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A systematic review of COVID-19 transport policies and mitigation strategies around the globe

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ABSTRACT

This paper reports a Scopus-based systematic literature review of a wide variety of transportation policies and mitigation strategies that have been conducted around the world to minimize COVID-19 contagion risk in transportation systems. The review offers a representative coverage of countries across all continents of the planet, as well as among representative climate regions – as weather is an important factor to consider. The readership interested in policies and mitigation strategies is expected to involve a wide range of actors, each involving a particular application context; hence, the literature is also characterized by key attributes such as: transportation mode; actor (users, operators, government, industry); jurisdiction (national, provincial, city, neighborhood); and area of application (planning, regulation, operations, research, incentives). An in-depth analysis of the surveyed literature is then reported, focusing first on condensing the literature into 151 distinct policies and strategies, which are subsequently categorized into 25 broad categories that are discussed at length. The compendium and discussion of strategies and policies reported not only provide comprehensive guidelines to inform various courses of action for decision-makers, planners, and social communicators, but also emphasize on future work and the potential of some of these strategies to be the precursors of meaningful, more sustainable behavioral changes in future mobility patterns.

Introduction

The Corona Virus Disease (COVID-19) has taken human civilization by storm, and it stands among the deadliest pandemics that humanity has witnessed. Unprecedented worldwide efforts have been triggered for vaccine development, allowing mass production and distribution in record-breaking timeframes. Mass vaccination campaigns are now underway worldwide, in a pursuit of eventually reaching herd immunity.

A study of mitigation strategies for COVID-19 without acknowledging the major role of vaccination (also known as pharmaceutical interventions) would lack background, *but challenges remaining must be acknowledged as well*. These challenges help frame and scope this paper, by justifying the critical role of transportation policies and mitigation strategies (non-pharmaceutical interventions - NPIs) in fighting the pandemic. Vaccination challenges still remaining are summarized next:

Vaccination rates. While several countries around the globe are achieving high vaccination rates, low-income countries have alarmingly low rates – Africa is expected to reach 70 % of its population vaccinated by August 2024 (US News & World Report, 2021).

Immunity waning. Vaccine immunity is an ongoing research field, yet consensus seems to exist on administering booster doses over 6-month periods (Doria-Rose et al., 2021; Zuo et al., 2021). This exacerbates the abovementioned burden on low-income-countries.

Staggered vaccination. Different countries (and provinces/cities) have deployed vaccination campaigns at different points in time, hence the loss of immunity will be staggered in time for different locations, increasing transmission risk related with inter-province and international travel.

Asymptomatic individuals. Put simply, undetectable virus carriers and transmitters. Research has found that asymptomatic individuals are accountable for 44 % of contagion in Mexico (López Olmedo et al., 2021), and even as high as 79 % in China (Li et al., 2020).

Variants and reinfection. Several COVID-19 variants have been identified so far (Deb et al., 2021), some of which are categorized by the WHO as Variants of Concern (VOC), as they have fundamentally different attributes than the original virus. The *effectiveness of current vaccines* against some of these variants remains to be determined conclusively and is an active research topic (Deb et al., 2021). For

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instance, Dejnirattisai et al. (2021) find that vaccines suffer from a substantial loss of neutralization against the latest *Omicron* variant. In this context of virus mutation and emergence of new VOCs, reinfection cases have been confirmed and remain being a threat.

Herd-immunity threshold. The WHO states that herd immunity can be achieved by surpassing a threshold proportion that depends on several factors. While this threshold is currently uncertain for COVID-19, Zhao et al. (2021) find a 95 % threshold for a small-scale university scenario. *Such a threshold seems quite difficult to reach currently, considering the abovementioned key facts.*

Antivaccine Groups. Particularly strong in the US, reaching 14 % of the population (Kaiser Family, 2021) – rendering a 95 % threshold out of reach, *at least until that 14 % became infected.*

Considering that vaccination still faces the critical challenges discussed above, non-pharmaceutical interventions play a vital role in fighting the pandemic. While worldwide consensus suggests that COVID-19 is not a predominantly airborne virus (it does not stay suspended in open air), *transportation systems may involve confined environments, making them a special case that plays a critical role in this pandemic.* Bare-minimum strategies such as social distancing are not easily transferable to the transportation context; for instance, Tarasi et al. (2021) highlight that a major challenge consists of public transit and shared mobility systems being incompatible with social distancing policies. Analyzing transportation-induced COVID-19 contagion brings forth several complexities, perhaps the most important arises from turbulent air flow dynamics within vehicles, generating risks that depend on the length of co-travel time (shared by passengers within a vehicle), seating arrangements, ventilation, among several other factors. Moreover, mitigation strategies can reach beyond targeting trips made by a given mode or service, and focus on *proactive measures such as planning and regulation of transportation systems*.

This paper conducts a comprehensive systematic review of academic literature that *analyzes, reports, and/or recommends transportation policies and mitigation strategies to minimize COVID-19 contagion risk*. The literature covers a wide array of countries around all continents of the globe, it focuses on assessing the efficiency of strategies and policies, presents guidelines for governments and operators, and proposes innovative ways to help reduce the spread of the disease. This paper offers a systematization and further characterization of the vast amount of knowledge generated thus far in research and practice, considering several attributes to address the needs of a wide readership, such as: *transportation mode; actor (users, operators, government, industry); jurisdiction (national, provincial, city, neighborhood); and area of application (planning, regulation, operations, research, incentives innovation/technology)*. A compilation of strategies such as the one provided in this paper can be instrumental in aiding planning, operations, decision-making, and research efforts.

This paper is structured as follows. Section 2 describes the method conducted for a systematic review of the literature. Section 3 describes an overall characterization of the literature reviewed, in terms of coverage and key attributes. Section 4 summarizes and classifies the transportation policies and mitigation strategies surveyed, followed by a discussion of each category. Section 5 summarizes future research directions found in the literature. Section 6 presents the limitations of the study and Section 7 concludes the paper.

Method

This study consists of a qualitative, systematic review of the COVID-19 literature (Grant & Booth, 2009; Snyder, 2019), which identifies research focused on transport policies and mitigation strategies to minimize contagion risk. Results are classified for governments, operators, users, and industry actors, for whom a "*What to do?*" guide is summarized and discussed. From a research perspective, future research directions proposed in the literature are reported as well.

The review is conducted following the method proposed by Snyder (2019). The first phase defines the rationale for conducting a literature review, which is already explained in the previous paragraph. The second phase consists of defining preliminary search inclusion criteria. Having conducted the first two stages, preliminary criteria are tested and analyzed, to define definitive criteria, as follows:

- Articles published from 2020 to the present (April 2022).
- Articles covering mode-specific strategies to minimize the COVID-19 risks or impacts.
- Articles written in English.
- Articles containing one or more search criteria in either their *Title*, *Abstract*, or *Keywords*.
- Articles related to maritime or air transport modes are out of the scope for this review.
- Only articles published in journals are considered, as research suggests journals as the most relevant means to disseminate and acquire knowledge (Martín-Martín et al., 2018). Other formats, such as conference papers, dissertations, books, etc. may have duplication of knowledge in journals, or report ongoing research in the case of conferences.

The process for article search and selection is conducted by two means:

- Articles identified in bibliographic citation databases. In this study, the Scopus database was selected since a large proportion of the indexed articles are journal articles, which does not occur in *Google Scholar* (Tong & Li, 2022). Furthermore, research suggests that the coverage of *recent articles* is more complete than the *Web Of Science* database (Aghaei Chadegani et al., 2013). Considering that the pandemic began in 2020, *Scopus* is deemed a suitable choice for this review.
- Relevant articles that are known to the authors of this review from their own experience and research networks, which also meet the inclusion criteria – except for the year of publication.

Search criteria are defined by a combination of two levels. The first one includes *transport mode* terms along with *processes related to their design and operation*. The second level consists of combining the first level terms with synonym terms alluding to the pandemic, by the logical expression *"AND* (COVID* OR Pandemic OR SARS-CoV-2)". Table 1

Table 1
Search results by search terms.

first-level search criterion	# Articles
"Frequencies setting"	2
"Demand management"	32
"Transportation planning"	72
"Transport Policy"	61
"Transport strategies"	7
"Mobility strategies"	11
Bus	348
Bike	120
Tram	22
Railway	238
Train	1318
"Private Vehicle"	49
"OD Matrix"	4
Ridesharing	11
Carsharing	8
"Transport modes"	75
"Means of transport"	42
Risk + Transport	1424
Walk*	1832
Transport +"Strategies against"	14
Total	**5690**

All first-level terms combine with the second-level criteria: "AND (COVID* OR Pandemic OR SARS-CoV-2)".

presents the search results arising from these criteria.

Regarding semantics, special search terms are utilized to cover wording variants. Quotation marks ("") instruct the search engine to consider multiple words as a single combined. The asterisk character (*) instructs the search engine to consider all variants of the prefix of a word (e.g., COVID* encompasses COVID, COVID-19, COVID19, etc.).

The resulting database of retrieved articles is then depurated by a semi-automatic process as follows:

- Remove articles that are not Journal Papers.
- Remove articles with incomplete data. For example, authors, journals, etc.
- Remove duplicate articles, based on their DOI numbers.
- Remove out-of-scope articles or irrelevant (e.g., transport* often appears in medical literature).

As a last step, 15 articles particular to the authors' knowledge that were not captured in the search results are added. *The final sample consists of 442 articles*, all of which are considered for a third, deeper analysis phase, as suggested in Snyder (2019).

For the analysis phase, information and attributes of each article are stored in a matrix of findings, which facilitates various subsequent analyses. Data obtained through the *Scopus export tool* include: *Title; DOI; Keywords; Document type; Source; Authors; and Year of publication.*

The analysis process begins with the review of the abstract, methods, and conclusions of each of the studies. Additional attributes that are relevant for characterization are added to the matrix of findings, and filled through a manual process, these attributes are the following:

- Strategies proposed/analyzed.
- Country.
- Transportation mode.
- *Actor*: Government, Industry, Operators, Users.
- *Jurisdiction*: International, National, Province/State/Department, City, Neighborhood, University.
- *Area of application*: Planning, Regulation, Research, Incentives, Innovation/Tech .
- Aims of the paper.
- Future Work.
- *Remarks* (general notes regarding articles' conclusions, or specific details to consider).

At last, articles that did not explicitly suggest/analyze COVID-19 strategies or guidelines are excluded from the last stage of analysis. This last depuration yields *134 articles*, which are inspected at full detail.

Overall Characterization of the Literature.

This section provides a concise multidimensional overview of the surveyed literature, which already unveils important research gaps remaining. The results are presented as statistical summaries of key categories such as country, year, transportation mode, actors, jurisdiction, and area of application.

The first attribute subject to discussion is *transportation mode*. Fig. 1 shows that the most frequent category in the literature is *multiple modes of transportation*, however, grouping all public transit categories together, this mode predominates (51.97 %). While this trend is expected due to a *perceived higher risk within public transit vehicles and infrastructure*, it also denotes research gaps in *other public-use modes such as ridehailing or taxis*.

If active transportation categories in Fig. 1 are aggregated, these account for 9.87 % of the literature surveyed, which is also expected as these modes are *argued to pose the lowest contagion risk* – this relatively high percentage denotes an *encouraging research direction from the lens of sustainability*.

