (about 4.300 passengers per hour, about 9% lower than Scenario A) is at Flaminio station, where there is the terminal of several tram and railway lines.

As it can be observed (Figs. 22 and 23), towards Laurentina, the maximum load is found at Termini (about 4.200 passengers per hours) and at Tiburtina station, about 11% lower than Scenario A of Phase 3; moreover, also, in the opposite direction, the maximum load (about 3900 passengers per hours) is at Termini station, about 15% lower than Scenario A of Phase 3.

Figs. 24 and 25 show the load profile of line C in both directions of travel. As can be observed, in both directions, the maximum load is at Malatesta station, more than 2600 passengers per hour towards San Giovanni, about 7% lower than Scenario A.

Figs. 26 and 27 show the load profile of line B (line B1). In both directions, the maximum load is found at Termini station (about 2300 and 2600 passengers per hour), respectively 23% and 13% lower than Scenario A.

8.2.3. Phase 3: Scenario B1/B2

As it can be observed (Figs. 20 and 21), towards Battistini, the maximum load is found between San Giovanni and Termini, and it is about 6800 passengers per hours, about 7% lower than Scenario B. In the opposite direction, the maximum load (about 3.800 passengers per hours) is at Flaminio station, about 10% lower than Scenario B.

As it can be observed (Figs. 22 and 23), towards Laurentina, the maximum load is found at Termini (about 3.900 passengers per hours) and at Tiburtina station, about 5% and 19% lower than respectively the Scenario B and Scenario A; moreover, also, in the opposite direction the maximum load (about 3.600 passengers per hours) is at Termini station, 8% and 20% lower than respectively the Scenario B and Scenario A.

Figs. 24 and 25 show the load profile of line C in both directions of travel. As can be observed, in both directions, the maximum load is at Malatesta station, about 2400 passengers per hour towards San Giovanni, 8%, and 17% lower than respectively the Scenario B and Scenario A.

Finally, Figs. 26 and 27 show the load profile of line B (line B1). As can be observed, in both directions, the maximum load is found at Termini station (about 2000 and 2400 passengers per hour), respectively 33% and 20% lower than Scenario A.

8.3. Observed metro passengers in phase 3

Fig. 28 shows the trend of detected entries to the subway lines, expressed as a percentage comparison with March 2nd. As can be observed, passengers fell by between 60% and 30% on the same lines compared with pre-Covid period, with metro B showing the greatest reduction in passengers and metro C the least.

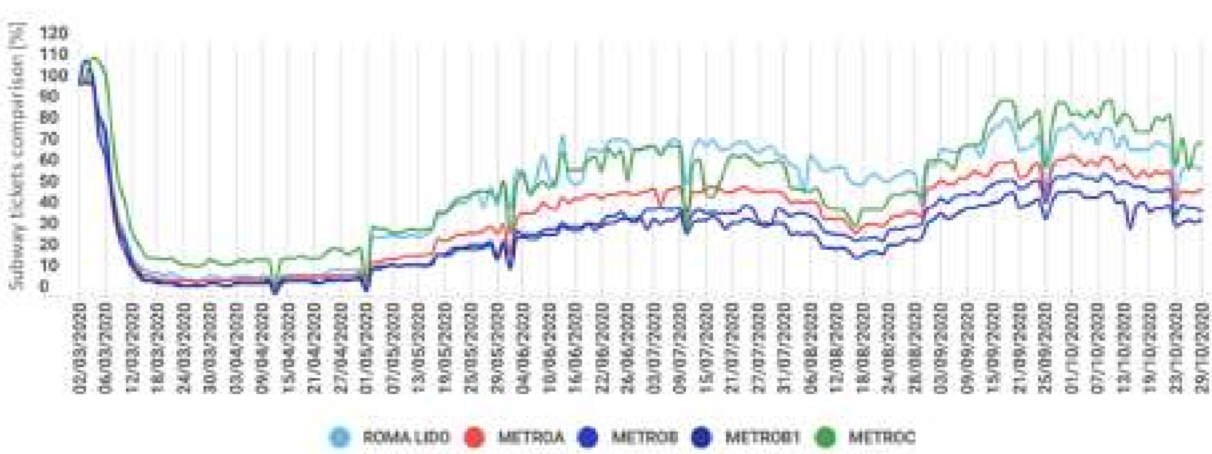

Fig. 28. Subway tickets daily comparison with respect to March 2, 2020.

8.4. Observed modal split in phase 3

The availability of data provided by the Transport Agency of Rome (RSM - Roma Servizi per la Mobilità) agency has allowed to deepen the considerations made in the previous paragraphs. Floating Car Data (FCD) are available, concerning speed and number of samples detected, and the number of validations occurred at the entrance on the lines of the subway network and the city's concessionary railways.

Neglecting a few months due to the partial lack of FCD, Fig. 29 shows how both data trends are characterized by a slump in the lockdown period, followed by a gradual recovery. However, the recovery observed in the month of September is at values that are, however, lower than those observed in previous years: 14% for passenger cars and 45% for the metro.

Applying these reductions to the demand values for the two modes of transport, known from previous surveys, it is possible to estimate the modal split after the restart, which shows the share of private transport increase by around 10%, in correspondence with a decrease in the overall demand for travel of around 30%.

