*sustainability*

*Review*

# Role of Transport during Outbreak of Infectious Diseases: Evidence from the Past

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**Abstract:** The outbreak of infectious diseases affects people's lifestyles significantly, as they undertake fewer outdoor activities as a protective measure and to follow government orders of restricted movements. This paper reviewed the scientific literature related to transport and infectious diseases to gain insights into managing such circumstances. The outcomes indicate that the transport sector has a two-fold role during the outbreak of infectious diseases: controlling the spread of infection and assessing the impact of reduced outdoor activities on the transport sector. It was found that local and international travel restrictions, if applied at the initial stages, are effective in controlling the spread of infectious disease; at a later stage, behavioral changes become prominent in limiting the spread. Further, the outbreaks resulted in a significant reduction in mobility, altering traffic patterns with lower peaks and improving traffic safety. The public transport mode share reduced considerably and people preferred cars and active modes. These changes also showed positive impacts on air pollution and water pollution. Further, the air transport and tourism sector were noted to be the hardest hit and will recover slowly. The outcomes from the review will be useful for planners and administrators in managing future emergency conditions better.

**Keywords:** infectious disease; pandemic; epidemic; transport effects; health emergencies; spread of diseases; traffic impacts

## 1. Introduction

Infectious diseases usually spread rapidly and affect a large number of people, disrupting daily activities of the majority of the population. These diseases create heath emergencies and are classified as pandemic or epidemic depending on their severity [1]. The history of infectious diseases affecting human lives dates back to many centuries, for example, Black Death in the 14th Century. In 1918, the Spanish Flu, an influenza pandemic, affected every third person in the world (around 500 million), causing deaths of 10% infected people (around 50 million) worldwide [2]. The movement of troops in World War I contributed to spreading the disease from continent to continent during the later phases of the war [3]. The chronological history of major health emergencies that occurred due to infectious diseases in the 21st century is depicted in Figure 1.

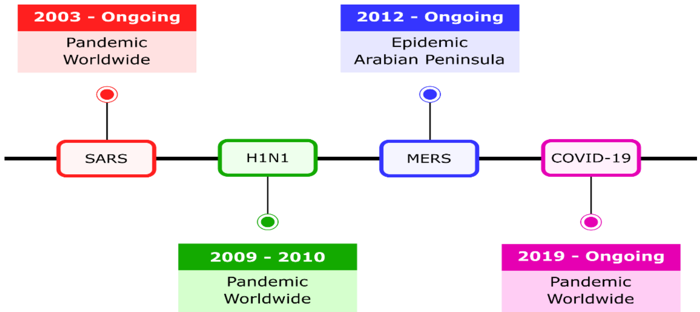


**Figure 1.** Chronology of major health emergencies in the 21st century.

SARS, the first pandemic in the 21st century, was identified on 26 February 2003 in Hong Kong [4]. The outbreak of SARS spread rapidly, resulting in 8422 infections around the world with almost 11% mortality rate [5]. The outbreak shattered local as well as regional economies [6]. Health screening among international travelers and home quarantine were applied as effective tools to interrupt SARS transmission. After this, in April 2009 residents of the USA and Mexico experienced an outbreak of a new strain of virus called Influenza A [7]. During the first year, H1N1 caused the death of 151,700–575,400 people worldwide [8]. Subsequently, on 10 August 2010, the World Health Organization (WHO) announced an end to the global pandemic of 2009 H1N1 influenza. Further, in 2012, the epidemic MERS, a viral respiratory disease caused by a novel coronavirus MERS-CoV, appeared in Saudi Arabia. Later, it spread over 27 countries, with Saudi Arabia, the United Arab Emirates, and the Republic of Korea being the worst-hit countries [9]. Recently, COVID-19, caused by a novel-Cov, was first detected in China in 2019. On 11 March 2020, the WHO declared COVID-19 as a pandemic. To date, it has affected 213 countries in the world, while the USA is the most severely affected in both aspects, infection and deaths [10].

In the past, as travel has influenced the outbreak/spread of infectious diseases, for emerging infections, travelers have been considered as a key part of the surveillance process [11]. Human interactions and behavior have a direct contribution to the spreading of infectious diseases, particularly during pandemics [12–14]. During an outbreak, controlling the further spread of disease is a crucial task for governments. Various mitigation strategies are applied to delay the peak stage, reduce the size of the peak, and spread the occurrence of cases over time [15]. Generally, tailor-made responses considering local conditions, socio-economic characteristics, and culture are employed [16]. Due to these measures, a pandemic affects various primary sectors, ranging from agriculture, petroleum, and oil, secondary sectors such as the manufacturing industry, to tertiary sectors such as education, finance, healthcare and pharmaceutical industry, aviation, hospitality and tourism, real estate and housing sector, research and development, media and information technology, and food sector. Besides these, there are some social effects as well on people's lives [17]. As a result, pandemics create a threat to health security, challenge the health care systems and livelihood of populations, extending its effects to the stability and growth of economies, and the transport sectors. This study focuses on the usefulness of human mobility in managing infectious diseases and further studies the effects of the same on the transport sector. The original contribution of this research is the presentation of the synthesis of scientific literature on the two-fold relationship between transport and infectious diseases to assist transport engineers and planners in selecting mitigation strategies, and the determination of future areas of research to aid researchers. The key aim of this paper is to review the scientific literature on the studies related to passenger transport and infectious diseases. More specifically, the objectives set for this study are:

- To review how transport-related attributes were used in understating/managing the spread of infectious diseases in the past;
- To determine the impact of the emergence of infectious diseases on the transport sector;
- To present gaps in the literature and suggest future directions for research based on the literature.

Although outbreaks of infectious diseases affect all modes/forms of transport, this paper focuses on road and air transport only, which are the main forms of passenger transport. The other forms of transport, such as freight transport and marine/water transport, are not studied and are out of the scope of this paper.

## 2. Method

A scientific literature search was conducted using various search engines, such as sciencedirect.com, Scopus, Web of Science, and Google Scholar. Different combinations of search terms were formed using keywords transport, travel, and traffic with pandemic, epidemic, or infectious disease, for example, "transport and pandemic", or "travel and infectious disease". The search was conducted until no new articles were retrieved. All the technical articles published until 10 June 2020 were checked for inclusion in this paper. The articles' inclusion or exclusion was checked using the code specified below for each search conducted using different search engines.

```
Open a search engine
Retrieve articles using a predefined keyword combination
Read the title of the article
If relevant
    Read abstract
        If relevant
            Perform detailed review
                If contents related to study objectives
                    Add review
                Else
                Exclude from study
                Go to title next article
Else
Read the title of the next article

Repeat steps to check for inclusion/exclusions for all articles.
```

This process was followed for various keyword combinations mentioned earlier. From the selected articles, working papers, studies without any specific findings, articles on freight transport and marine/water transport, and articles in own field of study but having some transport-related inferences (e.g., knowledge of spread and precautionary behavior, models on precautionary behavior and risk perception) were excluded. The criteria used for inclusion of articles is mentioned below:

- Articles with access to the full text;
- Articles written in English language;
- Peer-reviewed articles;
- Published or accepted articles;
- Articles on the spread of disease and transport;
- Articles on transport impacts of infectious diseases;
- Articles on traffic impacts of infectious diseases;
- Studies with practically applicable results.

Two team members undertook this task to ensure the inclusion of all relevant articles. All the selected articles were classified based on their area of study and a detailed review was conducted after reading the entire study in detail. The extensive literature search fetched 65 articles for inclusion in this study. Table 1 lists a summary of the articles. Among all the pandemic-related studies, the recent outbreak, COVID-19, had a major share of studies; this may be because of the severity and extent of the spread. Further, the majority of studies were focused on assessing the role of transport on the spread of infectious diseases. Recent studies focused on understanding the effects of a pandemic on various aspects of transport.