Fig. 1 also unveils a salient research gap regarding *motorcycles*, which

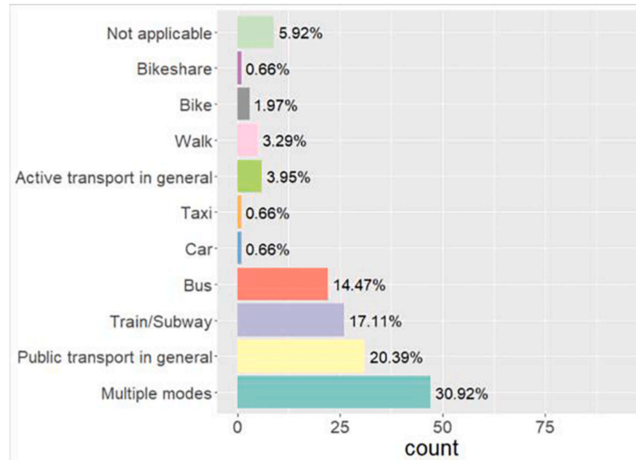

Fig. 1. Literature characterization by mode.

are quite popular in low- to middle-income countries around the globe. The *Not applicable* category stands for papers which analyzed strategies, but did not explicitly address a transportation mode (e.g., working from home policies).

A second attribute that provides an application-oriented perspective is the main actor involved in a given strategy – when multiple actors were involved, the one deemed as the most representative is reported. Fig. 2 evidences a clear predominance of the government actor (64.47 %), which is an expected outcome considering that governmental bodies are in charge of regulation and policy-making. Naturally, the second more frequent category are operators, as these actors are responsible for conducting a variety of biosafety measures for their fleets and passengers. User-oriented strategies appear in a much lower frequency, as this category has been limited to strategies focused explicitly on compliance with measurements enforced by the government and operators. The *literature for industry is very limited*, with only one article touching upon adjusting standards and developing technological solutions.

The jurisdiction to which policies and strategies pertain tells an interesting story regarding how different levels of government have taken action thus far. Fig. 3 shows that *more strategies have been developed at the city level than other levels*, which suggests that case studies have more often focused on cities, and that policy-making has been more often driven by city authorities. International (large-scale) and neighborhood/university (small-scale) levels are expectedly less frequent.

Fig. 4, shows a more balanced distribution according to the application field. Regardless, an expected predominance of planning-oriented strategies can be observed, while a *dearth of incentive-oriented strategies* highlights a clear research gap that could arguably offer impactful

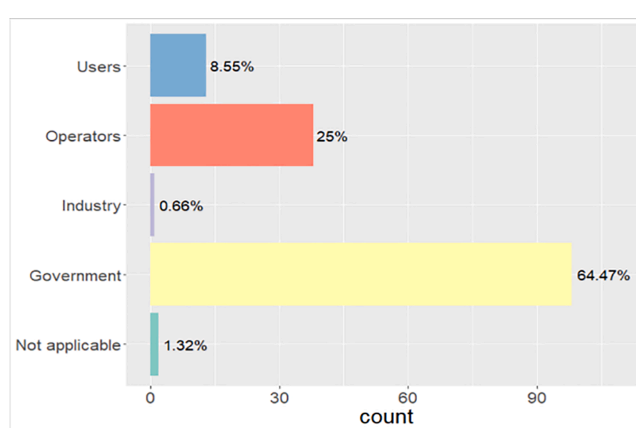

Fig. 2. Literature characterization by actor.

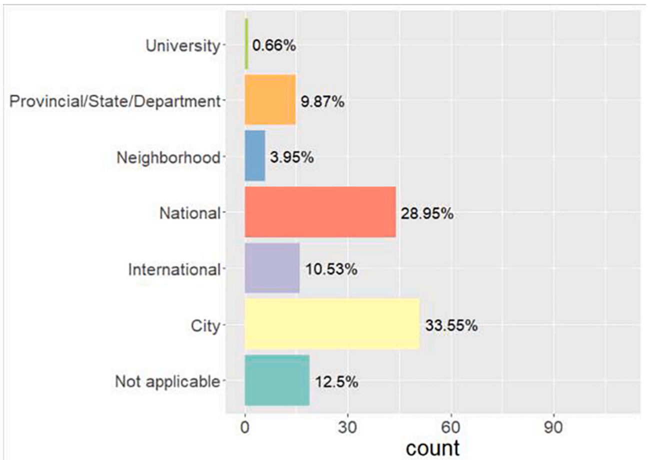

Fig. 3. Literature characterization by jurisdiction.

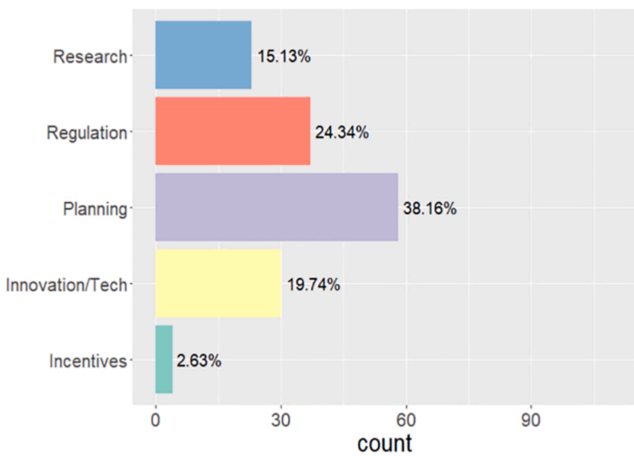

Fig. 4. Literature characterization by application.

results in managing contagion.

To provide further insights on the *relation among categories*, Fig. 5 below offers an overall snapshot of the systematic review conducted, though a more complex visualization that classifies the literature by *transportation mode*, *field of application*, and *actor* involved. Specific fields that have received the most attention are unveiled, as well as several fields which should grow in the near future.

As evidenced earlier in Fig. 1, and more evidently now in Fig. 5, public transit modes predominate with respect to car-based and active modes. The *Car*, *Taxi*, *Walk*, *Bike* and *Bikeshare* modes have been considerably understudied in comparison to transit, arguably due to their associated lower-risk perception. Further analyzing patterns of public transit modes, a relatively balanced mix of application fields can also be observed.

Another salient pattern of Fig. 5 is a vast predominance of government-led policies and strategies, followed by the operator-led category. Regarding *regulation*, it is expectedly prominent for government and operator actors, as governments make policies and operators abide or even help enforce them. Users also appear in regulation, as some articles propose auditing their compliance, such as the use of masks.

The spatial distribution of the literature is depicted in Fig. 6. On a continent-basis, the literature surveyed has a representative representation with one country per populated continent at the very least. Nevertheless, striking differences become evident in research/practice output. North America, Oceania, eastern Asia, Nordic countries, and western Europe all have excellent representation; as opposed to eastern Europe, the Middle East, Africa and South America.

From a climate perspective, *weather poses a critical influence on transmission risks, as well as on the applicability of some mitigation strategies*. Hence, this paper ensures that the literature is well-represented in each of the five *Koppen Classification System* climate zones (as evidenced in Fig. 7).

Transportation policies and mitigations strategies

The design of transportation policies and mitigation strategies to curb the spread of COVID-19 naturally derives from identifying and understanding contagion risks and transmission mechanisms. In this context, this section begins with a brief background and general notions regarding how the virus spreads, how contagion may take place, and some important risk factors.

A background on contagion risks and transmission

A fundamental notion governing transportation-related contagion states that risks are higher when people make trips that involve sharing space with other passengers inside an enclosed vehicle or within a given transportation infrastructure, such as a train station or even a crowded bus stop. The study conducted by Hu et al. (2021) analyzes contagion risk by different passenger seating arrangements within vehicles, and finds indeed that *closed and crowded environments shared by passengers* increase contagion risk.

Within a confined transportation vehicle or infrastructure, the virus can be transmitted by *droplets expelled from the mouth or nose of an infected subject*. These droplets may either be inhaled by another subject directly, or may land on a surface that can indirectly infect another subject (known as *fomite transmission*); in fact, van Doremalen et al. (2020) note that the virus can survive up to 3 days, depending on the surface and specific conditions of humidity and temperature.

Much speculation and social unrest has arisen regarding the impacts and contagion risks associated with the transportation system; a situation that has not quite yet been appeased by scientific findings, as research efforts have reached mixed results that vary over a wide spectrum; for example: from "no correlation", "transportation accounting to only 5 % of cases", to "transportation posing very high risk", or "significant and robust relationship between public transportation mobility and daily coronavirus cases" (Benning et al., 2021; Edwards et al., 2021; Hu et al., 2021; Iç et al., 2021; Jenelius & Cebecauer, 2020; Lee et al., 2020; Peng & Jimenez, 2021; Schwartz, 2020).

Despite transportation systems playing an important role in this pandemic, caution must be exercised when establishing causation, as correlating single trips with contagion may *overlook all other trips and activities* (e.g., *work, study, shopping, sports, etc.*) *performed by people throughout the day*. Each of these trips and activities involve a given level of risk depending on a given type of infrastructure (transportation, office, classroom, market, etc.), on a variety of biosafety conditions, and on how space is shared among people. Hence, it cannot be assumed that trips necessarily were the instance where contagion took place. For instance, a safely operated vehicle can pose a lower risk than people at a crowded place. Moreover, trips occupy only but a small portion of time of a person's daily schedule (see Fig. 8). Even when contagion took place while traveling, *a subject who utilized several modes in the day and became infected could have been exposed in any of those modes*. Hence, studies finding correlations based on aggregate data, or focusing on monitoring users' contagion, may erroneously determine mode-specific risks. In this context, disaggregated analyses of persons' full-day activities, and/or disaggregated modeling methods such as agent-based microsimulation approaches may offer appropriate solutions – an example of such methods can be found in Zafarnejad & Griffin 2021), applied for a school closed-environment.

Table 2 summarizes some risk factors found in the literature. Only a

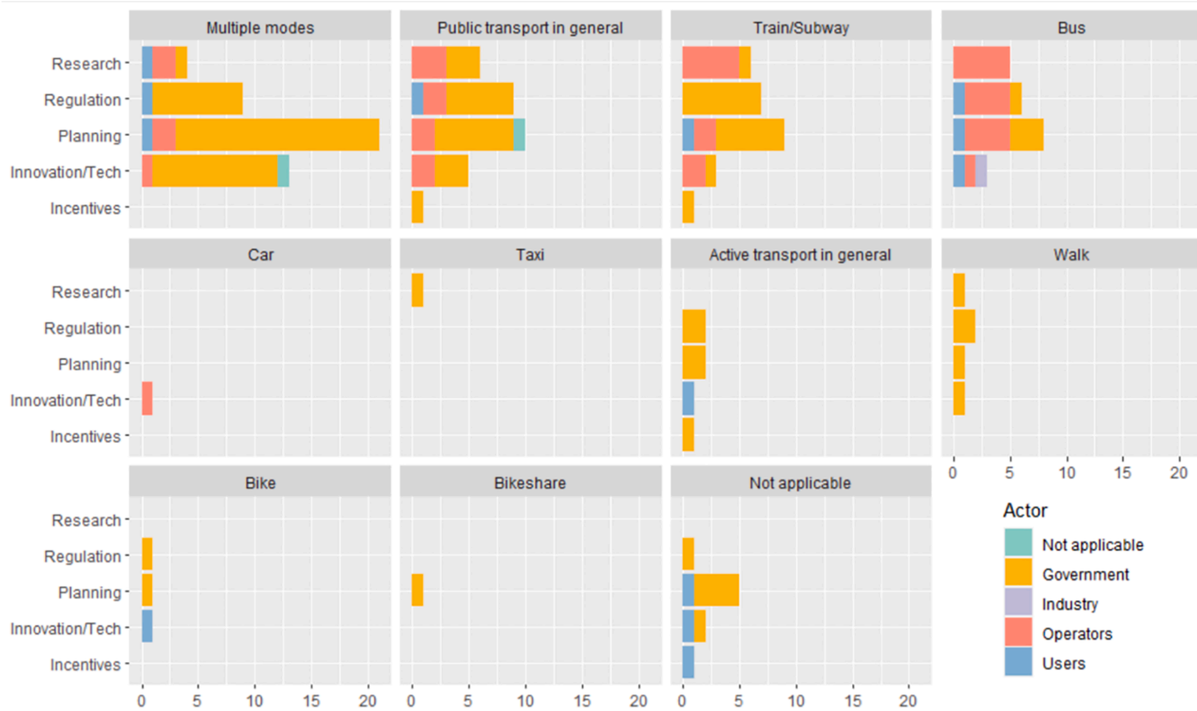

Fig. 5. Characterization of the literature by mode, application field, and color-coded by actor.