8.5. Behavioral evolution

With the reopening of normal activities, the consequent re-establishment of regular habits in people's behavior is expected, also in terms of mobility choices. These behaviors, affected by the significant upheavals caused by the health emergency, will not necessarily imply an integral restoration of pre-pandemic habits. The first evidence of this evolution of behavior is represented by the considerable diffusion of smart working during the health crisis (in Italy from 1.2% to 8.8% of workers with the exclusion of companies for which the work cannot be performed remotely, in the period of the first Lockdown, ISTAT, 2020). For many companies it will become a working mode according to which to organize not temporary relevant shares of staff (about 5.35 million compared to 6.58 million during the pandemic). This change will obviously entail greater flexibility in the weekly frequency and, therefore, also in the daily amount of travel time for work purposes. In the medium and long term, this circumstance will also have an impact on the market of housing choices resulting from the possible transfer of part of the population, free from the need to systematically reach the workplace, from urban centers to more peripheral areas.

The pandemic has also favored the phenomenon of the development of digitization of many processes, services and activities. The most important is represented by e-commerce, whose growth modifies the chain of movements carried out by individuals accentuating, moreover, the importance of logistics in urban areas.

8.6. Public transport measures

This section focuses on PT measures through the implementation of which PT can regain its modal share or even increase it compared to pre-pandemic period. The public transport system is a complex system, characterized by infrastructures that are very often shared with other components and by peculiar ways of managing and using services.

The measures to be implemented on the PT system are identified in order to improve the service offered, to improve accessibility to the different functions and activities present in the territory and finally to increase the attractiveness of the service in order to encourage the increase in the use of public transport. This analysis involves the identification of interventions on both the supply and demand side.

In the national planning document developed by the Ministry of Infrastructure and Transport, "Italia Veloce", provides for various targeted and structural actions for the development of integrated rail systems (Metropolitan Rail Systems, subways, tramways) through three distinct directions:

1) completion, extension or implementation of the rapid mass transit network;
2) renewal and improvement of the vehicle fleet;
3) upgrading and enhancement of existing rail, metro and tram lines.

An effective public transport service should be structured to ensure: a high speed of travel; high accessibility; low waiting times at stops and regularity of service. These aspects represent the key element to make public transport competitive with private transport.

The PT measures concern the realization of: a) a carrier network organized with Bus Rapid Transit (BRT) services, characterized by a high performance in capacity, speed and regularity; b) a network of adduction lines managed with "on-demand" services, Demand Responsive Transit (DRT). The latter should work not only in areas of weak demand with a reduced impact, but in the conventional road adduction services with larger users to be transformed.

In relation to the application of pricing measures on public transport, as in Italy the fares are low, they not lead to changes in the behavior of users. On the other hand, there are possible measures to build customer loyalty through the use of smart cards that, in addition to making it possible to manage highly articulated fare programs without difficulty, are able to offer a series of advantages and possible benefits, including economic ones, linked to the use of public transport.

A further element of growth in public transport systems is linked to the strengthening in terms of the spread and use of user information systems.

Technological evolution and the integration of different functions in

Fig. 29. FCD and Subway tickets in Phase 3.

a single platform have led, in recent years, to the development of the concept of Mobility as a Service (MaaS). One of the most interesting elements of MaaS is related to the possibility for travelers to purchase multimodal mobility plans, that include a certain amount of different transportation services, managed with smartphone technology for dynamic and real-time travel planning with ticketing and electronic payments.

9. Conclusions

The paper has presented the activities of monitoring, modeling, and planning of people mobility during the Covid-19 epidemic period in Rome, from March to June 2020.

Monitoring activities used different technologies to analyze the changes in mobility during the progressive strengthening of the lockdown and the subsequent restart of economic activities. During the strictest period of lockdown, which maintained only 'essential' economic activities (fundamentally: health services, food delivery, banks, petrol stations, and related manufactory), walking mobility in the historic center and the load on the subway have reduced up to 95% due to the reduction of shopping activities and the wide adoption of smart-working in the business district and because of the fear of contagion in an indoor environment, respectively. Lower reductions affected private car traffic (up to −70%), which ensured essential activities were carried out, and heavy-duty vehicles (up to −40%), which supplied goods deliveries to the town.

In order to predict the effects of a progressive restarting of the activities, the transport system model in use at the Mobility Agency of Rome was recalibrated based on the traffic data collected during the lockdown and was applied to the future scenarios assuming that different categories of activities could restart.

Reopening only the 'necessary' categories (which exclude almost non-food shops and recreational activities) produced a limited increase of mobility that was compatible with the minimum interpersonal distancing (1 m) even in the most loaded lines of the subway. However, the restarting of most activities (excluding only schools and universities) would have produced unacceptable crowding in the subway system, according to the model predictions.

Since the access to the subway system was metered to prevent such a contagion risk condition, to avoid long queues and passengers' waiting times to access the transit system, a timing policy for commercial activities was implemented that differentiates the opening hours depending on the business category. Also, an additional transit service with 70 buses was introduced in the peak period at the three main subway terminals.

Data collected after the restart of the activities showed that the peak period was shaved by about 15%, so that the maximum loading on the subway lines, as predicted, was kept below the admitted value of 150 passengers per train, that is, 3000 pax/hour.

Finally, predictions are presented for the subsequent Phase 3, when smart-working is expected to reduce, inter-regional mobility to restart, and the users progressively become more confident to use public transport. In this phase, a higher load on the public transport is seen as admissible (up to the 50%, according to the regional decree) because of the observed reduction of the contagion spread provided that all passengers are obliged wearing protective masks and gloves.

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