**Table 1.** Overview of studies on transport and infectious diseases.

| Author | Year | Country | Disease Name | Objective | Method of Analysis |
|---|---|---|---|---|---|
| **General studies** | | | | | |
| Saadat et al. | 2020 | World | COVID-19 | Study environmental effects of COVID-19 | Review |
| Shaw et al. | 2020 | Multiple | COVID-19 | Study response of East Asian countries and present lessons learned | Review |
| Sarla | 2020 | India | COVID-19 | Discuss impacts of COVID-19 | Review |
| Hiscott et al. | In press | World | COVID-19 | Study effects of COVID-19 on personal lives, the environment, economy, and scientific communication. | Review |
| **Spread of diseases** | | | | | |
| Poletto et al. | 2013 | General | General | Propose framework to model spread of a disease using time spent at destination | Analytical calculations and numerical simulations (non-Markovian mobility) |
| Xu et al. | 2019 | China | Influenza A (H1N1) | Study impact of road travel and socioeconomic factors on spread of influenza A | Correlation analysis, spatial Autoregressive analysis |
| Zhang et al. | 2011 | China | Influenza A (H1N1) | Study role of different transport modes in spreading of influenza within the province and with other provinces | Spatio-temporal simulation based on SEIR model |
| Cooley et al. | 2011 | USA | Influenza | Investigate role of passengers in spreading influenza | Agent-based computer simulation |
| Yilmazkuday | 2020 | USA | COVID-19 | Assess effect of restricted inter-county travel on number of COVID-19 cases and deaths. | Multiple linear regression |
| Kraemer et al. | 2020 | China | COVID-19 | Use real-time mobility data to understand dynamics of COVID-19 | Negative binomial generalized linear model, log-linear regression, correlation coefficients |
| Belik et al. | 2011 | Germany | General | Model spatial epidemic spread by considering bidirectional movement of individuals | Mathematical modeling—numerical simulation |
| Milne et al. | 2008 | Australia | Influenza | Model spread of influenza and assess effect of four social distancing measures on infection rates | Stochastic, individual-based spatial simulations |
| Zhao et al. | 2018 | China | SARS | Determine effects of travel strategies on infection control. | A game theory model, epidemic model, simulation |
| Browne et al. | 2016 | - | Multiple | Review evidences of air, sea, and road transport systems in spreading pandemics | Review |

**Table 1.** *Cont.*

| Author | Year | Country | Disease Name | Objective | Method of Analysis |
|---|---|---|---|---|---|
| Pu et al. | 2016 | China | General | Study epidemic spreading based on traffic dynamics in networks. | Simulation |
| Chinazzi et al. | 2020 | World | COVID-19 | Assess impact of travel restrictions on the spread of pandemic nationally and internationally | A global metapopulation disease transmission model |
| Lau et al. | 2020 | World | COVID-19 | Assess relationship between domestic and international passenger air traffic volume and number of cases | Unpaired student's *t*-test |
| Tuncer and Le | 2014 | Multiple | Avian influenza | Study dynamics of the spread of avian influenza on air travel | Two-city mathematical model, numerical simulations |
| Yang and Wang | 2016 | - | General | Develop adaptive routing strategies to control traffic-related spread of an epidemic | Mathematical modeling |
| Denphedtnong et al. | 2013 | Thailand | General | Develop a model to understand the role of transport-related infection on the spread of disease | An SEIRS epidemic model, mathematical model and numerical solution |
| Yang et al. | 2012 | China | General | Model spread of epidemic in bus transport networks | Space P approach, SIS model for simulation, mean-field theory |
| Marini et al. | 2020 | Switzerland | influenza | Model spatio-temporal behavior of an influenza using daily activity and mobility models | Agent-based epidemic and mobility models |
| Apolloni et al. | 2014 | Multiple | influenza A (H1N1) | Propose theoretical framework to study heterogeneous mixing and travel behavior for propagation of pandemic | Analytical modeling approach-multi-host stochastic epidemic metapopulation model |
| Rizzo et al. | 2014 | - | Respiratory syndromes and sexually transmitted infections | Assess the relationship between behavioral changes and spread of a disease | Susceptible-infected-susceptible model in activity-based networks |
| De Luca et al. | 2018 | Belgium | Seasonal influenza | Explore the role of behavioral changes associated with holidays on the dynamics of seasonal influenza. | Stochastic spatial age-specific metapopulation model/Stochastic numerical simulations |
| Linka et al. | 2020 | Europe | COVID-19 | Study the effect of travel restrictions on the outbreak dynamics | Mathematical Modeling-global network mobility model with a local epidemiology model |
| Otsuki and Nishiura | 2016 | - | Ebola virus | Analyze the role of travel restrictions in controlling the spread | Simple hazard-based statistical model |

**Table 1.** *Cont.*

| Author | Year | Country | Disease Name | Objective | Method of Analysis |
|---|---|---|---|---|---|
| Bajardi et al. | 2011 | Mexico | Influenza A (H1N1) | Study the effectiveness of travel restrictions in stopping and delaying the pandemic | Global Epidemic and Mobility model |
| Lam et al. | 2011 | - | Influenza, H1N1 | Explore the importance of age-based travel restrictions for controlling influenza | Simple stochastic mathematical model, simulation |
| Lee et al. | 2020 | South Korea | COVID-19 | To study the relationship between traffic volume and spread | Non-linear and linear regression analysis |
| | | | **Transport** | | |
| Aloi et al. | 2020 | Spain | COVID-19 | Assess effect of quarantine restrictions on internal mobility | Comparative analysis |
| Hotle et al. | 2020 | USA | Influenza and COVID-19 | Model individuals' risk perception related to travel and mitigation when infected and not infected | Ordered logit regressions, generalized ordered logit regressions |
| Gao et al. | 2020 | USA | COVID-19 | Develop an interactive web-based mapping platform to quantify how people responded to social distancing guidelines by mapping daily mobility changes | GIS and big data |
| Kim et al. | 2017 | South Korea | MERS | Assess effect of MERS on transit use and related travel behavior | Pearson Correlation Coefficients, T-test, regression analysis, Queen's Contiguity-Based Spatial Weight Matrix |
| De Vos | 2020 | UK | COVID-19 | Discuss the impacts of social distancing on travel behavior, and health and wellbeing. | Review |
| Engle et al. | 2020 | USA | COVID-19 | Assess effect of perceived risk of contracting disease and stay home orders by government on mobility | Multiple linear regression |
| Warren and Skillman | 2020 | USA | COVID-19 | Measure mobility (distance population moves in a day) changes due to COVID-19 | Comparative analysis |
| Ruffino et al. | 2020 | Italy | COVID-19 | Develop a model for determining costs and benefits for public transport mode shift scenarios post COVID-19 | Scenario testing |
| Nguyen and Coca-Stefaniak | 2020 | China | COVID-19 | Analyze residents' perceptions during a pandemic and their post-pandemic planned travel behaviors | Chi-square Automatic Interaction Detection (CHAID) modeling technique, structural equation modeling |

**Table 1.** *Cont.*

| Author | Year | Country | Disease Name | Objective | Method of Analysis |
|---|---|---|---|---|---|
| Cahyanto et al. | 2016 | USA | Ebola virus | Assess factors influencing domestic travel avoidance due to outbreak | Descriptive, ordered response model |
| Peak et al. | 2018 | Sierra Leone | Ebola virus | Evaluate the effect of travel restrictions on human mobility | Agnostic anomaly detection algorithm, autoregressive integrated moving-average (ARIMA), time-series intervention analysis, McNemar test |
| Tirachini and Cats | 2020 | - | COVID-19 | Discuss how public transportation can be made safer after post-lockdown phase | Review |
| de Haas et al. | 2020 | Netherlands | COVID-19 | Assess effect of lockdown on residents' travel behavior and activities | Descriptive-Chi-square test |
| Mogaji | 2020 | Nigeria | COVID-19 | Determine effects of COVID-19 on transportation | One-Way ANOVA |
| Bucsky | 2020 | Hungary | COVID-19 | Evaluate changes in mode share due to COVID-19 | Comparative analysis |
| Balkhi et al. | 2020 | Pakistan | COVID-19 | Study people's psychological and behavioral differences due to COVID-19 | Chi-square tests |
| **Traffic and Related Safety** | | | | | |
| Favale et al. | 2020 | Italy | COVID-19 | Assess the variation in the traffic patterns in university campuses due to the lockdown | Competitive analysis |
| Brodeur et al. | 2020 | USA | COVID-19 | Determine effect of stay-at-home orders on pollution, traffic and collisions. | Differences-in-differences framework and synthetic control methods |
| Shilling and Waetjen | 2020 | USA | COVID-19 | Assess effect of stay-at-home orders on traffic conditions and safety | 2-tailed *t*-test |
| Oguzoglu | 2020 | Turkey | COVID-19 | Evaluate reduction in traffic crashes, fatalities and injuries due to stay-at-home orders | Diff-in-Diff estimates, Poisson regression models |
| **Air Quality** | | | | | |
| Wang and Su | 2020 | China | COVID-19 | Evaluate impact of COVID-19 lockdown on environment | Comparative analysis |
| Kerimray et al. | 2020 | Kazakhstan | COVID-19 | Assess effect of the lockdown on the concentrations of air pollutants | Comparative study, spatial effects analysis using ArcGIS cokriging method, linear regression analysis |
| Muhammad et al. | 2020 | Multiple | COVID-19 | Determine impact of lockdown on environmental pollution in various countries | Comparative analysis |