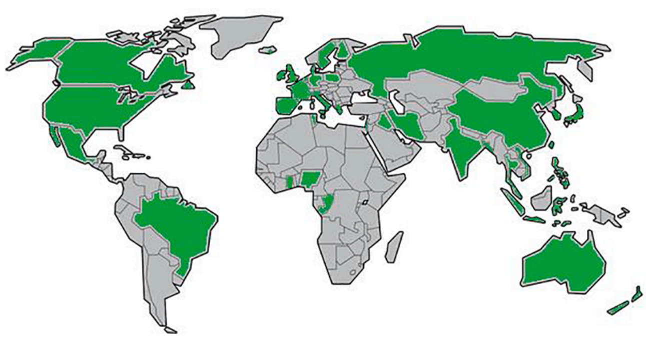

Fig. 6. Worldwide coverage of the literature review.

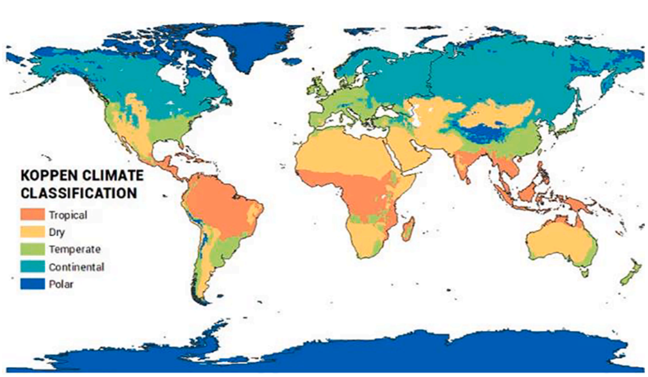

Fig. 7. The Koppen Climate Classification System. Retrieved from: https://earthhow.com/ koppen-climate-classification/.

high-level description is provided in this section, as discussions of strategies and policies *linked to these risks* are offered in Section 4.2.

Compendium of strategies and policies

As shown in Section 2, a vast literature exists focusing on the interplay between COVID-19 and transportation. The characterization efforts undertaken in this paper led to the definition of *25 broad strategy categories and 151 focused strategies*. Since an output of such magnitude brings forth visualization and reporting challenges, Table 3 below reports the characterization of the 25 strategies at the broad-level categories. A full-fledged characterization of the 151 distinct strategies becomes prohibitively large, hence, it is not reported in this paper, but can be found instead in a *publicly-available shared folder*[1] managed by the authorś research group.

Table 3 characterizes broad strategies by the main attributes that have been defined in this study: *transportation mode, actor, jurisdiction, and application field*. The table is complemented by some key visualizations presented in Figs. 8 and 9, which shed light into particular patterns of the reviewed literature, but also help readers and actors in easily identifying a particular strategy of interest. Last, in-depth discussions of these broad strategies are provided, tailored for each type of actor.

The frequency of each of the 25 broad strategies found in the literature is shown in Fig. 8. As expected, most of the attention has been drawn to the promotion of active mobility and changes in activity/mobility patterns. Even before the onset of the pandemic, several countries began making efforts to stimulate active mobility as a strategy to discourage motorization and achieve objectives proposed in the Paris Agenda as well as Sustainable Development Goals. Mobility restrictions and social distancing measures imposed by the pandemic strengthened and accelerated active mobility promotion.

The broad strategies are classified by actor in Fig. 9. Most of the strategies are oriented towards the government, which is expected since

[1] https://drive.google.com/drive/folders/1dG8cb27isvLLjNVu7yMCV9EmjAp7372s.

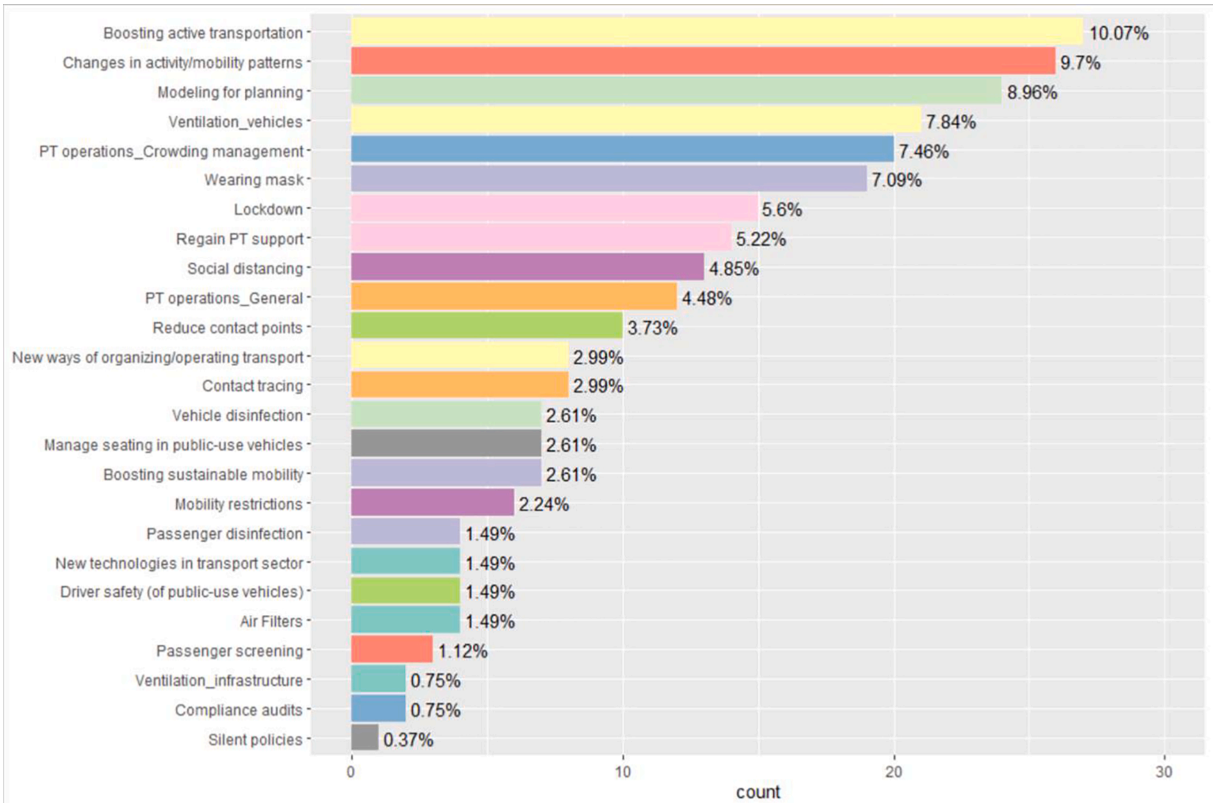

Fig. 8. Frequency of broad strategies found in the literature.

it has competencies regarding basic services such as health and transportation, but also because the government establishes norms that industry, operators and users must comply with to safeguard life and well-being of the population. It is noteworthy that there is a dearth of research reporting *compliance audits* conducted by the government, leaving this task to operators. Similarly, there is no research focusing user-oriented strategies related with *lockdown, mobility restrictions, passenger disinfection, passenger screening* and *silent policies*, yet it would be useful to understand users' compliance as well as their perceptions.

Discussion of government-oriented strategies

This section offers a focused discussion of government-oriented strategies, which has been found to be the most extensive branch of the surveyed literature, covering 24 out of the 25 categories shown in Table 3.

From the government, several strategies can be designed, to later become regulatory measures that operators must abide to. In this sense, *ventilation systems* include the recirculation of air inside the units (Yu et al., 2020; Z. Wang et al., 2022) and in related services such as stations (Clegg et al., 2022; Zou and He, 2021). Yu et al. (2020) highlight that transportation has a certain role in promoting the spread of the epidemic, thus, measures such as isolation and reducing passenger occupancy to avoid the contact between passengers can effectively reduce the infection risk of passengers, and the effect is significantly better than the ventilation and disinfection measure. Zou and He (2021) show that the wind and its power to spread the virus inside a train could mean that measures such as the distance of 2 m between passengers are not enough. Park and Kim (2021) note that the ventilation system in the units should be equipped with a virus filter.

Strategies regarding *model-supported, evidence-based planning/policy-making* are based on models and simulations that show the level of transmission of the virus in transport systems. The literature suggests that governments should: include differential policies for super spreader and super susceptible locations (Chin & Bouffanais, 2020); focus policymaking on crowding at stations and households, rather than population density (Hamidi & Hamidi, 2021); establish correlation among walkability, population density, and population size on COVID-19 spread (Lima et al., 2021); generate spatially differentiated travel restriction policies (Zanin & Papo; 2020). Moreover, Chin & Bouffanais (2020) conclude that busy peripheral bus interchanges are riskier places than crowded central train stations.

Other authors examine the relationship between modes of transportation and the level of contagion (Lima et al., 2021; Zhang et al., 2021b; Tiikkaja & Viri, 2021). In this regard, Lima et al. (2021) conclude that urban immunity can be achieved through urban reorganization of the built environment and promotion of hyper pedestrian-oriented development – both being within the government course of action. Zhang et al. (2021a), Zhang et al. (2021b), Zhang et al. (2021c) highlight that, developing countries are equally active in implementing measures to control the spread of the virus by managing the crowding in the transport system as developed countries.

Several findings from research focused on modelling can be utilized by governments for better, evidence-based decision-making. Nikparvar et al., (2021), Aragão et al., (2022), Benning et al., (2021), Seno, (2020) and Aragão et al. (2022) use prediction models with some peculiarities such as including the effect of active mobility, weather, and contact among people. Aragão et al. (2022) find a correlation between humidity, temperature, and air quality with the number of COVID-19 deaths. Some authors model the effect of mobility restrictions on the decrease in the number of infections (Bian et al., 2021; Lima et al., 2021) and the crowding of people in stations (Hamidi & Hamidi, 2021; Mahmud et al., 2021; Scott et al., 2021). Hamidi & Hamidi (2021) note that there is no evidence that subway ridership is related to the COVID-19 infection rates, and show that racial and socioeconomic compositions are identified among the most significant predictors of spatial variation of the spread of the virus.

Bohman et al., (2021) propose the use of open spaces for holding events that require the attendance of many people. Other studies

Table 2
Key Risks of COVID-19 Contagion.

RISK	SOURCE	REMARKS
Proximity In Passengerś Seating In Buses	Hu et al. (2021)	Risks are considerably higher in the same row of a COVID + subject, risk for subsequent rows is much lower.
Turbulent Airflow Dynamics Within Vehicles	Edwards et al. (2021)	Leaving windows and doors closed, and not relying on ventilation/filtration systems involves a high risk of contagion.
Weather	Wei et al. (2020)	Average temperature, cumulative precipitation, and average wind speed have strong, combined, and non-linear effects on contagion risks.
Co-Travel Time (Shared By Passengers Within A Vehicle)	Hu et al. (2021)	The attack rate of the virus increases 0.15 % per hour of co-travel time, and to 1.3 % per hour if passengers are seated adjacently. Even a distance of 2.5 m becomes unsafe after 2 h of co-travel time.
Bus Drivers And Assistants	Dzisi and Dei. (2020)	Bus drivers and assistants are exponentially more exposed than the rest of people, hence pose a high risk of being transmission vectors if appropriate precautionary measures are not taken.
Passengerś Compliance	Dzisi and Dei. (2020)	This depends largely on the idiosyncrasy of passengers. But, in locations where compliance is low, contagion risks are considerably high.
Type Of Mask	Edwards et al. (2021); Dzisi and Dei. (2020)	The level of protection of KN-95 masks is much higher than surgical masks and cloth masks. Contagion risks vary accordingly.
Informal Public Transit	Bonful et al. (2020)	Informal services cannot be controlled and monitored for compliance with strategies.
Circulating through transportation infrastructure	López Olmedo et al. (2021)	This inevitably creates close contacts, especially in crowded environments.
Physical selling of tickets	Mogaji (2020); Shen et al. (2020a), Shen et al. (2020b)	Increases close contact, and implies a high probability of fomite transmission.

analyze the effect and compliance with government impositions in transportation systems such as the use of the mask (Kumar et al., 2022) and the disinfection of units (Kruszewska et al., 2022). F. Chen et al. (2021) analyze alternatives for the boarding and disembarking of passengers, and propose an interdisciplinary framework to manage strategic visions, to implement systems to improve urban quality of life, and to inform managers and citizens about the spread of the virus. The areas included in the framework were urban design, planning, engineering, environmental science, and data science.

Other authors address the use of cell phones to determine the movement of people and relate this information to levels of contagion (Douglas et al., 2021; Walker & Sulyok, 2020). Results suggest an association between mobility and case occurrence. Finally, (Osorio et al., 2022) analyze the effect of discounts and promotional activities within public transport and show that the socio-demographic characteristics of passengers directly influence the evolution of the pandemic.

Strategies regarding *public transit operations* focus mainly on the analysis of service reduction to decrease the number of infections (Chan and Wen, 2021; Sasidharan et al., 2020; Cooley et al., 2011; Shirai Reyna et al., 2021; Kushnir et al., 2022). Sasidharan et al. (2020) find a strong correlation (R2 > 0.7) between increases in air pollution and increases in the risk of COVID-19 transmission within London boroughs, while Cooley et al. (2011) find a relevant percentage (4 %) of transmissions in New York City have taken place in the subway. Chan and Wen (2021) show that transfer activities can be a crucial risk factor as they increase the probability of interpersonal transmission. On the other hand, Thombre & Agarwal (2021) and Love et al. (2021) highlight that planning for the public transport system must be resilient and should be shared with the state in order to face disasters such as the pandemic.

Strategies regarding *public transit operations - crowding management* focus on planning and informing the user about the operation of the public transport system (Cho & Park, 2021; Budd & Ison, 2020; Lima et al., 2021; Yu et al., 2020; Park and Kim (2021)). In this regard, Cho & Park (2021) rely on crowding multipliers to compare passengers' behavioral differences before and after the pandemic, results suggest that crowding impedances after the pandemic are about 1.04 to 1.23 times higher than before. Kushnir et al. (2022) note that governments have made different decisions based on the same indicators.

Governments around the world have established the *lockdown* as a strategy to stop the transmission of the virus. In this sense, Xin et al. (2021); Parr et al. (2021); Fountoulakis et al. (2022); Yu et al. (2020); Zhang et al. (2020); Liu et al. (2020); Thomas et al. (2022); Lei & Ozbay (2021) and Zhang et al., 2021a analyzed the required lockdown duration to stop the transmission of the virus, while Cartenì et al. (2021); Kong et al. (2021) and Mogaji (2020) focused on the effect of lockdown on virus transmission. Zhu & Guo (2021) perform the analysis on high-speed rail and Murano et al. (2021) analyze the convenience of restricting air travel instead of issuing lockdown. Ohi et al. (2020) uses an agent-based model to analyze the duration of lockdowns. Xin et al. (2021) and X. Zhang et al., 2020 agree that ridership reduction is influenced by the severity and duration of lockdowns. According to X. Zhang et al. (2020) a combination of cyclic lockdowns and short length lockdowns halve the resurgence of the disease; however, lockdowns may be ineffective in states with high population density, poor transportation infrastructure and a large informal economy. The study of Liu et al., 2021 highlights the opportunity brought by the COVID-19 pandemic to promote sustainable transportation systems. As evidenced, this strategy has been widely covered, and the summary provided offers a comprehensive starting point for government officials seeking guidance on the matter.

Another strategy implemented by some governments consists of *passenger screening*. Pre-travel testing is studied by Zhou et al. (2021) with an emphasis on reducing the risk of contagion. The study demonstrates how testing 3 days before traveling could significantly reduce the risk of transmission, and it is more economical and efficient than testing for all passengers. The study also finds that people without access to private vehicles and the elderly face disadvantages in accessibility to testing sites, even in urban areas. A notable exception is related to black and low-income population groups, which are disproportionately concentrated in neighborhoods with above-average accessibility in terms of a close proximity to testing sites. The equality in accessibility to testing sites is also studied by Tao et al. (2020). On the other hand, Melo et al. (2022) applied an AI-based model to detect the temperature and mask usage of de passengers, and Shen et al. (2020a) analyze the importance of personal protection, environmental cleaning, ventilation, disinfection, and health education on driver safety of public-use vehicles.

With respect to *mobility restrictions*, studies focusing on government assess spatially differentiated travel restriction policies, determine policy lag for mobility restrictions, and travel restrictions around epicenters and their immediate geographic surroundings (Zanin & Papo, 2020; Bian et al., 2021; Parr et al., 2021; Thomas et al., 2022; Lima et al., 2021; Gibbs et al., 2020). Zanin & Papo (2020) conclude that allowing individuals to move from regions of high to low infection rates may have a positive effect on the aggregate, although such positive effect is nevertheless reduced if a bidirectional flow is allowed. Bian et al. (2021) demonstrate that The National Declaration of Emergency in the US had immediate effects on mobility; stay-at-home and reopening policies even

Table 3
Broad characterization of strategies, by transport mode, actor, jurisdiction, and application field.

Broad strategy	Source	Transport mode	Actor	Jurisdiction	Application Field
Ventilation within vehicles	Ho & Binns (2021)	Bus	Operators	City	Research
	Yao & Liu (2021)	Bus	Operators	N/A	Research
(doors, windows, AC/HVAC, fans)	Zhang et al. (2021c)	Bus	Operators	University	Research
	Shinohara et al. (2021)	Train/Subway	Operators	N/A	Research
	Edwards et al. (2021)	Bus	Operators	City	Research
	Querol et al. (2022)	Bus	Operators	City	Regulation
	Shinohara et al. (2021)	Train/Subway	Operators	N/A	Research
	Edwards et al. (2021)	Bus	Operators	City	Research
	Querol et al. (2022)	Bus	Operators	City	Regulation
	Zhang et al. (2021c)	Bus	Operators	University	Research
	Furuya (2007)	Train/Subway	Operators	National	Research
	Lin et al. (2022)	Multiple modes	Operators	National	Research
	Shen et al. (2020b)	Bus	Operators	Provincial/State/ Department	Research
	Moreno et al. (2021)	Multiple modes	Operators	City	Regulation
	Matheis et al. (2022)	Multiple modes	Users	N/A	Research
	Yu et al. (2020)	Train/Subway	Government	Provincial/State/ Department	Planning
	Wang et al. (2022)	Train/Subway	Government	National	Research
	Querol et al. (2022)	Bus	Operators	City	Regulation
	Querol et al. (2022)	Bus	Operators	City	Regulation
	Mathai et al. (2022)	Car	Operators	N/A	Innovation/Tech
	Mesgarpour et al. (2022)	Public transport in general	Operators	N/A	Research
Ventilation in transportation infrastructure	Clegg et al. (2022)	Train/Subway	Government	Neighborhood	Innovation/Tech
	Zou and He (2021)	Train/Subway	Government	N/A	Regulation
Air Filters	Lin et al. (2022)	Multiple modes	Operators	National	Research
	Edwards et al. (2021)	Bus	Operators	City	Research
	Hoffman et al. (2022)	Bus	Operators	City	Innovation/Tech
	Park and Kim (2021)	Multiple modes	Government	National	Planning
Model-supported, evidence-based planning/ policymaking	Chin & Bouffanais (2020)	Bus	Government	National	Regulation
	Hamidi & Hamidi (2021)	Train/Subway	Government	Neighborhood	Regulation
	Lima et al. (2021)	Walk	Government	Provincial/State/ Department	Research
	Zanin & Papo (2020)	Multiple modes	Government	City	Planning
	Bohman et al. (2021)	Multiple modes	Government	City	Planning
	Nikparvar et al. (2021)	Walk	Government	National	Planning
	Lima et al. (2021)	Multiple modes	Government	City	Planning
	Bian et al. (2021)	Multiple modes	Government	City	Planning
	Benning et al. (2021)	Public transport in general	Government	City	Planning
	Aragão et al. (2022)	Multiple modes	Government	City	Planning
	Wei et al. (2020)	Multiple modes	Operators	National	Research
	Mahmud et al. (2021)	Multiple modes	Government	Neighborhood	Innovation/Tech
	Seno (2020)	Multiple modes	Government	International	Innovation/Tech
	Scott et al. (2021)	Multiple modes	Government	Provincial/State/ Department	Innovation/Tech
	Doubleday et al. (2021)	Active transport in general	Users	Provincial/State/ Department	Innovation/Tech
	Douglas et al. (2021)	Multiple modes	Government	International	Innovation/Tech
	Walker & Sulyok (2020)	Multiple modes	Government	National	Innovation/Tech
	Osorio et al. (2022)	Public transport in general	Government	City	Research
	Kumar et al. (2022)	Public transport in general	Government	N/A	Innovation/Tech
	Kruszewska et al. (2022)	Public transport in general	Government	N/A	Research
	Chen et al. (2021)	Public transport in general	Government	City	Planning
	Mesgarpour et al. (2022)	Bus	Operators	N/A	Regulation
	Zhang et al. (2021b)	Multiple modes	Government	Provincial/State/ Department	Planning
	Tiikkaja & Viri (2021)	Public transport in general	Government	City	Planning
Public transit operations – General	Chan and Wen (2021)	Train/Subway	Government	National	Planning
	Sasidharan et al. (2020)	Public transport in general	Government	City	Regulation
	Cooley et al. (2011)	Train/Subway	Government	City	Planning
	Shirai Reyna et al. (2021)	Train/Subway	Government	City	Planning
	Gkiotsalitis (2021)	Bus	Operators	National	Planning
	Kamga et al. (2021)	Multiple modes	Operators	International	Planning
	Lucchesi et al. (2022)	Public transport in general	Operators	National	Research

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Table 3 (*continued*)