**Table 1.** *Cont.*

| Author | Year | Country | Disease Name | Objective | Method of Analysis |
|---|---|---|---|---|---|
| Mahato et al. | 2020 | India | COVID-19 | Examine air quality due to lockdown in megacity | Comparative analysis, correlation, spatial display |
| Dantas et al. | 2020 | Brazil | COVID-19 | Study impact of partial lockdown on air quality | Comparative analysis |
| Nakada and Urban | 2020 | Brazil | COVID-19 | Assess impact of partial lockdown on air quality | Comparative analysis |
| Sharma et al. | 2020 | India | COVID-19 | Analyze effect of restricted activities on air quality in 22 cities | Comparative analysis and WRF (Weather Research Forecasting)-AERMOD (Air Quality Dispersion Modelling System) modeling |
| Bao and Zhang | 2020 | China | COVID-19 | Assess the effect of travel restrictions on air pollution | Baseline regression, Least-Square Dummy Variable model estimator, graphic analysis (ArcGIS), regression discontinuity design |
| Tobías et al. | 2020 | Spain | COVID-19 | Assess changes in air quality due to lockdown | Comparative analysis |
| **Air Travel** | | | | | |
| Fenichel et al. | 2013 | USA | Influenza A/H1N1 | Study individuals' voluntary response to air travel during pandemic from number of missed flights | Negative binomial models using maximum likelihood |
| Sharangpani et al. | 2011 | USA | Influenza | Assess international air travelers' attitudes towards interventions to curb influenza and protective measures at destination | Qualitative-univariate logistic regression, multivariate backward stepwise logistic regression |
| Iacus et al. | 2020 | World | COVID-19 | Assess socio-economic impact of travel restrictions on aviation sector | Forecasting model based on non-homogeneous Poisson process |
| Suau-Sanchez et al. | 2020 | - | COVID-19 | Determine effects of COVID-19 on commercial aviation from industry perspective | Inferences from data |
| **Tourism** | | | | | |
| Gössling et al. | 2020 | Multiple | COVID-19 | Compare impact of COVID-19 on tourism with other pandemics/crises and explain effects on tourism industry | Review |
| Zenker and Kock | 2020 | - | COVID-19 | Speculate the research areas in the tourism sector to respond post-pandemic situation | Review |

## 3. Role of Transport in Predicting the Spread

Travel restrictions are implemented at a local level, state level, national level, or international travel based on the severity of the outbreak of the infectious disease. Various studies have assessed the role of travel restrictions at different levels on predicting the spread of infectious diseases. Air travel mobility network was used to study the global outbreak patterns in the early stages. The results showed that without travel restrictions, the spread of COVID-19 could have accelerated significantly, especially in Central Europe, France, and Spain [18]. A recent study found a strong correlation between passenger volumes, number of flight routes, and the number of domestic and international COVID-19 cases, highlighting the role of air transport on the spread of the pandemic [19]. Further, each 0.1 weekly increase in the share of Home-County stayers resulted in about six fewer COVID-19 cases or about 0.1 fewer COVID-19 deaths in the USA [20]. More specifically, limiting children's overseas travel was found to reduce short-term risks and contribute to delaying the outbreak by a few weeks [21]. Further, the travel restrictions at the source of the outbreak had delayed the spread of the pandemic by a few days at the national level, while it was effective in limiting the spread internationally by a couple of weeks; after that public health interventions and behavioral changes will be needed to curb the spread [22]. The international travel restrictions were suggested to have limited value and feasibility to limit the spreading of the H1N1 influenza pandemic. Further, considering the increased mobility of people, it was unlikely that travel restrictions can be applied effectively for future pandemics [23].

A review of studies suggested that air transport accelerates and amplifies the propagation of influence, while no similar evidence was found for sea transport and road transport [24]. However, other studies showed that road transport affects the spread of disease. The movement of people affects the number of infected people and the duration of the disease severely [25]. Travel between cities is a major factor in affecting the outbreak of a disease. The mobility and length of stay at the destination and spatially controlled individual mobility affect the dynamics of an epidemic [12,26]. The load distribution and increased network density contribute to the epidemic spreading [27]. Further, it was determined that the epidemic spread can be limited by using an adaptive routing strategy rather than a conventional static routing strategy [28]. Recently, in South Korea, with the outbreak of COVID-19 the traffic volumes decreased, and as soon as the newly detected cases decreased the traffic volumes showed an increasing trend [29].

Previous studies which explored the role of transport on other epidemics, such as influenza A/H1N1, SARS, and Ebola, explained that the road transport and socioeconomic status [30], railways, highways, and civil aviation (railways and airlines at early stages, and highways simultaneously) [31], subway ridership [32], and air travel rate between cities [33] affected the spread of the disease significantly. In the case of high subway ridership, the disease propagated and the interventions used for passengers provided limited benefits [32]. It was found that a bus transport network has a finite epidemic threshold. If the rate of infection is below this threshold then large-scale outbreaks are not possible. However, if the infection rate is more, then the spread stabilizes in a balanced state [34].

The early and continuous implementation of social distancing measures have been shown to limit the spread of a pandemic [35]. The travel restrictions were found to be effective if imposed at the time of the early stage of the outbreak, and once the outbreak has spread widely, the restrictions become less effective [36]. Another study also emphasized that if travel restrictions are implemented at a suitable time, then it can help to prevent large-scale outbreaks of the disease [37]. Local travel restrictions in the early stage of the disease were found to be more efficient in controlling the spread (Ebola virus) rather than controlling the global spread through international travel restrictions [38]. Further, the spread of influenza was more during recreation and daily needs activities rather than at home, work, or school [39]. It was suggested to limit the contact of less active individuals and allow optimal contact between the active groups to reduce the potential of an outbreak [40]. The way of interacting with others during holidays is a key factor in moderating the effect of school closures on the seasonal influenza epidemic. Moreover, weekends and school breaks aided in containing the size of the epidemic [41]. Behavioral changes, such as self-protection and quarantine, were effective in the disease spreading as they led to an increased epidemic threshold and decreased steady-state fraction of infected individuals [42].

## 4. Impact on Road Transport

Transport, being a primary sector, is the worst affected sector amongst all followed by the industrial and manufacturing sector due to lockdown because of COVID-19 [43]. The various degrees of restrictions adopted to curb pandemic change peoples' lifestyles and affect their social interactions and economic conditions. This has a direct effect on their travel and outdoor activities [43,44]. Most of the studies conducted a before and after comparative study to highlight the impacts. The detailed road transport impacts are classified into four major categories, as presented below.

### 4.1. Impact on Mobility

The movement restrictions found to be effective in limiting the spread have directly affected mobility. Eight studies assessed the changes in mobility by comparing the before and after values at the city level. Globally, a large dip was seen in mobility due to fear from COVID-19 and the government orders to mitigate the spread [45]. In the severely affected cities, the mobility was reduced up to 90% [43]. In the USA, population mobility was reduced by 7.87% due to official stay-home orders. Further, a rise of local infection rate from 0% to 0.0003% lowered the mobility by 2.31% [46]. After the introduction of a national emergency in the USA, New York observed 73% reduction in mobility and a median maximum distance to less than 0.1 km compared to base conditions [47]. A study that used data of 44 cities in China showed a drop in mobility by 70% after travel bans were implemented [48]. Similarly, an overall reduction in mobility by 76% was observed in Spain [49]. In Sierra Leone, the travel restrictions substantially decreased travel, especially for long-distance trips, i.e., 31%, 46%, and 76% reduction for distance within 15 km, 15 to 30 km, and more than 30km, respectively. However, the travel patterns became normal quickly after the lifting of restrictions [50]. During a pandemic, anxiety and fear of infection, which is particularly influenced by social media, significantly reduce people's mobility. About 90% of people in Karachi, Pakistan refrained from making outdoor trips to crowded areas due to fear of infection and health risks for their families due to COVID-19 [51].

### 4.2. Impact on Traffic Conditions

The reduced movement of people will have a direct effect on the operating characteristics of traffic, such as patterns, volumes, speeds, and level of service. Only four studies were found to have analyzed operational characteristics at various places. The confinement measures resulted in a reduction in the morning and midday traffic, lesser than normal afternoon volumes, and afternoon peaks disappeared in Spain [49]. An Italian university observed 10% of the total traffic with massive changes in the traffic patterns during the lockdown as the students were offered online lectures [52]. In California, the shelter-in-place order reduced the traffic volumes from 20% to 55% on highways compared to before the order was in place. This increased the maximum and average traffic speeds significantly by an amount of 1 to 4 mph [53]. In South Korea, initially, an increase of 17.3% traffic was observed after confirmation of the first case, later the traffic dropped by about 23% to 26% as the pandemic severity increased [29].

### 4.3. Impact on Traffic Safety

The changes in traffic conditions alter the traffic safety situation. They can improve traffic safety due to the availability of more space and lesser conflicts on the road or worsen the situation as the presence of a lesser number of vehicles can trigger unsafe driving behaviors. Thus, it is important to study the effect of changed transport conditions on traffic safety. Subsequently, only five studies on the traffic safety impact assessment were found from different countries. The road traffic crashes were reduced significantly due to lockdown in India. Around 10,000 road fatalities were avoided in a month at the cost of 200 loss of lives due to COVID-19 [54]. The traffic crashes were reduced by 67% in Spain due to quarantine measures [49]. After the release of the state order for stay-at-home, many states in the

USA observed a 50% reduction in traffic collisions, which accounted for saving in the range of $7 billion to $24 billion [55]. California also experienced a significantly lower daily number of collisions in 22 days of shelter-in-place order compared to the value before the restrictions. The collisions with injury and fatality were reduced by half along with total collisions per day. Further, a significant reduction of trauma injuries by 38% and 46% was observed in motorcycle and bicycle/pedestrian-related injuries, respectively. These reductions in collisions accounted for a saving of $40 million/day [53]. In Turkey, when strict stay-at-home orders were implemented for a whole month, the traffic crashes, fatalities, injuries, and crashes with material loss reduced by 60%, 43%, 64%, and 75%, respectively, compared to the same time during the previous year [56].