Broad strategy	Source	Transport mode	Actor	Jurisdiction	Application Field
	Matheis et al. (2022)	Multiple modes	Users	N/A	Research
	Thombre & Agarwal (2021)	Multiple modes	Government	National	Planning
	Love et al. (2021)	Public transport in general	Government	National	Planning
	Chen et al. (2020)	Multiple modes	Operators	National	Planning
	Kushnir et al. (2022)	Multiple modes	Government	National	Regulation
Public transit operations – Crowding management	Cho & Park (2021)	Public transport in general	Government	City	Regulation
	Furuya (2007)	Train/Subway	Operators	National	Research
	Hörcher et al. (2021)	Multiple modes	Operators	International	Planning
	Hörcher et al. (2021)	Multiple modes	Operators	International	Planning
	Hörcher et al. (2021)	Multiple modes	Operators	International	Planning
	Wiseman (2022)	Train/Subway	Operators	National	Innovation/Tech
	Naveen & Gurtoo (2022)	Bus	Operators	National	Planning
	Zorgati et al. (2021)	Train/Subway	Users	National	Planning
	Hörcher et al. (2021)	Multiple modes	Operators	International	Planning
	Hörcher et al. (2021)	Multiple modes	Operators	International	Planning
	Budd & Ison (2020)	Multiple modes	Government	International	Regulation
	Wiseman (2022)	Train/Subway	Operators	National	Innovation/Tech
	Cheranchery et al. (2021)	Bus	Users	Provincial/State/ Department	Planning
	Naveen & Gurtoo (2022)	Bus	Operators	National	Planning
	Lucchesi et al. (2022)	Public transport in general	Operators	National	Research
	Lima et al. (2021)	Walk	Government	Provincial/State/ Department	Research
	Yu et al. (2020)	Train/Subway	Government	Provincial/State/ Department	Planning
	Gkiotsalitis (2021)	Bus	Operators	National	Planning
	Bauer et al. (2021)	Public transport in general	Operators	City	Regulation
	Park and Kim (2021)	Multiple modes	Government	National	Planning
Lockdown	Xin et al. (2021)	Train/Subway	Government	International	Regulation
	Parr et al. (2021)	Multiple modes	Government	National	Planning
	Fountoulakis et al. (2022)	Walk	Government	City	Regulation
	Yu et al. (2020)	Train/Subway	Government	Provincial/State/ Department	Planning
	Zhang et al. (2020)	Multiple modes	Government	City	Research
	Liu et al. (2020)	Train/Subway	Government	Provincial/State/ Department	Planning
	Thomas et al. (2022)	Public transport in general	Government	City	Planning
	Lei & Ozbay (2021)	Multiple modes	Government	National	Innovation/Tech
	Kong et al. (2021)	Multiple modes	Government	National	Regulation
	Cartenì et al. (2021)	Bus	Government	National	Planning
	Mogaji (2020)	Multiple modes	Government	City	Regulation
	Zhu & Guo (2021)	Train/Subway	Government	National	Regulation
	Ohi et al. (2020)	Multiple modes	Government	N/A	Planning
	Murano et al. (2021)	Public transport in general	Government	National	Regulation
	Zhang et al. (2021a)	Multiple modes	Government	International	Regulation
Passenger screening	Zhou et al. (2021)	Train/Subway	Government	National	Regulation
	Melo et al. (2022)	Multiple modes	Government	N/A	Innovation/Tech
	Tao et al. (2020)	Multiple modes	Government	Provincial/State/ Department	Planning
Driver safety (of public-use vehicles)	Edwards et al. (2021)	Bus	Operators	City	Research
	Shen et al. (2020a)	Public transport in general	Government	National	Regulation
	Bauer et al. (2021)	Public transport in general	Operators	City	Regulation
	Kamga et al. (2021)	Multiple modes	Operators	International	Planning
Mobility restrictions	Zanin & Papo (2020)	Multiple modes	Government	City	Planning
	Bian et al. (2021)	Multiple modes	Government	City	Planning
	Parr et al. (2021)	Multiple modes	Government	National	Planning
	Thomas et al. (2022)	Public transport in general	Government	City	Planning
	Lima et al. (2021)	Multiple modes	Government	City	Planning
	Gibbs et al. (2020)	Multiple modes	Government	Provincial/State/ Department	Planning
Silent policies	López Olmedo et al. (2021)	Public transport in general	Government	N/A	Regulation
Reduce contact points	Budd & Ison (2020)	Multiple modes	Government	International	Regulation
	Naveen & Gurtoo (2022)	Bus	Operators	National	Planning
	Moreno et al. (2021)	Public transport in general	Operators	City	Regulation

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Table 3 (*continued*)

Broad strategy	Source	Transport mode	Actor	Jurisdiction	Application Field
	Naveen & Gurtoo (2022)	Bus	Operators	National	Planning
	Budd & Ison (2020)	Multiple modes	Government	International	Regulation
	Abulhassan & Davis (2021)	Bus	Operators	National	Planning
	Sun et al. (2021a)	Train/Subway	Operators	City	Research
	Naveen & Gurtoo (2022)	Bus	Operators	National	Planning
	Sidorchuk et al. (2020)	Train/Subway	Operators	City	Planning
	Zorgati et al. (2021)	Train/Subway	Users	National	Planning
Changes in activity/mobility patterns	Parr et al. (2021)	Multiple modes	Government	National	Planning
	Thomas et al. (2022)	Public transport in general	Government	City	Planning
	Zhang & Zhang (2021)	Multiple modes	Government	City	Planning
	Duren et al. (2021)	Multiple modes	Users	National	Planning
	Marsden & Docherty (2021)	Multiple modes	Government	International	Planning
	Moreno et al. (2021)	Public transport in general	Operators	City	Regulation
	Mogaji et al. (2022)	Multiple modes	Government	City	Planning
	Al-Habaibeh et al. (2021)	Multiple modes	Users	City	Incentives
	Beck & Hensher (2022)	Multiple modes	Users	National	Planning
	Eregowda et al. (2021)	Multiple modes	Government	National	Regulation
	Thomas et al. (2022)	Public transport in general	Government	City	Planning
	Thombre & Agarwal (2021)	Multiple modes	Government	National	Planning
	Thomas et al. (2022)	Public transport in general	Government	City	Planning
	Duren et al. (2021)	Multiple modes	Users	National	Planning
	Bohman et al. (2021)	Multiple modes	Government	City	Planning
	Mogaji et al. (2022)	Multiple modes	Government	City	Planning
	Moreno et al. (2021)	Public transport in general	Operators	City	Regulation
	Thombre & Agarwal (2021)	Multiple modes	Government	National	Planning
	Thomas et al. (2022)	Public transport in general	Government	City	Planning
	Zhang & Zhang (2021)	Multiple modes	Government	City	Planning
	Duren et al. (2021)	Multiple modes	Users	National	Planning
	Marsden & Docherty (2021)	Multiple modes	Government	International	Planning
	Bohman et al. (2021)	Multiple modes	Government	City	Planning
	Thombre & Agarwal (2021)	Multiple modes	Government	National	Planning
	Rajput et al. (2022)	Public transport in general	Government	Provincial/State/Department	Innovation/Tech
	Paiva et al. (2022)	Multiple modes	Government	International	Innovation/Tech
Social distancing	Zou and He (2021)	Train/Subway	Government	N/A	Regulation
	Lee et al. (2020)	Multiple modes	Government	National	Regulation
	Aghdam et al. (2021)	Multiple modes	Users	City	Regulation
	Liu et al. (2020)	Train/Subway	Government	Provincial/State/Department	Planning
	Zhang et al. (2020)	Multiple modes	Government	City	Research
	Bilde et al. (2021)	Multiple modes	Government	City	Regulation
	Wang et al. (2022)	Train/Subway	Government	National	Research
	Kamga et al. (2021)	Multiple modes	Operators	International	Planning
	Yu et al. (2020)	Train/Subway	Government	Provincial/State/Department	Planning
	Thomas et al. (2022)	Multiple modes	Government	City	Planning
	Kamga et al. (2021)	Multiple modes	Government	City	Planning
	Mohammed Salih and Hussein (2021)	Active transport in general	Government	Neighborhood	Planning
	Talavera-Garcia and Pérez-Campaña (2021)	Walk	Government	Neighborhood	Regulation
Manage seating in public-use vehicles	Edwards et al. (2021)	Bus	Operators	City	Research
	Hu et al. (2021)	Train/Subway	Operators	National	Research
	Duren et al. (2021)	Multiple modes	Users	National	Planning
	Kamga et al. (2021)	Multiple modes	Operators	International	Planning
	Budd & Ison (2020)	Multiple modes	Government	International	Regulation
	Setiyo & Waluyo (2021)	Bus	Industry	National	Innovation/Tech
	Abulhassan & Davis (2021)	Bus	Operators	National	Planning
Passenger disinfection	Budd & Ison (2020)	Multiple modes	Government	International	Regulation
	Zhang et al. (2020)	Multiple modes	Government	City	Research
	Liu et al. (2020)	Train/Subway	Government	Provincial/State/Department	Planning
	Moreno et al. (2021)	Multiple modes	Operators	City	Regulation
Vehicle disinfection	Caggiano et al., 2021	Bus	Operators	Provincial/State/Department	Research
	Shen et al. (2020a)	Public transport in general	Government	National	Regulation
	Moreno et al. (2021)	Multiple modes	Operators	City	Regulation
	Lucchesi et al. (2022)		Operators	National	Research

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Table 3 (*continued*)

Broad strategy	Source	Transport mode	Actor	Jurisdiction	Application Field
		Public transport in general			
	Yu et al. (2020)	Train/Subway	Government	Provincial/State/ Department	Planning
	Falcó et al. (2021)	Public transport in general	Operators	City	Innovation/Tech
	Baldelli et al. (2022)	Train/Subway	Operators	N/A	Innovation/Tech
Contact tracing	Mogaji et al. (2022)	Multiple modes	Government	City	Planning
	Mogaji et al. (2022)	Multiple modes	Government	City	Planning
	Auad et al. (2021)	Multiple modes	Government	City	Planning
	Naveen & Gurtoo (2022)	Bus	Operators	National	Planning
	Sidorchuk et al. (2020)	Train/Subway	Operators	City	Planning
	Zorgati et al. (2021)	Train/Subway	Users	National	Planning
	Ng et al. (2022)	Multiple modes	Users	N/A	Innovation/Tech
	Cartenì et al. (2020)	Multiple modes	Government	National	Innovation/Tech
Compliance audits	Abulhassan & Davis (2021)	Bus	Operators	National	Planning
	Bonful et al. (2020)	Public transport in general	Users	City	Regulation
Wearing mask	Duren et al. (2021)	Multiple modes	Users	National	Planning
	Mogaji et al. (2022)	Multiple modes	Government	City	Planning
	Fountoulakis et al. (2022)	Walk	Government	City	Regulation
	Lucchesi et al. (2022)	Public transport in general	Operators	National	Research
	Zhang et al. (2020)	Multiple modes	Government	City	Research
	Matheis et al. (2022)	Multiple modes	Users	N/A	Research
	Wang et al. (2022)	Train/Subway	Government	National	Research
	Liu et al. (2020)	Train/Subway	Government	Provincial/State/ Department	Planning
	Aghdam et al. (2021)	Multiple modes	Users	City	Regulation
	Bauer et al. (2021)	Public transport in general	Operators	City	Regulation
	Zhang et al. (2021c)	Bus	Operators	University	Research
	Lin et al. (2022)	Multiple modes	Operators	National	Research
	Edwards et al. (2021)	Bus	Operators	City	Research
	Furuya (2007)	Train/Subway	Operators	National	Research
	Duren et al. (2021)	Multiple modes	Users	National	Planning
	Dzisi & Dei (2020)	Bus	Operators	City	Regulation
	Liu et al. (2020)	Train/Subway	Government	Provincial/State/ Department	Planning
	Liu & Zhang (2020)	Bus	Users	City	Regulation
	Abulhassan & Davis (2021)	Bus	Operators	National	Planning
Regain social support for public transit	Sunio & Mateo-Babiano (2022)	Multiple modes	Government	City	Planning
	Liu et al. (2020)	Train/Subway	Government	Provincial/State/ Department	Planning
	Rothengatter et al. (2021)	Multiple modes	Government	International	Planning
	Dai et al. (2021)	Train/Subway	Government	City	Incentives
	Thombre & Agarwal (2021)	Multiple modes	Government	National	Planning
	Mogaji et al. (2022)	Multiple modes	Government	City	Planning
	Mogaji et al. (2022)	Multiple modes	Government	City	Planning
	Mogaji et al. (2022)	Multiple modes	Government	City	Planning
	Torbacki (2021)	Multiple modes	Government	City	Planning
	Mogaji et al. (2022)	Multiple modes	Government	City	Planning
	Zorgati et al. (2021)	Train/Subway	Users	National	Planning
	Liu et al. (2020)	Train/Subway	Government	Provincial/State/ Department	Planning
	Naveen & Gurtoo (2022)	Bus	Operators	National	Planning
	Dzisi & Dei (2020)	Bus	Operators	City	Regulation
Boosting active transportation	Duren et al. (2021)	Multiple modes	Users	National	Planning
	Nikitas et al. (2021)	Bike	Government	International	Regulation
	Combs & Pardo (2021)	Multiple modes	Government	International	Planning
	Combs & Pardo (2021)	Multiple modes	Government	International	Planning
	Kraus & Koch (2021)	Bike	Government	International	Planning
	Combs & Pardo (2021)	Multiple modes	Government	International	Planning
	Budd & Ison (2020)	Multiple modes	Government	International	Regulation
	Nikitas et al. (2021)	Bike	Government	International	Regulation
	Thombre & Agarwal (2021)	Multiple modes	Government	National	Planning
	Nikitas et al. (2021)	Bike	Government	International	Regulation
	Nikitas et al. (2021)	Bike	Government	International	Regulation
	Liu et al. (2021)	Multiple modes	Government	Neighborhood	Planning
	Duren et al. (2021)	Multiple modes	Users	National	Planning
	Maltese et al. (2021)	Multiple modes	Government	National	Regulation
	Marsden & Docherty (2021)	Multiple modes	Government	International	Planning
	Mogaji et al. (2022)	Multiple modes	Government	City	Planning
	Sunio & Mateo-Babiano (2022)	Multiple modes	Government	City	Planning
	Sun et al. (2021b)	Multiple modes	Government	City	Incentives