### *4.4. Impact on Travel Behavior*

The preventive measures will affect the way people undertake their travel, including limiting the number of trips to changing modes of travel and destinations. It was speculated that due to COVID-19, people would reduce their travel, and would prefer active modes or cars over public transport, which would put additional pressure on available road infrastructure. This would reduce traffic volumes and affect people's well-being [57,58]. The social cost associated with the shifting of public transport users to cars was estimated as €11–20 billion depending upon the scenarios [59]. In South Korea, MERS reduced the number of people traveling by public transport by more than 10%. Around 14% and 9% reduction in trips was observed to affected areas and other areas, respectively. Further, the travel cost per person and total travel time by transit was also reduced. It was found that the fear from the pandemic influenced the travel by transit depending upon the regional characteristics and life fixity levels [60]. Another study also found that individuals tended to reduce travel to locations in which they perceived medium or high risk of contracting influenza/COVID-19, such as stores [61].

The quarantine measures modified people's trip purposes and work remained as the only important purpose in Spain. Public transport observed the highest drop, i.e., 93%, amongst all modes due to confinement measures [49]. The movement restrictions experienced different changes for various modes, the share of private cars increased from 43% to 65%, while the share of public transport reduced from 43% to 18%. The mode share by cycling (4%) was doubled compared to 2018 [62]. The analysis of the Netherland's Mobility Panel data showed that the lockdown affected people's travel behavior and activities temporarily, with about 80% of respondents reducing their outdoor activities. Further, compared to 2019, 55% fewer trips were undertaken and the travel distance was reduced by 68%. Additionally, travel by walking or cycling increased and people preferred private cars and rejected public transport. After the lockdown, about 20% of people were expected to walk or cycle more and fly less [63].

The influenza risk perception showed that during health emergencies, perceived risk for all trip types would be increased. Perceived susceptibility and self-efficacy significantly influenced domestic travel avoidance [64]. Besides, travel avoidance was attributed to the perceived risk, subjective knowledge, age, and gender of respondents. Further, males showed a lesser tendency to change their travel plans compared to female counterparts. Even though the increased risk was perceived at work, it did not alter their work travel significantly. However, the travel to other locations was reduced where perceived risk was high or medium [61]. The Google mobile phone data of users in the USA showed that the safer-at-home policy reduced the frequency and time spent at parks, grocery stores, retail, transit stations, at work, and increased time spent at home significantly [55].

Furthermore, the interrupted transportation service in Nigeria affected residents' economic, social, and religious activities. The residents pointed out the increased cost of transport, unavailability of transport and traffic congestion as major transport issues during COVID-19 [65]. It was concluded that the regulations to control the spread should be chosen depending upon the phase of the outbreak. Further, some evidence to provide safe public transportation after lockdown is lifted was found to be emerging [66].

## 5. Impact on the Environment

Transport being one of the major contributors to air pollution, the impact of reduced trips on environment needs to be quantified. Several studies were found assessing the impact of COVID-19 on air quality in various cities. The travel restrictions and related reduction in economic activities resulted in a short-term impact on air quality around the world [44,67,68]. Generally, $PM_{2.5}$, CO, $NO_2$, $O_3$, $SO_2$, and $PM_{10}$ are taken as indicators of air quality. Studies showed that the concentration of $PM_{2.5}$, CO, $NO_2$, and $PM_{10}$ were reduced significantly [67,69–74] and consequently the ozone level was improved in different parts of the world [69,71–74]. The concentration of Black Carbon (BC) was also reduced by half during the lockdown period in Spain [74]. The total excessive risk due to these pollutants was reduced by four times due to reduced pollutants levels [73]. Environmental pollution reduced up to 30% in severely affected cities [43]. Further, the air quality near transport and industrial hubs were improved by about 60% in India [70]. A decrease in the Air Quality Index (AQI) of around 8% was observed in 44 cities in China. Further, the reduction in AQI, CO, and $PM_{2.5}$ was partially mediated by reduced mobility due to travel bans, while the reduction in $SO_2$, $NO_2$, and $PM_{10}$ were completely mediated [48]. The reduced economic activities resulted in reduced coal consumption in China and subsequently lower energy consumption and Greenhouse Gas (GHG) emissions [67]. Along with air pollution, water pollution was also reduced across the world [44]. In the USA, the concentration of $PM_{2.5}$ was reduced by a quarter, which translated to a saving of $650 million to $13.8 billion. The pollution levels reduced more in urban counties compared to smaller counties [55].

## 6. Other Impacts

### *6.1. Impact on Air Travel*

International travel restrictions affect air travel significantly. The travelers' response to influenza A showed that people undertake protective behaviors depending upon their demographic characteristics and perceived risk of illness; they might cancel their travel plans to avoid the risks [75,76]. Only two studies quantified the impact of travel restrictions on air travel. An assessment of the impact of the travel ban on the aviation sector during COVID-19 showed that in the worst-case scenario, the world GDP will suffer a loss of 1.41% to 1.67% with 25 to 30 million job losses across the world by the end of 2020 [77]. The industry experts believed that COVID-19 would result in serious consequences in the air transport supply in the long run. The recovery of business-related travel was a concern due to the advancement in technologies. On the contrary, leisure travel could make a quick recovery, but lack of disposable income would be a barrier, and hence would need subsidies [78].

### *6.2. Tourism*

The pandemic was thought to impact tourists' thinking and would result in altering the way they travel. Further, the residents would not welcome the tourists and support tourism. Hence, the indirect effects and long-term impacts should be considered [79]. Due to COVID-19, all over the world, the tourism sector was one of the most badly hit sectors due to the closure of borders and restrictions on internal movements. All countries experienced at least 50% decline in visitors. Further, the future predictions were also uncertain, estimating severe impacts in the next six to twelve months and a slower growth thereafter [80]. Further, most of the respondents in the USA considered Ebola to be serious and as a protective measure tended to avoid domestic travel, which greatly affected the tourism sector [64]. A survey of post-pandemic travel behavior of Chinese residents showed that respondents planned shorter holidays and delayed their travel plans at least six months after the pandemic was under control. However, the duration of the holiday was not shortened by respondents with a higher level of education [58].

## 7. Discussion

A strong relationship was found between the emergence of infectious diseases and the transport sector. As the spread of infectious diseases starts, government authorities stop/discourage outdoor activities to reduce contact between communities to control the infection. This results in reduced travel and lower rates of infection. However, once the infection rates are controlled, people start to undertake outdoor activities that pose the risk of a new outbreak. To control the outbreak, spread needs to be minimized even though travel is undertaken. This research explored the role of the transport sector in controlling infectious diseases and the effect of the mitigation strategies on the transport sector from scientific evidence. Overall, the emergence of all infectious diseases showed similar responses by people; however, COVID-19 was the most researched pandemic in the 21st century.

Many studies have utilized the link between transport and infectious diseases to predict the spread of the diseases using various models. The relationship of various parameters with spread of infectious disease is as shown in Figure 2. It was noted that the travel restrictions, for local as well as domestic or international air travel, are effective if applied at the early stage of the outbreak. At the later stage, the travel restrictions become less effective, and behavioral changes become prominent in controlling the outbreak. Further, travel restrictions at the source of the outbreak help to delay the spread internationally. The mitigation measures applied to public transport were found to be ineffective and achieved fewer benefits. Further, the diseases spread rapidly during daily needs activity and recreational activities compared to activities at home, work, or school. Also, the activities during weekends and school breaks aggravated the spread. Lastly, the mitigations should be planned such that the less active age groups, being more vulnerable, have limited contact and active groups have optimal contact to limit the spread.

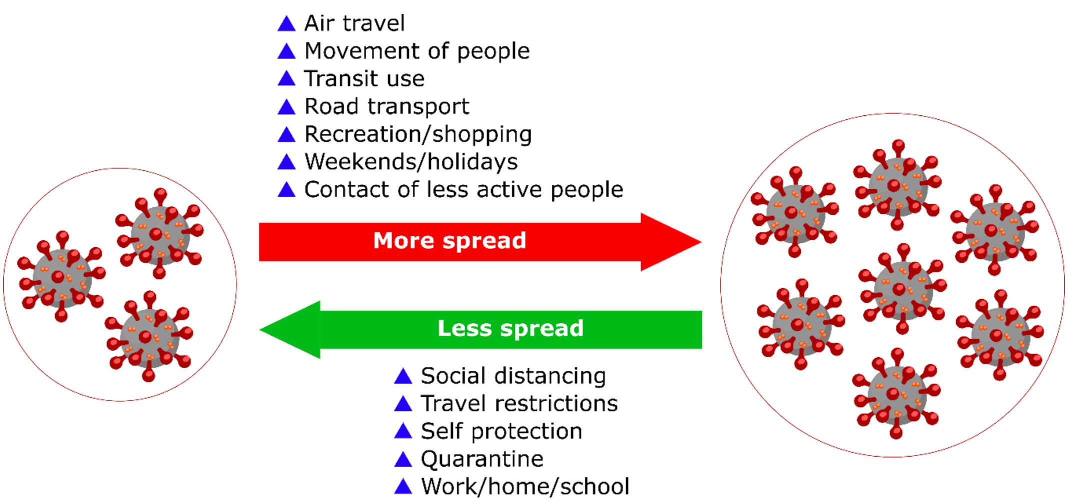


**Figure 2.** Transport and spread of infectious diseases.

The occurrence of infectious diseases affects travel and outdoor activities significantly. The effects are shown in Figure 3. People reduced outdoor activities and related travel due to fear of contracting the disease and also to follow the government orders. As a result, a significant drop in mobility was observed across many cities around the world, particularly due to COVID-19. The traffic patterns changed with lower peak traffic volumes and reduced congestion levels across cities. The drastic drop in traffic volume led to marginally increased travel speeds on some highways. On a positive side, the number of crashes, fatalities, and injuries due to crashes reduced significantly for all modes of transport. In addition, lower material losses were reported due to traffic crashes compared to before the occurrence of diseases or a similar time the previous year. These reduced crashes resulted in considerable savings to the government.

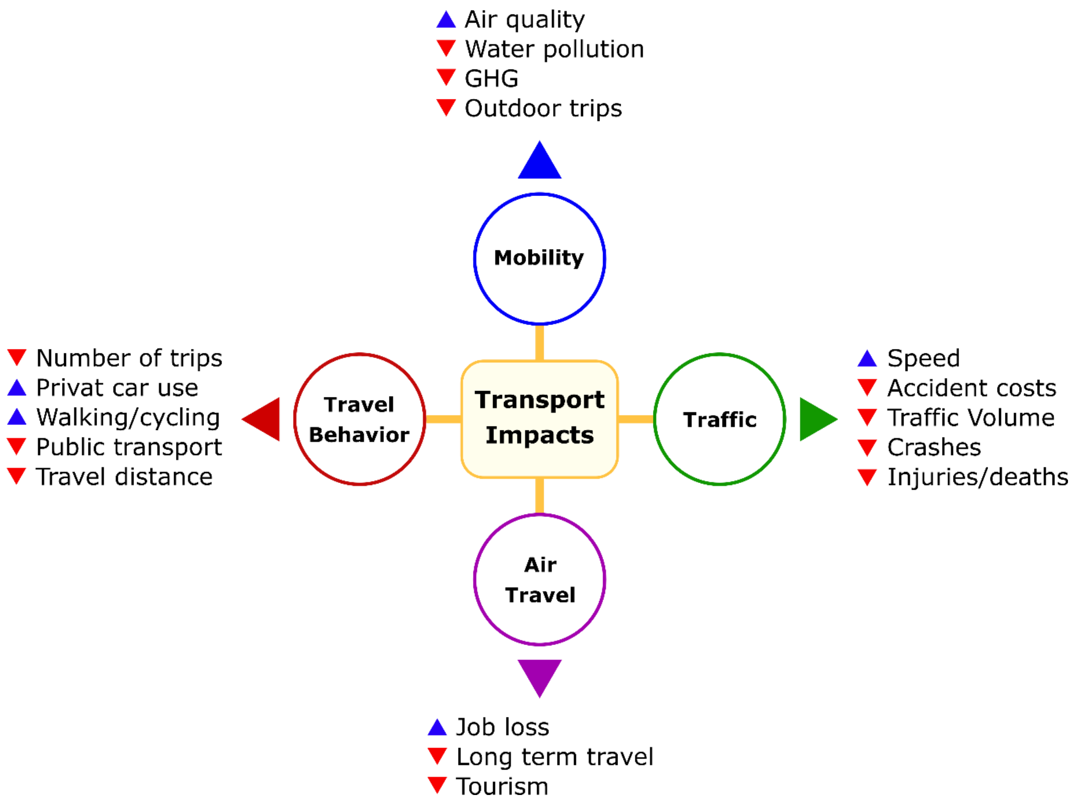


**Figure 3.** Transport impacts of occurrence of infectious diseases.

The studies on travel behavior indicated that the perceived risk and self-efficacy affect travel for various trip purposes. Work travel was found to be the most important and was not affected unless strict lockdown measures were implemented, while all other trip purposes such as social, shopping, visits to parks, religious activities, etc., remain highly restricted. People generally avoided trips to crowded places where the risk of infection was medium to high. The gender differences revealed that males were less likely to change their travel plans compared to female counterparts. Overall, the number of trips and travel distances observed a decrease. All the mode shares during the infected period were affected by changes in the conditions, while public transport observed the most significant reduction. People preferred to travel by private cars and for short distances they preferred walking or cycling. The preference for private cars incurred social costs to the nations. In a developing country, restricted public transport services affected people's daily activities.

The reduced travel showed positive impacts on air quality due to lesser vehicles on the road. The concentration of major air pollutants such as $PM_{2.5}$, CO, $NO_2$, $O_3$, $SO_2$, BC, GHG, and $PM_{10}$ was reduced drastically and the ozone levels were improved. Along with air pollution, water pollution has also seen a reduction, providing health benefits to the public and economic benefits to the nation.

Along with local/road transport, travel by air and the tourism sector is also affected by the outbreak of infectious diseases. People tend to cancel their travel plans to minimize the risks of infection. Due to the wider spread of COVID-19, these sectors suffered severe losses and it is predicted that the full recovery will take a long time, especially for business travel. The tourism sector faced severe consequences due to a sense of insecurity among tourists (delayed holidays) and residents' non-acceptance (not welcoming tourists). In summary, the outbreaks change people's lifestyles significantly and the impacts last for a much longer time than expected.

## 8. Applications and Future Research

This paper summarized the outcomes of the research on the impacts of outbreak of infectious diseases on the transport sector. The insights gained from the review will be useful in planning future mitigation/control strategies during health emergencies or any other situation that requires prevention and control measures. Targeted interventions and protective behaviors can be planned to handle future outbreaks of infectious diseases. Further, the inferences from the literature will help to identify target groups and specific travel restrictions to be implemented at different stages of an outbreak. The outcomes can also be used for scenario testing, which will aid planners in managing emergency conditions. The direct application of the results is possible, because many studies were based on actual/practical observations. Further, this review will assist decision-makers to compare responses for different pandemics and provide results to assist in handling future pandemics better.

Although many studies were found on the latest pandemic of COVID-19, this research has identified some areas for future research. Table 2 provides details of the gaps and areas for future research along with benefits or applications. Many studies focused on understanding the link between transport and the spread of infectious diseases. However, there is limited knowledge of the most/least effective transport strategies in controlling the spread and timing of the application of these strategies. The studies on the transport impacts assessment were limited and mostly using a comparative approach for transport impact assessment on mobility, traffic conditions, travel behavior, traffic safety, and environment. Detailed studies are required to understand each aspect completely to aid in the development of response strategies. A remarkable mode shift was observed as people preferred cars, walking, and cycling. Studies are required to be undertaken to make some temporary infrastructure changes to accommodate increased demand by active modes of transport, considering the requirements of social distancing. Experimental studies will contribute significantly in this regard. Further, to shift people back to public transport and design resilient public transport, strategies need to be speculated and implemented carefully to achieve a balance between revenue and expenditure. Studies related to policymaking, perception, and attitudes will be vital for this. Besides this, although few studies have shown that the traffic volumes were approaching normalcy after a decrease in the number of new cases, more research is required to assist people in bringing back normal life and study time required for the same. Further, the health impacts of increased car usage and driver behavior change, if any, should be investigated. Studies on behavioral research can help to fill this gap. Furthermore, no study was found on assessing the impacts on paratransit modes, such as taxis and autos, and shared transport such as ride-sharing, ride-hailing, carpooling, etc. With the advances in transport systems, effects and strategies for resilient shared transport should be prepared through discussion and consultation with experts and residents. Further, little research was found on air travel and tourism despite being one of the severely affected sectors. Another least explored aspect was the economic impact assessment for various affected transport sectors.