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Table 3 (*continued*)

Broad strategy	Source	Transport mode	Actor	Jurisdiction	Application Field
	Nikitas et al. (2021)	Bike	Government	International	Regulation
	Combs & Pardo (2021)	Multiple modes	Government	International	Planning
	Nikitas et al. (2021)	Bike	Government	International	Regulation
	Nikitas et al. (2021)	Bike	Government	International	Regulation
	Nikitas et al. (2021)	Bike	Government	International	Regulation
	Bohman et al. (2021)	Multiple modes	Government	City	Planning
	Valente et al. (2021)	Multiple modes	Government	Provincial/State/ Department	Innovation/Tech
	Mohammad et al. (2021)	Multiple modes	Government	Provincial/State/ Department	Research
	Barbarossa (2020)	Active transport in general	Government	National	Regulation
Boosting sustainable mobility	Torbacki (2021)	Multiple modes	Government	City	Planning
	Mogaji et al. (2022)	Multiple modes	Government	City	Planning
	Torbacki (2021)	Multiple modes	Government	City	Planning
	Mogaji et al. (2022)	Multiple modes	Government	City	Planning
	Dzisi & Dei (2020)	Bus	Operators	City	Regulation
	Rothengatter et al. (2021)	Multiple modes	Government	International	Planning
	Sunio & Mateo-Babiano (2022)	Multiple modes	Government	City	Planning
New technologies in transport sector	Basu & Ferreira (2021)	Multiple modes	Government	City	Innovation/Tech
	Sunio & Mateo-Babiano (2022)	Multiple modes	Government	City	Planning
	Ceder & Jiang (2020)	Public transport in general	Operators	National	Planning
	Anandkumar et al. (2022)	Public transport in general	Operators	n/a	Innovation/Tech
New ways of leading, organizing or operating transport	Amit & Kafy (2022)	Multiple modes	Government	International	Innovation/Tech
	Wang et al. (2021)	Train/Subway	Government	National	Regulation
	Glaser & Krizek (2021)	Multiple modes	Government	National	Planning
	Cartenì et al. (2022)	Multiple modes	Government	Provincial/State/ Department	Planning
	Vickerman (2021)	Multiple modes	Government	National	Planning
	Molin & Kroesen (2022)	Train/Subway	Government	City	Planning
	Krysiński & Uss-Lik (2022)	Public transport in general	Government	National	Incentives
	Ramirez et al. (2021)	Bus	Operators	City	Regulation

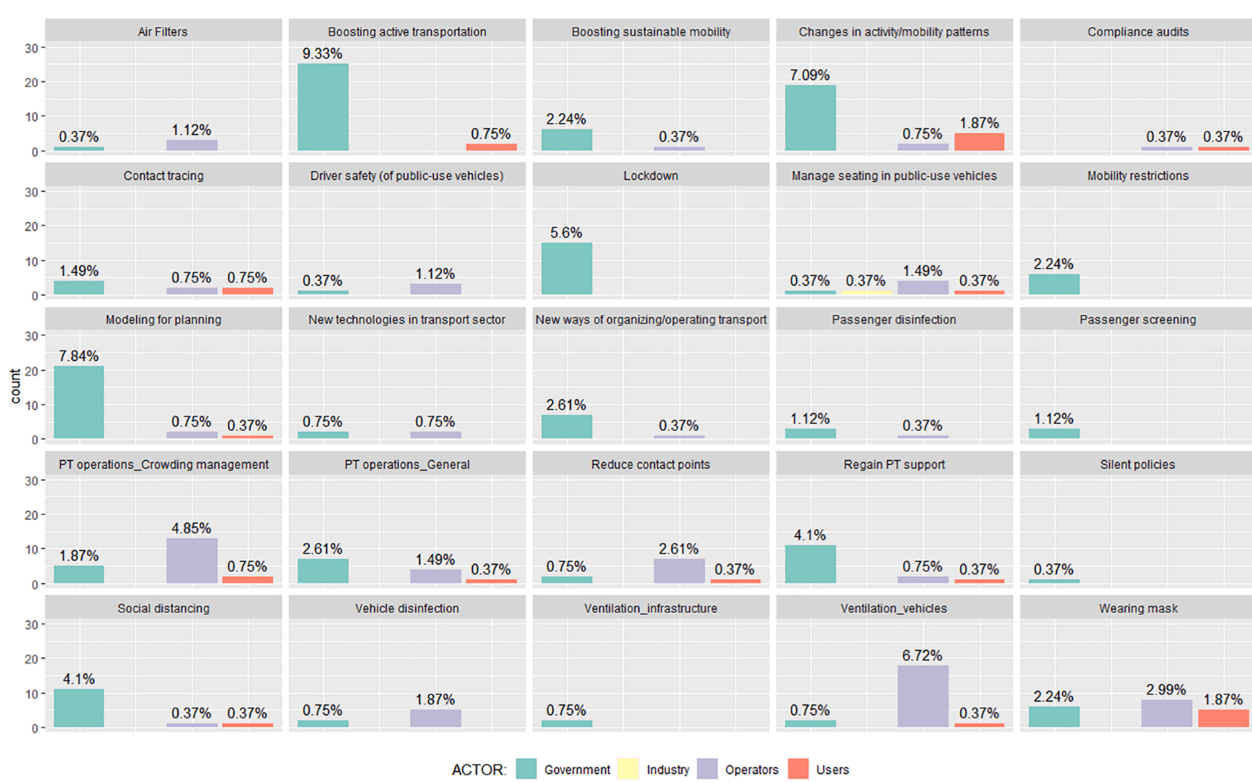

Fig. 9. Broad strategies classified by actor.

had a lead effect because the public responded early. Parr et al. (2021) find that public behavioral response, viral spread mechanisms, and health outcomes are not as closely linked as it is thought.

López Olmedo et al., (2021) studied the effect of *silent policies* in the public transport system and highlighted that an inappropriate deployment of vehicle disinfection poses health risks for workers. With respect to reducing contact points in the transport system, Budd & Ison (2020) analyze the use of contactless door sensors and clear screens between seats.

Many governments have promoted *change in activity/mobility patterns* within the community, a strategy that has received much attention within the scientific community. To generate this change, measures such as work from home (telework) have been imposed (Parr et al., 2021; Thomas et al., 2022; R. Zhang & Zhang, 2021; Marsden & Docherty, 2021; Mogaji et al., 2022).; Eregowda et al., 2021), flexible work arrangements (Thomas et al., 2022; Thombre & Agarwal, 2021), staggered working, school, services and organizations hours to eliminate peak commuting hours (Thomas et al., 2022; Bohman et al., 2021; Mogaji et al., 2022; Thombre & Agarwal, 2021), use of online/door-to-door services (Thomas et al., 2022; Zhang & Zhang, 2021; Marsden & Docherty, 2021). Bohman et al. (2021) present a study about adjusting ticketing pricing and policies to meet new travel patterns, while Rajput et al. (2022) study the impact of curfew in restaurants and bars. Thombre & Agarwal (2021) analyze how to encourage self-sustainable neighborhoods and Paiva et al. (2022) highlight the importance that cities become more pedestrian friendly. In the analysis, authors find that age has a strong influence on changes in mobility. In Spain, groups with a higher mean age show a lower reduction in mobility, while the opposite is found in Portugal, which is why the findings and related policies or strategies cannot be generalized from one region to another.

Regarding the *social distancing* strategy, Zou and He (2021) reviews social distancing while waiting at stations for train-induced wind. Lee et al. (2020) analyzes the total social distancing when returning to activity. Other authors analyze the physical distance in public transportation vehicles (Liu et al., 2020; Zhang et al., 2020; Bilde et al., 2021; Wang et al., 2022; Yu et al., 2020; Thomas et al., 2022; Kamga et al., 2021). Mohammed Salih and Hussein (2021) analyze the effect of social distance on walking and cycling, and indicate that social distance can act as what they label an "Urban Antigen" to any epidemic. Talavera-Garcia and Pérez-Campaña, 2021 analyze the effect of tactical urbanism to maintain the social distance on walking.

Budd & Ison (2020) addresses the study of *manage seating in public-use vehicles*, proposing an internal reconfiguration of seats that complies with social distancing and optimizes the internal capacity of the units. On another area, Shen et al. (2020a) and Yu et al. (2020) address *vehicle disinfection*. The authors analyze the effect of disinfection on different surfaces such as handrails, stop request buttons, seat handles, door open/close buttons, tables, and toilet handles, with the transmission of the virus.

Another government strategy is *contact tracing*. Studies in this area focus on recommending the use of smartcard-based contact tracing (Mogaji et al., 2022), operator-controlled contact tracing (Mogaji et al., 2022; Auad et al., 2021), and on the definition and estimation of positivity detection time and its correlation with mobility patterns. Regarding the latter, Cartenì et al. (2020) find that the standard two-week quarantine period may be insufficient as a containment strategy, since COVID + cases suspected of having been infected on public transport are associated with trips made 22 days before identifying infection.

Many governments have set *wearing mask* regulations in open and closed places, with special attention within public transport systems (Mogaji et al., 2022; Zhang et al., 2020; Wang et al., 2022; Liu et al., 2020). The study by Fountoulakis et al. (2022) focuses on the use of masks among pedestrians, and Liu et al. (2020) analyze the production and distribution of affordable/reusable face masks for citizens.

The widespread news and recommendations from many governments to restrict the use of public transport to avoid contagion hit this sector deeply. Therefore, an important strategy promulgated by governments focuses on *regaining social support for public transit*. The studies analyzed include: how to motivate social support for transport (Sunio & Mateo-Babiano, 2022; Liu et al., 2020; Rothengatter et al., 2021); effective communication and public fear mitigation (Liu et al., 2020; Mogaji et al., 2022; Torbacki, 2021); fare-free policies to lure passengers back to public transport (Dai et al., 2021); and reducing public transport fares (Thombre & Agarwal, 2021). Other authors have focused on achieving equity within public transport by analyzing or proposing subsidies for the most vulnerable groups of the population such as the older people, less abled people and children (Mogaji et al. 2022).

The strategy that has received the most attention within governments is undoubtedly *boosting active transportation*. As a whole, these strategies aim at encouraging active mobility as a measure to stop the spread of the virus, but also aim at enabling people to continue with their daily activities in a safer way. Some studies focus on instate traffic calming measures (Nikitas et al., 2021; Combs & Pardo, 2021; Barbarossa, 2020). In this regard, Nikitas et al. (2021) note that bicycles, as a mode that favors social distancing, should be redefined and accompanied by policies to promote a more bicycle-centric future. Combs & Pardo (2021) and Kraus & Koch (2021) recommend putting pedestrian walk signals on recall.