**Table 2.** Gaps and areas of future research.

| Gap | Future Research | Applications/Benefits |
|---|---|---|
| **Transport and Spread of Disease** | | |
| Limited research on the applicability of various transport policies in controlling spread effectively | • Develop models to test the effect of various transport restrictions on the spread of the disease<br>• Develop models to assess spread based on local conditions and timing of implementation of measures | Effective controlling of spread<br>Most effective/least effective method |
| Limited research on spatiotemporal models of spread | • Develop spatiotemporal models considering the latest transport technologies | Apply localized restrictive measures |
| **Mobility** | | |
| No evidence of detailed impact on mobility | • Investigate impact on mobility for various segments and trip purposes/type of destination | Detailed understanding of mobility changes |
| No evidence on the impact of mobility changes on transport costs | • Assess impacts on vehicle operation and maintenance cost<br>• Assess impacts on road infrastructure operation and maintenance cost | Economic impacts of mobility changes |

**Table 2.** *Cont.*

| Gap | Future Research | Applications/Benefits |
|---|---|---|
| **Traffic Conditions** | | |
| Little evidence on the impact of travel restrictions on traffic conditions | • Assess immediate impact of sudden travel restrictions on traffic conditions<br>• Determine the impact of staged travel restrictions on traffic conditions<br>• Assess impacts of temporary changes in infrastructure on traffic conditions | Planning for temporary management measures<br><br>Plan for better implementation of travel restrictions |
| Limited research on the effect of traffic performance | • Assess effect of changed traffic conditions on speeds on various road types in urban and rural areas<br>• Assess immediate and short-term effects of travel restriction | Better management of enforcement measures |
| Limited research on traffic flow over the city | • Models to predict traffic conditions due to sudden changes | Effect of travel restrictions on performance levels |
| No evidence on impacts on auxiliary modes of transport | • Assess impact on taxi, auto rickshaw, personalized rapid transit, etc. | Understanding of transport impacts |
| No evidence on impacts on emerging modes of transport | • Assess shared transport, autonomous vehicles, personal mobility vehicles | Understanding of transport impacts |
| **Traffic Safety** | | |
| Limited impact assessment studies | • More studies on impact of various travel restrictions on traffic safety | Improve understanding of traffic safety situation |
| Little research on economic assessment | • Assess the effect of changes in traffic conditions on accident costs, physical damage and maintenance costs, hospital costs, and insurance costs, etc. | Economic impacts of changed traffic safety situation |
| No evidence of detailed analysis of traffic safety assessment | • Detailed study to assess traffic crash variations for various socioeconomic subgroups and locations | Improve understanding on traffic safety situation |
| No evidence of impact on driving behavior | • Determine impact on driver behavior to find out most/least affected subgroups | Development of enforcement strategies |
| No evidence of effect on violations | • Assess effect on different types of violations, penalties issued, and revenues from penalties | Better understanding of driver behavior and economic impacts |
| No evidence of impact of mental health on driving behavior | • Assess impact of changed mental/psychological conditions on driver behavior | Formulate strategies to improve traffic safety |
| No evidence on impact of modified infrastructure (to address pandemic) | • Assess impacts of changed infrastructure conditions on traffic safety | Managing transport infrastructure better |
| **Travel Behavior** | | |
| Limited research on changes in travel behavior during outbreak | • Detailed studies to assess changes in travel behavior for various socioeconomic subgroups<br>• Studies to determine changes in perceptions of travel behavior<br>• Studies to determine changes in the attitudes of the people towards various modes of transport<br>• Studies on insight into temporary and permanent shift in travel behavior | Better understanding to develop strategies for recovery |
| Little evidence on the impact on trips by active modes and well being | • Investigate effect on travel by walking and cycling and related health benefits | Strategies to promote active modes of transport |
| No evidence of modeling travel behavioral changes | • Develop models for travel behavior changes | Assist in planning |
| **Environment** | | |
| Little evidence on savings/benefits related to environmental changes | • Assess the economic impacts of changes in the environment | Economic impacts of air pollution |
| No evidence on noise pollution | • Assess impacts on noise levels at various transport facilities | Better understanding of environmental impacts |
| No evidence on long-term impacts | • Models to investigate long-term impacts of short-term improvements in environment | Assist in future response strategies |

**Table 2.** *Cont.*

| Gap | Future Research | Applications/Benefits |
|---|---|---|
| **Air Travel** | | |
| Very limited evidence of impact on air travel | • Assess impacts at national and global level in various sectors such as volumes, trip patterns, etc.<br>• Impact of reduced air travel by population subgroups<br>• Assess changes in perception and attitudes of domestic and international air travel | Better understanding of impacts to plan for mitigation measures |
| Very limited evidence of impact on economic aspects of air travel | • Assess economic and financial impacts on air transport at various levels | Better planning of recovery strategies |
| **Tourism** | | |
| Very limited evidence of effect on travel-related to tourism sector | • Quantify impacts on domestic and international tourism<br>• Assess impacts on local transport due to reduced tourism | Better planning of recovery strategies |
| Very limited evidence of economic impacts on tourism | • Assess economic impacts on travel and tourism on national and international level<br>• Perform cost-benefit analysis after considering the local cultural and social impacts | Strategies for economic management |
| **Other Areas—Transport Planning** | | |
| No evidence was found on impact on transport policies | • Assess impacts on planning and operations of private modes of transport<br>• Assess impact on planning and operations of public transport policies<br>• Development of policies considering existing and before conditions (using existing results) | Develop robust transport policies |
| No evidence on changes in transport policies and link to travel behavior | • Determine relationship between revised transport policies with travel behavior by subgroups | Strategies to sustain shift towards sustainable/active modes |
| **Other Areas—Post-Infectious Disease/Pandemic Research** | | |
| No evidence was found on transition from outbreak (pandemic) to normal situation (post-pandemic) | • Decision of optimal timing and ways of lifting of travel restrictions<br>• Assess impact on operations while transition from lower traffic conditions to normal traffic conditions<br>• Assess impact on use of pedestrians and cyclists due to the changed traffic conditions<br>• Determine pedestrians' acceptance of precautionary measures such as social distancing and impact on performance of pedestrian facilities.<br>• Develop a plan to promote active/sustainable modes<br>• Develop a plan to open public transport, balancing revenues and expenditure<br>• Develop strategies to build trust and sense of safety among passengers to promote public transport usage<br>• Prepare a plan for promoting use of auxiliary modes of transport<br>• Develop strategies to promote safe use of auxiliary modes of transport<br>• Study of actual road user behavior post-infectious disease<br>• Determine use of distractions during driving post disease era due to excessive use of IT devices while stay-at-home<br>• Model traffic recovery patterns and obtain the recovery period<br>• Develop strategies to maintain improved traffic safety situation<br>• Develop strategies to retain environmental benefits/savings<br>• Develop strategies to promote air travel post-infectious disease control era<br>• Application of existing ITS infrastructure for smooth transition | Effective transition to new normal phase, prevention of sudden spikes, a second wave |

**Table 2.** *Cont.*

| Gap | Future Research | Applications/Benefits |
| --- | --- | --- |
| Limited research on people's changed attitudes on transport | • Assess the impact of peoples' changed attitudes on driving behavior<br>• Assess the impact of perceived risk/fear of infection on travel behavior<br>• Investigation of impact on concerns over traffic issues after disease is over<br>• Investigate effect on attitudes and concerns towards use of public and auxiliary modes of transport | Assist in planning of mitigation strategies |
| **Other Areas—Resilient Transport Systems** | | |
| No evidence of strategies for resilient transport system (without increasing spread of disease) | • Develop framework and policies for resilient sustainable transport systems in response to health emergencies<br>• Resilient land use and density planning | Some essential transport systems, in addition to private vehicles, can provide service |
| No evidence of use of existing ITS infrastructure during health emergencies | • Investigate role of existing intelligent transport infrastructure in developing resilient transport system | Effective utilization of existing infrastructure in managing transport operations |
| No evidence of development of sustainable resilient tourism | • Develop strategies for sustainable resilient tourism | Strategies to manage tourism sector effectively |

No studies were found addressing the short-term or long-term impacts on transport planning due to the outbreak of infectious diseases. Further, a lot of research is required on the transport impacts of post-disease or post-pandemic period, as its severity, spread, and time of infection is considerably long. Consequently, all the sectors will need time and application of special strategies to recover and achieve new normal situation. Very little evidence on the post-pandemic period was found, which highlights the need for research on various aspects. Further, the impact and usefulness of various recovery strategies applied after controlling the spread of infectious disease need to be investigated in detail for effective application. This area has a lot of potential for further research to make a smooth transition from outbreak phase to the new-normal life. As the transport sector is badly hit during the outbreak of infectious diseases, strategies for building resilient transport systems need to be developed. Overall, limited studies were found on developing countries, which calls for research in all relevant areas.

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## References

1. WHO. Emergencies Preparedness, Response: Diseases. 2010. Available online: https://www.who.int/csr/disease/swineflu/frequently_asked_questions/pandemic/en/ (accessed on 28 June 2020).
2. CDC. 1918 Pandemic (H1N1 Virus). 2019. Available online: https://www.cdc.gov/flu/pandemic-resources/1918-pandemic-h1n1.html (accessed on 29 June 2020).
3. Fee, E.; Brown, T.M.; Lazarus, J.; Theerman, P. The Influenza Pandemic of 1918. *Am. J. Public Health Source* **2001**, *91*, 1953. [CrossRef] [PubMed]
4. WHO. Emergencies Preparedness, Response: Severe Acute Respiratory Syndrome. 2003. Available online: https://www.who.int/csr/don/2003_03_16/en/ (accessed on 28 June 2020).
5. Chan-Yeung, M.; Xu, R.H. SARS: Epidemiology. *Respirology* **2003**, *8*, S9–S14. [CrossRef] [PubMed]
6. LeDuc, J.W.; Barry, M.A. SARS, the First Pandemic of the 21st Century1. *Emerg. Infect. Dis.* **2004**, *10*, e26. [CrossRef]
7. Al-muharrmi, Z. Understanding the Influenza a H1N1 2009 Pandemic. *Sultan Qaboos Univ. Med. J.* **2010**, *10*, 187–195. [PubMed]