The first concern in boosting active transportation is ensuring user safety. Therefore, the greatest amount of effort is directed towards the construction and improvement of infrastructure for cyclists and pedestrians. Combs & Pardo (2021), Budd & Ison (2020), Nikitas et al. (2021), Thombre & Agarwal (2021) analyze the reconfiguration of road space to stimulate active mobility (pedestrians, cyclists, e-scooter users), from the construction of pop-up cycle lanes, bicycle superhighways, cycling parking and bike storage, and even e-bike charging stations. Other studies such as those by Liu et al. (2021), Maltese et al. (2021), Marsden & Docherty (2021), Mogaji et al. (2022) and Sunio & Mateo-Babiano (2022) focus on promoting active mobility on low-traffic corridors. Some stimuli for active mobility are heat mitigation by planting trees on active routes (Sun et al., 2021b), subsidizing bike sharing (Combs & Pardo, 2021), subsidizing e-bikes, grant 30-minutes free bike -share use, and providing workplace showers (Nikitas et al., 2021). Other authors emphasize: access to education in active mobility (Bohman et al., 2021); the benefits of active mobility in the environment (Valente et al., 2021); and setting incentives for the recreational use of the bicycle (Mohammad et al., 2021). Mohammad et al. (2021) demonstrate how improving the frequency of transport services contributes to reducing the relative risk of viral infection by avoiding crowds.

In addition to the scientific production regarding the encouragement that governments should give to active mobility, some studies were also identified regarding the more general objective of *boosting sustainable mobility*. An insightful perspective in the literature focuses on banning informal transportation to enable control of mitigation strategies (Torbacki, 2021), while some studies encourage a change from inefficient, wasteful and motorized means of traveling to cleaner, greener, healthier and more economical means such as walking, cycling and public transportation (Mogaji et al., 2022; Rothengatter et al., 2021; Sunio and Mateo-Babiano, 2022; Torbacki, 2021).

Governments must also be concerned with implementing *new technologies in the transport sector*. Within this strategy, studies focus on the promotion and encouragement of Mobility as a Service, MaaS, programs (Basu & Ferreira, 2021; Sunio & Mateo-Babiano, 2022).

At last, governments can consider *new ways of leading, organizing or operating transport*. Scientific production includes studies regarding support for shared economic activities (Amit & Kafy, 2022), evaluating trade-offs for different reopening policies (D. Wang et al., 2021), installing guideposts to transition to an alternative type of street (Glaser & Krizek, 2021), cognitive and participative decision-making models (Cartenì et al., 2022), a national road pricing scheme (Vickerman, 2021), assessing safety perceptions of and support for policy measures (Molin & Kroesen, 2022), and innovative business models (Krysiński & Uss-Lik, 2022). In this regard, Krysiński & Uss-Lik (2022) highlight the importance of maintaining public transport attractiveness post-Covid, to allow for a recovery of investments in this sector.

Discussion of operator-oriented strategies

Among the literature that has addressed public transport (which is predominant, as previously shown in Fig. 5), only 9 out of the 25 broad strategies defined pertain to public transport service operators. It is worth noting that many government-oriented strategies have a direct application through operators, especially regarding regulation. Hence, the discussion provided below touches upon some strategies already discussed, yet now from the viewpoint of operators. An important distinction to make is related to public versus private operation of transport/mobility services, since public operation allows for complete control, whereas private operation brings forth challenges in regulation and control.

Every broad strategy directed to operators is to some extent related to decreasing contagion risks within vehicles, which is reflected in a predominance of the broad strategy *ventilation within vehicles*, followed by the study of *air filters*. Naturally, strategies related with safety measures for passengers and drivers are also reported for operators (*social distancing, disinfection, driver safety*), in the sense of *what they can do to enforce or nudge compliance*.

The area of application related to *ventilation within vehicles* is divided mainly between Research and Regulations, which is a promising combination encompassing a diversity of regulatory strategies coupled with formal scientific studies focused on modeling the problem – such a mix can contribute to finding more robust solutions. Scientific production focusing on ventilation within vehicles aims at regulating the use of air conditioning and windows (opening/closing), and subsequently measuring their influence on contagion risk within vehicles. The literature is mixed regarding window opening/closing, and has not reached consensus on an optimal configuration, although most studies considering factors such as speed, the specific seating location of infected passengers, the number of users, etc. agree on the potential of this strategy to reduce in-vehicle concentration of the virus (Ho & Binns, 2021; Shinohara et al., 2021; Yao & Liu, 2021). *Door opening/closing* at stops, as a ventilation mechanism for public transit vehicles is also proposed in (Edwards et al., 2021; Ho and Binns, 2021; Querol et al., 2022). Operators can enact protocols establishing how, when, and for how long doors are opened during fleet operations.

Inadequate usage of *air conditioning* systems could increase the spread of the virus within vehicles, or result in particular locations with high virus concentrations (Zhang et al., 2021c). Therefore, service operators must carefully assess air conditioning settings, and should consider acquiring technological tools to monitor and self-regulate this type of systems. Operators should also implement *air filters* in vehicles, even if this strategy is not enough to prevent contagion on its own. In fact, its effectiveness has only been proven when applied concurrently with *social distancing* (Gkiotsalitis, 2021; Lucchesi et al., 2022; Naveen & Gurtoo, 2022). Some strategies suggested in the literature that enhance social distancing focus on reducing passenger crowding by increasing the number of wagons (Kamga & Eickemeyer, 2021), or increasing the number of routes and their frequencies (Bauer et al., 2021).

Ventilation protocols in general (doors and windows, A/C, filters, etc.) can be complemented by CO2 measurements and monitoring contagion rates, which would provide data for future research leading to efficient and standardized solutions.

Naturally, *driver safety* inherently falls within operators' duties, yet it can also be enforced through government regulations. Drivers must have a safe work environment and should avoid contact with users to limit potential virus transmission. Strategies suggest installing fans to increase airflow in the driver's area, coupled with separating drivers from users by of walls made of plastic or other materials (Edwards et al., 2021). Furthermore, operators should avoid relying on payment/ticketing transactions that require drivers interacting with users, and should provide sanitization material (Naveen & Gurtoo, 2022).

Operators can implement *social distancing* through management and control of seat restrictions in public-use vehicles; clearly, the default vehicle seating layout of public transport vehicles does not meet with safe social distancing. The broad strategy of *managing seats in vehicles for public use* follows two tendencies in the literature: restricting strategically located seats, and modifying vehicle layout. While the first trend is fully within service operators' reach, the second trend depends on industrial production operators of vehicles meeting biosecurity standards. Anandkumar et al. (2022) suggest passenger temperature screenings before boarding as a way to reduce the need for restricted seating; for such screenings, Kumar et al. (2022) recommend using IoT-enabled sensors, GSM and GPS modules with LCD display. These technological strategies are suggested in the above-mentioned literature because the risk of contagion has been shown high variation with respect to co-travel time and seat location.

Vehicle disinfection stands as the most commonly applied biosecurity measure for public transport, as its operations involve high passenger turnover. In this sense, several disinfection mechanisms have been tested on surfaces of various materials (Caggiano et al., 2021; Lucchesi et al., 2022; Moreno et al., 2021). To a certain extent, studies have found evidence of disinfection having a positive effect in reducing virus transmission, yet more research is needed to establish conclusive evidence. The use of ozone as a disinfectant is studied by Falcó et al. (2021), who find that ozone concentrations must be monitored and kept at specific levels required to eliminate viral infectivity. Moreover, the literature proposes innovative alternatives such as relying on UV-C LEDs and continuous sanitation air systems (CSAs) based on ionizers (Baldelli et al., 2022). Regardless of the alternative chosen, operators must embrace vehicle disinfection as a compulsory practice, whereby the best method should will depend on expected benefits and resources required. Moreover, operators might consider requesting support from health authorities for provision of biosafety supplies. From a user perspective, yet in the context of operators, increasing user awareness of safety and bio-protocols can be a beneficial tool to maintain regular service demand.

All considered, any strategy applied must be monitored for compliance, especially those established as mandatory requirements in public or private policies. An operator-oriented implementation example of *compliance audits* suggests incorporating a bus monitor in school buses (Abulhassan & Davis, 2021). Regarding ventilation best practices, service operators must not only keep regularly updated about how the pandemic is evolving, but also about new mitigation strategies, and should make every effort to collect data about activity within their units to assess which strategy is the most appropriate to implement.

Discussion of user-oriented and industry-oriented strategies

Strategies oriented towards users amount to 12 out of the 25 broad strategies identified in this paper. It is worth noting that every strategy pertaining to users should be understood from the perspectives of: *compliance with recommended measures by operators and government actors;* and/or *commitment to travel and activity behavior changes incentivized by the government*. In this sense, the role that users play regarding strategies can be considered to be derived from the actions conducted by the other two actors.

In terms of *ventilation within vehicles*, research has found that turbulent airflow is quite complex and dynamically changing, and that opening doors/windows and the usage of HVAC and fans should be carefully studied according to local conditions (Edwards et al., 2021; Ho & Binns, 2021; Wang et al., 2022; Yao & Liu, 2021). Hence, users must abide with instructions on *keeping doors/windows opened strictly according to the established patterns*. In locations where passengers are subject to inclement weather, they can contribute by preparing and dressing accordingly.

The most well-known strategy that pertain to users consists of *mask wearing*, hence, adequate mask usage must be fully understood by users. Improving using awareness can be achieved by communicating research findings to the general public; some key findings worth spreading are reported next. Zhang et al. (2021a), Zhang et al. (2021b), Zhang et al. (2021c) note that well-fitted surgical masks worn by infected and susceptible subjects nearly eliminate transmission. In terms of effectiveness, some studies assume a surgical mask effectiveness of 90 %, whereas handmade masks are assumed to block only 30 % of particles (Zhang et al., 2021c). Complex studies of computational fluid dynamics find that wearing masks reduced particle dispersion distances by several feet, as well as the overall particle count released into the bus decreased by an average of 50 % or more (depending on mask quality) (Edwards et al., 2021). From an equity perspective, (Dzisi & Dei, 2020) note that users in low-income countries often wear fabric masks due to their economic constraints, and urge governments to provide good-quality masks to the general public. For general guidelines of mask usage, refer to (Abulhassan & Davis, 2021; X. Liu & Zhang, 2020).

Clearly, an important user strategy is *social distancing* when traversing transportation infrastructure and riding vehicles – the latter in the form of users abiding to regulated seating arrangements within vehicles. Edwards et al. (2021) suggest that, in the absence of seating data, adjacent seating should only be allowed for household family members. In a study of passengers waiting at subway stations, (Zou and He, 2021) find that the default 2-meters social distancing guideline may not be enough due to train-induced wind; in contraposition, (Kamga & Eickemeyer, 2021) suggest reducing social distancing by 10 % to reduce operational burden; while (Kamga et al., 2021) suggest a 1-meter social distancing combined with mandatory mask-wearing, floor and seats stickers, and off-board fare collection to avoid the 2-meter distancing. Related to this category, ***the only industry-oriented strategy found in the literature*** proposes *changes in bus layouts*, reducing the seats in the vehicles from 32 to 24 units (Setiyo & Waluyo, 2021). Still in relation to social distancing, but classified under another strategy, the literature does suggest reducing userś stay time within stations, by efficient operation of public transit systems (Zanin & Papo, 2020).

The incidence of *model-supported, evidence-based planning* in users can be viewed from the lens of the effects that policies can have on user travel behavior. Namely, the literature includes a strategy suggesting spatially differentiated travel restriction policies according to COVID-19 hotspots and coldspots in a city (Zanin & Papo, 2020).

Crowding management, as part of public transit operations, is an instrumental strategy that inherently intertwines with user behavior. This interaction is often achieved through technology, in the form of app-based and web-based services such as *capacity reservation with advance booking, online ticket purchase, and e-ticketing* (Zorgati et al., 2021); as well as *real-time mobile phone apps for travel routes and crowding levels* (Cheranchery et al., 2021). Crowding management holds great relationship with the broader strategy of *reducing contact points*, specifically through contactless transactions. Similarly, the technological component involved implies a strong linkage between crowding management and *contact tracing.* The literature on contact tracing that pertains to users covers aspects of app-based user-fed tracing (Zorgati et al., 2021), and an interesting innovation application of contact tracing through passengerś clothing (Ng et al., 2022). A third strategy that can be discussed in the context of information provision consists of *regaining social support for public transit*, through communication and fear mitigation campaigns (which can certainly benefit from real-time crowding information) (Zorgati et al., 2021).

A relevant strategy that has not received much attention in the literature consists of conducting *audits of userś compliance* to guidelines and measures. Applications found in this review include the case of Ghana, where compliance was found to be very low for mask usage (Bonful et al., 2020), and the already mentioned implementation of a bus monitor in school buses (Abulhassan & Davis, 2021).

Finally, popular strategies about *boosting active transportation* include traffic calming measures, and promoting active mobility on low-traffic corridors. While these policies pertain to governments, they also depend heavily on users' willingness to embrace these changes and to shift their mobility patterns.

Future research recommended in the literature

As a last analysis, this paper classifies future work trends suggested in the literature. This adds a relevant dimension to a literature review in general, but particularly more so in the case of COVID-19 literature, given the ever-changing nature and constant evolution of the pandemic.

Future work directions found in the literature are summarized in Fig. 10, classified by area of application and by the research/work direction proposed. For all application areas, the literature seems to agree on the need for *inclusion/disaggregation of new data* and *conducting additional studies*. Moreover, the need for *calibration, validation and replication model results* appears in all areas, and is particularly important when transferring findings or model results to other contexts. In the same sense, another research direction suggests *implementation of models in similar contexts,* for validation purposes.

Some key propositions are also worth mentioning. In the area of *innovation and technology*, some authors emphasize the need to *collect data* on app response and readiness for adoption related to contact tracing, travel information sharing, detours, congested infrastructure, etc. In the area of planning, it is important to *include and complement data from different sources* (e.g., smartphones, surveys, transit cards, etc.) to obtain a more representative and realistic sample. An interesting proposition for *planning and regulation* consists of seizing the post COVID-19 opportunity to adopt *innovative forms of transportation.*

Finally, on a more general note, research directions highlight the need of additional studies to complement the existing knowledge base and evidence; but also emphasize on the importance of improving computational efficiency of modeling efforts through optimization and more efficient algorithms.

Limitations

The method applied in this systematic review paper has some limitations, which are acknowledged next. First, the article retrieval conducted in Scopus only searched the key terms that appear in *titles, keywords or abstracts*. Therefore, articles in which search terms figure in other sections, or perhaps use alternative terms, are omitted. The only exception consists of relevant articles manually added by the authors.

Second, the scope of this review may have been limited due to the search being restricted to the Scopus bibliographic citation database only; nonetheless, this decision is justified in Section 2. Third, articles written in a language other than English are excluded, consequently, the amount of scientific production on the subject in countries with official languages other than English may be reduced. Last, the analysis phase conducted in this paper relies on a *matrix of findings,* which includes categories defined based on the authors' knowledge of the subject. This matrix could be improved to provide more detailed categorization to broaden the scope of the discussion.

Conclusions

The wide variety of transportation policies and mitigation strategies that have been designed to control the spread of COVID-19 have profoundly impacted the transport sector, especially for the case of mass transportation services. Meanwhile, widespread vaccination campaigns continuously increase the percentage of immunized people, which offers an opportunity for transport services to return to *adjusted operations,* although constrained by several policies and strategies (non-pharmaceutical interventions). Recent times seem to indicate that the pandemic might finally provide an opportunity to return to business-as-usual conditions, hence, lessons learned thus far by the transport sector

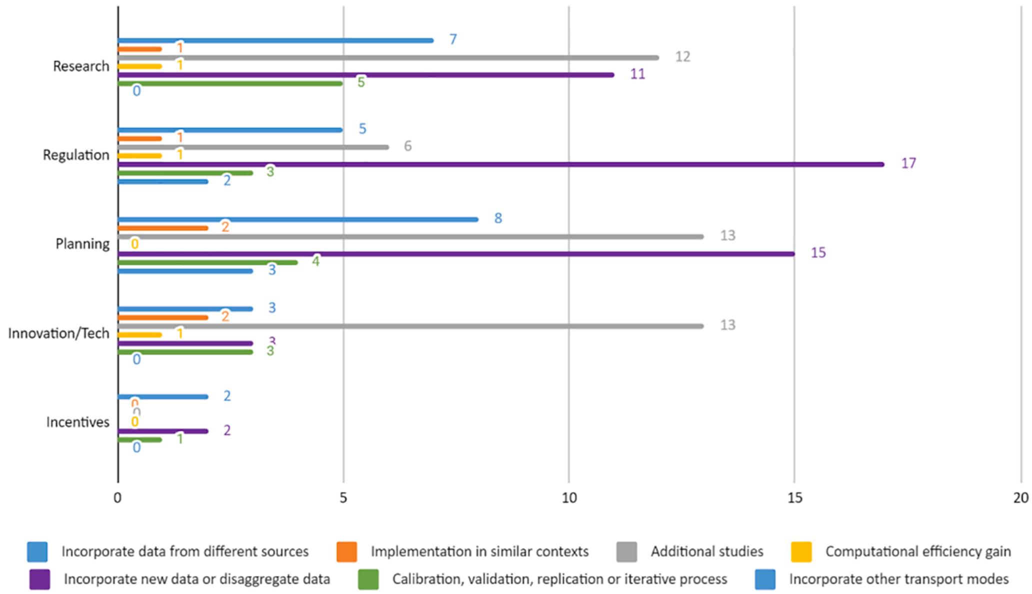

Fig. 10. Classification of future work directions by category.

must be disseminated as extensively as possible – which stands as the main objective and contribution of this paper. Further, the profound behavioral and operational changes that have been triggered should motivate governments, operators, industry and users to think, plan and embrace new transportation and mobility paradigms.

A compendium of strategies against COVID-19 are reported, as found in the literature until April 2022, yielding 134 articles selected through a systematic approach. The final selection considered includes articles that either analyze, design, propose, test and recommend transportation policies and strategies. A multidimensional categorization is then conducted, defining broad strategies that offer guidance to different *actors,* seeking to implement *mode-specific* strategies at different *jurisdictions,* and *application fields*. The most important findings of this paper provide comprehensive *What to do?* guides for each type of actor, yet main lessons for each actor can be summarized as follows:

Governments: the broad strategies provide guidance to international, national and local authorities. A large number of studies focus on providing data on vehicle ventilation mechanisms, modeling the use of different modes of transport, simulating risk situations, recommending new ways of managing transport infrastructures, reducing user crowding, regulating the use of seats within vehicles, analyze proposals for measures such as lockdown, promote health education programs, analyze social distancing policies, etc. Governments can resort to a wide range of studies to support their decisions to face this pandemic and implement strategies and regulations to prevent similar situations in the future.

Operators: the broad strategies include recommendations for transport and mobility service operators. Operators could, based on the scientific evidence reported in this study, decide which strategies to apply in their fleet daily operations, including: ventilation door/window settings, air filtering, ensuring biosafe environments for their drivers, adjusting their service operation (frequencies, lines, schedules), disinfection of vehicles and passengers, and control mechanisms for compliance with the strategies adopted. Operators must work closely alongside governments to reach adequate implementations of regulations and subsidies.

Industry: only 1 out of the 25 broad strategies captured in this review refers to the industry, which encourages on proposing new vehicle designs to facilitate in-vehicle social distancing, as well as incorporating new technologies for ventilation and air filtering. The contribution of the industry in mitigating the effects of a health crisis should not be limited to what is currently reported; rather, the industry should work together with researchers to produce innovative solutions, and then with the government to implement new solutions – through regulation and perhaps even subsidies in cases involving cutting-edge technology.

Users: according to the broad strategies, users are encouraged to reassess the way in which they address their mobility needs with modes of transport. Every user for which active transportation is a feasible option should make a concerted effort to utilize such modes, not only for societies' sake, but to minimize personal risk as well. Whenever feasible, users should also shift their activity patterns through strategies such as teleworking – this clearly depends on organizations' policies and goodwill, even involving government action in the case of the public sector. Users must also adopt biosafe behavior during trips, through the correct use of masks, proper sanitization, social distancing at stations, abiding with seating restrictions, and even silent policies in some cases. Finally, users are encouraged and expected to embrace and support campaigns proposed by the authorities, while abiding with imposed regulations and mobility restrictions.

Regarding transportation modes, this literature review unveiled a predominance of public transit modes (understandably so, due to crowding), and a much lower representation for the automobile, and even walk, and bicycle modes. This research gap could be addressed by future research. More importantly, a dearth exists for studies covering taxis, ridehailing, motorcycles, and e-scooters. While parallels may be drawn from other modes to address this gap, specific research covering these omitted modes would be desirable.

Regarding the jurisdiction involved in designing/implementing strategies, the literature shows that cities have "taken the steering wheel" in the fight against the pandemic, as this jurisdictional level predominates. Clearly, this pattern largely depends on the government model of the country in question, whereby decentralization and autonomy favor the role of cities; as opposed to centralized state-led governments. Regardless of the government model, well-articulated government tiers are fundamental for taking coordinated actions and should facilitate policy-making and subsequent implementation.

Another research gap found in the literature that denotes a pressing need relates to industry-oriented strategies – only one found in this review. This stands as a particularly surprising fact, considering that a great number of research articles have focused on studying seating arrangements, vehicle layout, HVAC systems, air filtering, etc. In this context, this finding denotes a common disconnection among academia, government, and industry; especially in low-income and developing countries. In pandemic times, establishing better linkages among these actors becomes particularly important.

A final remark regarding research gaps identified relates to the lack of incentive-oriented strategies. Incentives can be expected to inflict high impact in terms of modal shifts toward active transportation, activity timing shifts, or teleworking; all of which can offer profound beneficial effects to curb the pandemic. This rationale is intimately related to a methodological limitation of the literature identified in this paper, which consists of overlooking the overall context of daily activity and mobility of the population (several activities are conducted every day besides trip-making, as well as several modes can be utilized within a typical day). An instructive example offered argues that a safely operated vehicle can pose a lower risk than people at a crowded place (an elevator, a bar, a dining room, or even an office).

Overcoming a pandemic is a global effort that first and foremost depends on reaching high vaccination rates worldwide, yet all-encompassing vaccination is a challenging feat to achieve in a world with stark economic differences. In the meantime, non-pharmaceutical interventions play a critical role as palliative measures in this long-standing fight, whereby research focusing on mitigation strategies and policies must be continuously updated to keep improving our understanding of associated benefits and limitations. All considered, this review provides a systematic compendium and a guide on which strategies and policies are currently proposed to mitigate contagion risks, and presents a discussion of where future studies should focus. The policies and strategies designed today will not only help curb the impacts of pandemics, but could also lead to a renewed perception of the benefits of active transportation, sustainable use of land and the built environment, and patterns of activity redesigned as teleworking or flexible work schedules. Throughout history, profound changes have always been difficult to inflict, if not now, when?

Note

Francisco Calderón Peralvo, Patricia Cazorla Vanegas, and Elina Avila-Ordóñez contributed equally for this paper.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2022.100653.

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