8. CDC. Videos from 2009 H1N1 Pandemic (H1N1pdm09 Virus). 2020. Available online: https://www.cdc.gov/flu/pandemic-resources/2009-h1n1-pandemic.html (accessed on 2 July 2020).
9. Killerby, M.E.; Biggs, H.M.; Midgley, C.M.; Gerber, S.I.; Watson, J.T. Middle East Respiratory Syndrome Coronavirus Transmission. *Emerg. Infect. Dis.* **2020**, *26*, 191–198. [CrossRef]
10. Worldometers. 2020. Available online: https://www.worldometers.info/coronavirus/ (accessed on 10 July 2020).
11. Chen, L.H.; Wilson, M.E. The role of the traveler in emerging infections and magnitude of travel. *Med. Clin. N. Am.* **2008**, *92*, 1409–1432. [CrossRef]
12. Belik, V.; Geisel, T.; Brockmann, D. Natural human mobility patterns and spatial spread of infectious diseases. *Phys. Rev. X* **2011**, *1*, 011001. [CrossRef]
13. Funk, S.; Salathé, M.; Jansen, V. A Modelling the influence of human behaviour on the spread of infectious diseases: A review. *J. R. Soc. Interface* **2010**, *7*, 1247–1256. [CrossRef]
14. Yan, Q.L.; Tang, S.Y.; Xiao, Y.N. Impact of individual behaviour change on the spread of emerging infectious diseases. *Stat. Med.* **2018**, *37*, 948–969. [CrossRef]
15. Fong, M.W.; Gao, H.; Wong, J.Y.; Xiao, J.; Shiu, E.Y.; Ryu, S.; Cowling, B.J. Nonpharmaceutical measures for pandemic influenza in nonhealthcare settings—Social distancing measures. *Emerg. Infect. Dis.* **2020**, *26*, 976. [CrossRef]
16. Shaw, R.; Kim, Y.K.; Hua, J. Governance, technology and citizen behavior in pandemic: Lessons from COVID-19 in East Asia. *Prog. Disaster Sci.* **2020**, *6*, 100090. [CrossRef]
17. Nicola, M.; Alsafi, Z.; Sohrabi, C.; Kerwan, A.; Al-Jabir, A.; Iosifidis, C.; Agha, M.; Agha, R. The socio-economic implications of the coronavirus and COVID-19 pandemic: A review. *Int. J. Surg.* **2020**, *78*, 185–193. [CrossRef] [PubMed]
18. Linka, K.; Peirlinck, M.; Sahli Costabal, F.; Kuhl, E. Outbreak dynamics of COVID-19 in Europe and the effect of travel restrictions. *Comput. Methods Biomech. Biomed. Eng.* **2020**, *23*. [CrossRef] [PubMed]
19. Lau, H.; Khosrawipour, V.; Kocbach, P.; Mikolajczyk, A.; Ichii, H.; Zacharksi, M.; Bania, J.; Khosrawipour, T. The association between international and domestic air traffic and the coronavirus (COVID-19) outbreak. *J. Microbiol. Immunol. Infect.* **2020**, *53*, 467–472. [CrossRef]
20. Yilmazkuday, H. COVID-19 Deaths and Inter-County Travel: Daily Evidence from the US. *SSRN* **2020**, 3568838. [CrossRef]
21. Lam, E.H.; Cowling, B.J.; Cook, A.R.; Wong, J.Y.; Lau, M.S.; Nishiura, H. The feasibility of age-specific travel restrictions during influenza pandemics. *Theor. Biol. Med Model.* **2011**, *8*, 44. [CrossRef]
22. Chinazzi, M.; Davis, J.T.; Ajelli, M.; Gioannini, C.; Litvinova, M.; Merler, S.; Piontti, A.P.; Kunpeng, M.; Rossi, L.; Sun, K.; et al. The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. *Science* **2020**, *368*, 395–400. [CrossRef]
23. Bajardi, P.; Poletto, C.; Ramasco, J.J.; Tizzoni, M.; Colizza, V.; Vespignani, A. Human mobility networks, travel restrictions, and the global spread of 2009 H1N1 pandemic. *PLoS ONE* **2011**, *6*, e16591. [CrossRef]
24. Browne, A.; St-Onge Ahmad, S.; Beck, C.R.; Nguyen-Van-Tam, J.S. The roles of transportation and transportation hubs in the propagation of influenza and coronaviruses: A systematic review. *J. Travel Med.* **2016**, *23*, tav002. [CrossRef]
25. Denphedtnong, A.; Chinviriyasit, S.; Chinviriyasit, W. On the dynamics of SEIRS epidemic model with transport-related infection. *Math. Biosci.* **2013**, *245*, 188–205. [CrossRef]
26. Poletto, C.; Tizzoni, M.; Colizza, V. Human mobility and time spent at destination: Impact on spatial epidemic spreading. *J. Theor. Biol.* **2013**, *338*, 41–58. [CrossRef] [PubMed]
27. Pu, C.; Li, S.; Yang, X.; Xu, Z.; Ji, Z.; Yang, J. Traffic-driven SIR epidemic spreading in networks. *Phys. A Stat. Mech. Its Appl.* **2016**, *446*, 129–137. [CrossRef] [PubMed]
28. Yang, H.X.; Wang, Z. Suppressing traffic-driven epidemic spreading by adaptive routing strategy. *Chaos Solitons Fractals* **2016**, *93*, 147–150. [CrossRef]
29. Lee, H.; Park, S.J.; Lee, G.R.; Kim, J.E.; Lee, J.H.; Jung, Y.; Nam, E.W. The relationship between trends in COVID-19 prevalence and traffic levels in South Korea. *Int. J. Infect. Dis.* **2020**, *96*, 399–407. [CrossRef] [PubMed]
30. Xu, B.; Tian, H.; Sabel, C.E.; Xu, B. Impacts of Road Traffic Network and Socioeconomic Factors on the Diffusion of 2009 Pandemic Influenza A (H1N1) in Mainland China. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1223. [CrossRef] [PubMed]

31. Zhang, Y.; Zhang, Y.; Liu, Z. The Role of Different Transportation in the Spreading of New Pandemic Influenza in Mainland China. In Proceedings of the 2011 19th International Conference on Geoinformatics, Shanghai, China, 24–26 June 2011; pp. 1–6.
32. Cooley, P.; Brown, S.; Cajka, J.; Chasteen, B.; Ganapathi, L.; Grefenstette, J.; Hollingsworth, C.R.; Lee, B.Y.; Levine, B.; Wheaton, W.D.; et al. The role of subway travel in an influenza epidemic: A New York City simulation. *J. Urban Health* **2011**, *88*, 982. [CrossRef] [PubMed]
33. Tuncer, N.; Le, T. Effect of air travel on the spread of an avian influenza pandemic to the United States. *Int. J. Crit. Infrastruct. Prot.* **2014**, *7*, 27–47. [CrossRef]
34. Yang, X.H.; Wang, B.; Chen, S.Y.; Wang, W.L. Epidemic dynamics behavior in some bus transport networks. *Phys. A Stat. Mech. Its Appl.* **2012**, *391*, 917–924. [CrossRef]
35. Milne, G.J.; Kelso, J.K.; Kelly, H.A.; Huband, S.T.; McVernon, J. A small community model for the transmission of infectious diseases: Comparison of school closure as an intervention in individual-based models of an influenza pandemic. *PLoS ONE* **2008**, *3*, e4005. [CrossRef]
36. Kraemer, M.U.; Yang, C.H.; Gutierrez, B.; Wu, C.H.; Klein, B.; Pigott, D.M.; Du Plessis, L.; Faria, N.R.; Li, R.; Hanage, W.P.; et al. The effect of human mobility and control measures on the COVID-19 epidemic in China. *Science* **2020**, *368*, 493–497. [CrossRef]
37. Zhao, S.; Bauch, C.T.; He, D. Strategic decision making about travel during disease outbreaks: A game theoretical approach. *J. R. Soc. Interface* **2018**, *15*, 20180515. [CrossRef] [PubMed]
38. Otsuki, S.; Nishiura, H. Reduced risk of importing Ebola virus disease because of travel restrictions in 2014: A retrospective epidemiological modeling study. *PLoS ONE* **2016**, *11*, e0163418. [CrossRef]
39. Marini, M.; Brunner, C.; Chokani, N.; Abhari, R.S. Enhancing response preparedness to influenza epidemics: Agent-based study of 2050 influenza season in Switzerland. *Simul. Model. Pract. Theory* **2020**, *103*, 102091. [CrossRef]
40. Apolloni, A.; Poletto, C.; Ramasco, J.J.; Jensen, P.; Colizza, V. Metapopulation epidemic models with heterogeneous mixing and travel behaviour. *Theor. Biol. Med Model.* **2014**, *11*, 3. [CrossRef]
41. De Luca, G.; Van Kerckhove, K.; Coletti, P.; Poletto, C.; Bossuyt, N.; Hens, N.; Colizza, V. The impact of regular school closure on seasonal influenza epidemics: A data-driven spatial transmission model for Belgium. *BMC Infect. Dis.* **2018**, *18*, 29.
42. Rizzo, A.; Frasca, M.; Porfiri, M. Effect of individual behavior on epidemic spreading in activity-driven networks. *Phys. Rev. E* **2014**, *90*, 042801. [CrossRef]
43. Muhammad, S.; Long, X.; Salman, M. COVID-19 pandemic and environmental pollution: A blessing in disguise? *Sci. Total Environ.* **2020**, *728*, 138820. [CrossRef] [PubMed]
44. Saadat, S.; Rawtani, D.; Hussain, C.M. Environmental perspective of COVID-19. *Sci. Total Environ.* **2020**, *728*, 138870. [CrossRef] [PubMed]
45. Warren, M.S.; Skillman, S.W. Mobility changes in response to COVID-19. *arXiv* **2020**, arXiv:2003.14228.
46. Engle, S.; Stromme, J.; Zhou, A. Staying at home: Mobility effects of COVID-19. *SSRN* **2020**. [CrossRef]
47. Gao, S.; Rao, J.; Kang, Y.; Liang, Y.; Kruse, J. Mapping county-level mobility pattern changes in the United States in response to COVID-19. *SSRN* **2020**, 3570145. [CrossRef]
48. Bao, R.; Zhang, A. Does lockdown reduce air pollution? Evidence from 44 cities in northern China. *Sci. Total Environ.* **2020**, *731*, 139052. [CrossRef] [PubMed]
49. Aloi, A.; Alonso, B.; Benavente, J.; Cordera, R.; Echániz, E.; González, F.; Ladisa, C.; Lezama-Romanelli, R.; López-Parra, Á.; Mazzei, V.; et al. Effects of the COVID-19 Lockdown on Urban Mobility: Empirical Evidence from the City of Santander (Spain). *Sustainability* **2020**, *12*, 3870. [CrossRef]
50. Peak, C.M.; Wesolowski, A.; zu Erbach-Schoenberg, E.; Tatem, A.J.; Wetter, E.; Lu, X.; Power, D.; Weidman-Grunewald, E.; Ramos, S.; Moritz, S.; et al. Population mobility reductions associated with travel restrictions during the Ebola epidemic in Sierra Leone: Use of mobile phone data. *Int. J. Epidemiol.* **2018**, *47*, 1562–1570. [CrossRef] [PubMed]
51. Balkhi, F.; Nasir, A.; Zehra, A.; Riaz, R. Psychological and Behavioral Response to the Coronavirus (COVID-19) Pandemic. *Cureus* **2020**, *12*, e7923. [CrossRef] [PubMed]
52. Favale, T.; Soro, F.; Trevisan, M.; Drago, I.; Mellia, M. Campus Traffic and e-Learning during COVID-19 Pandemic. *Comput. Netw.* **2020**, *176*, 107290. [CrossRef]
53. Shilling, F.; Waetjen, D. *Special Report (Update): Impact of COVID19 Mitigation on Numbers and Costs of California Traffic Crashes*; Road Ecology Center, University of California: Davis, CA, USA, 2020.

54. Sarla, G.S. COVID Dairies: An Indian Perspective. *J. Med. Res. Surg.* **2020**, *1*, 1–3.
55. Brodeur, A.; Cook, N.; Wright, T. *On the Effects of COVID-19 Safer-At-Home Policies on Social Distancing, Car Crashes and Pollution*; IZA Discussion Paper No. 13255; IZA Institute of Labor Economics: Bonn, Germany, 2020.
56. Oguzoglu, U. *COVID-19 Lockdowns and Decline in Traffic Related Deaths and Injuries*; IZA Discussion Paper No. 13278; IZA Institute of Labor Economics: Bonn, Germany, 2020.
57. De Vos, J. The effect of COVID-19 and subsequent social distancing on travel behavior. *Transp. Res. Interdiscip. Perspect.* **2020**, *5*, 100121.
58. Nguyen TH, H.; Coca-Stefaniak, J.A. Coronavirus impacts on post-pandemic planned travel behaviours. *Ann. Tour. Res.* **2020**. [CrossRef]
59. Ruffino, P.; Jarre, M.; van Ommeren, K. *Social Costs and Benefits of Post COVID-19 Lockdown Mobility Scenarios in Italy*; Bikeconomy Osservatorio: Rome, Italy, 2020.
60. Kim, C.; Cheon, S.H.; Choi, K.; Joh, C.H.; Lee, H.J. Exposure to fear: Changes in travel behavior during MERS outbreak in Seoul. *KSCE J. Civ. Eng.* **2017**, *21*, 2888–2895. [CrossRef]
61. Hotle, S.; Murray-Tuite, P.; Singh, K. Influenza risk perception and travel-related health protection behavior in the US: Insights for the aftermath of the COVID-19 outbreak. *Transp. Res. Interdiscip. Perspect.* **2020**, *5*, 100127. [CrossRef]
62. Bucsky, P. Modal share changes due to COVID-19: The case of Budapest. *Transp. Res. Interdiscip. Perspect.* **2020**, 100141. [CrossRef]
63. De Haas, M.; Faber, R.; Hamersma, M. How COVID-19 and the Dutch 'intelligent lockdown'change activities, work and travel behaviour: Evidence from longitudinal data in the Netherlands. *Transp. Res. Interdiscip. Perspect.* **2020**, *6*, 100150.
64. Cahyanto, I.; Wiblishauser, M.; Pennington-Gray, L.; Schroeder, A. The dynamics of travel avoidance: The case of Ebola in the US. *Tour. Manag. Perspect.* **2016**, *20*, 195–203. [CrossRef] [PubMed]
65. Mogaji, E. Impact of COVID-19 on transportation in Lagos, Nigeria. *Transp. Res. Interdiscip. Perspect.* **2020**, *6*, 100154. [CrossRef]
66. Tirachini, A.; Cats, O. COVID-19 and Public Transportation: Current Assessment, Prospects, and Research Needs. *J. Public Transp.* **2020**, *22*, 1. [CrossRef]
67. Wang, Q.; Su, M. A preliminary assessment of the impact of COVID-19 on environment—A case study of China. *Sci. Total Environ.* **2020**, *728*, 138915. [CrossRef]
68. Hiscott, J.; Alexandridi, M.; Muscolini, M.; Tassone, E.; Palermo, E.; Soultsioti, M.; Zevini, A. The global impact of the coronavirus pandemic. *Cytokine Growth Factor Rev.* **2020**. [CrossRef] [PubMed]
69. Kerimray, A.; Baimatova, N.; Ibragimova, O.P.; Bukenov, B.; Kenessov, B.; Plotitsyn, P.; Karaca, F. Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty, Kazakhstan. *Sci. Total Environ.* **2020**, *730*, 139179. [CrossRef]
70. Mahato, S.; Pal, S.; Ghosh, K.G. Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. *Sci. Total Environ.* **2020**, *730*, 139086. [CrossRef]
71. Dantas, G.; Siciliano, B.; França, B.B.; da Silva, C.M.; Arbilla, G. The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. *Sci. Total Environ.* **2020**, *729*, 139085. [CrossRef] [PubMed]
72. Nakada, L.Y.K.; Urban, R.C. COVID-19 pandemic: Impacts on the air quality during the partial lockdown in São Paulo state, Brazil. *Sci. Total Environ.* **2020**, *730*, 139087. [CrossRef] [PubMed]
73. Sharma, S.; Zhang, M.; Gao, J.; Zhang, H.; Kota, S.H. Effect of restricted emissions during COVID-19 on air quality in India. *Sci. Total Environ.* **2020**, *728*, 138878. [CrossRef] [PubMed]
74. Tobías, A.; Carnerero, C.; Reche, C.; Massagué, J.; Via, M.; Minguillón, M.C.; Alastuey, A.; Querol, X. Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. *Sci. Total Environ.* **2020**, *726*, 138540. [CrossRef]
75. Fenichel, E.P.; Kuminoff, N.V.; Chowell, G. Skip the trip: Air Travelers' behavioral responses to pandemic influenza. *PLoS ONE* **2013**, *8*, e58249. [CrossRef]
76. Sharangpani, R.; Boulton, K.E.; Wells, E.; Kim, C. Attitudes and behaviors of international air travelers toward pandemic influenza. *J. Travel Med.* **2011**, *18*, 203–208. [CrossRef]
77. Iacus, S.M.; Natale, F.; Santamaria, C.; Spyratos, S.; Vespe, M. Estimating and projecting air passenger traffic during the COVID-19 coronavirus outbreak and its socio-economic impact. *Saf. Sci.* **2020**, *129*, 104791. [CrossRef]

78. Suau-Sanchez, P.; Voltes-Dorta, A.; Cugueró-Escofet, N. An early assessment of the impact of COVID-19 on air transport: Just another crisis or the end of aviation as we know it? *J. Transp. Geogr.* **2020**. [CrossRef]
79. Zenker, S.; Kock, F. The coronavirus pandemic—A critical discussion of a tourism research agenda. *Tour. Manag.* **2020**, *81*, 104164. [CrossRef]
80. Gössling, S.; Scott, D.; Hal, C.M. Pandemics, tourism and global change: A rapid assessment of COVID-19. *J. Sustain. Tour.* **2020**, 1–20. [CrossRef]