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Analysis of mobility trends during the COVID-19 coronavirus pandemic: Exploring the impacts on global aviation and travel in selected cities

Azzam Abu-Rayash⁎, Ibrahim Dincer

Faculty of Engineering and Applied Science, Ontario Tech. University, 2000 Simcoe Street North, Oshawa, Ontario L1H 7K4, Canada

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ABSTRACT

This paper analyzes the impact of COVID-19 on the transportation sector and subsequent implications on the sectoral energy savings and greenhouse gas emissions in some selected cities worldwide. A model for smart transportation is proposed by considering four indicators, including transport efficiency, technology integration, traffic congestion rate, and accessibility ratio. While prior health crises, such as SARS, impacted the transportation sector, the COVID-19 pandemic is unprecedented, resulting in exceptional impacts on this sector. Canadian Civil Aviation activities dropped by 71%, compared to business as usual, whereas military aviation activities declined by 27%. As of the end of June 2020, cities with higher than 50% mobility index include Brussels, Singapore, Stockholm, Lyon, Paris, Moscow, and Hong Kong with the highest mobility index of 76%. American cities have the lowest mobility indexes as of the end of June with mobility indexes lower than 20%. It is expected and reasonable to assume that the public’s response to COVID-19 will exceed that of SARS. While Britons and Canadians are the biggest supporters of keeping the economy and businesses shut until COVID-19 is fully contained, the Chinese, Russians, Indians, and Italians find it vital to restart the economy regardless. Results show that the majority of the world is in a state of mental distress and will face nervousness and anxiety issues post-COVID-19. This sentiment is strongest in India, Japan, China, the U.K., Brazil and Canada, ranging between 68% and 78%. The trucking industry is the main contributor to the greenhouse gas (GHG) emissions of the Canadian transportation sector, accounting for more than 62% of the total emissions in 2019. Given the impact of COVID-19, forecasted GHG emissions of the Canadian transportation sector for 2020 is evaluated to be 93 megatonnes of carbon dioxide equivalents.

1. Introduction

The COVID-19 coronavirus pandemic has impacted all aspects of energetic and social life dimensions. Due to government restrictions and fears of contracting the virus, mass transport modes have been limited. The transportation sector, including air, rail, road and water transportation have all been affected. Passenger and freight transportation have also been impacted severely, due to the complex supply and demand trends. Global road transport activity was almost 50% below the 2019 average by the end of March 2020 and commercial flight activity almost 75% below 2019 by mid-April 2020 [1]. Furthermore, UK’s restrictions on public transport has led to a 95% reduction in underground journeys in London [2]. Aviation activity worldwide has halted, resulting in severe mobility challenges.

The decline on transportation demand, consequently, translates to reduction in energy and fuel demand. China’s National Bureau of Statistics and Chinese Customs data on refinery production and trade indicate a decline in total oil demand in February of over 2.5 mb/d, or 20%, relative to February 2019 [1]. This drop in energy demand is traced back to the depression in aviation activity in February. Furthermore, the overall electricity demand of Ontario for the month of April of this year amidst pandemic conditions declined by 14%, totaling 1267 GW as reported by [3]. According to Ref. [1], 60% of global oil demand is associated with mobility and aviation. Since, mobility had been curtailed due to COVID-19, oil demand was severely hit, decreasing nearly 5% in the first quarter [1]. More specifically, passenger transport is responsible for almost 40% of final oil demand and 15% of global energy-related carbon emissions [4]. In Ontario, the transportation sector is the second largest sector in terms of energy demand after the industrial sector. The transportation sector accounts for approximately 30% of the energy demand. The sources supplying this demand are fossil-based with substantial environmental impacts. Motor gasoline supplies 142,500 GWh of energy to meet the transportation demand. Diesel is the second major source in this sector accounting for

⁎ Corresponding author.
E-mail address: Azzam.abu-rayash@uoit.ca (A. Abu-Rayash).

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28% of all supplied energy. Electric fuel supplies an insignificant amount of 55.5 GWh to this sector [5]. Therefore, any crisis-induced changes to this sector or the mobility behavior due to COVID-19 will result in significant global implications from an energy and greenhouse gas emissions’ (GHG) perspective. While mobility disruptions can have negative interferences, it can be an opportunity to adapt more sustainable transportation behaviors. Ref. [6] analyzed this phenomenon by applying bridge closures to identify any opportunities for travel practice changes towards low carbon alternatives. They used a social practice approach to behavior and identified several opportunities that may have existed to change practices to low carbon alternatives that were not taken up due to the desire to return infrastructure to pre-event conditions rather than an improved future of low carbon travel. Indirect impacts of COVID-19 also include export revenue, foreign direct investments and manufacturing capacity [7]. The Pearson correlation between the pandemic and exports for instance is −0.496 while it is −0.873 between GDP growth and pandemic.

Will the COVID-19 global crisis result in long-lasting reductions and behavioral changes in transport demand? The novelty of this research paper lies in the analysis of the impact of COVID-19 on the transportation sector with an energy focus. Behavioral trends will be analyzed and future demand will be forecasted to answer the main question of this research paper. If any, changes on the global transportation demand will result in significant energy savings and GHG emission reductions. This paper is unique because it addresses a novel and emerging global trend due to the COVID-19 pandemic. This topic is seldomly discussed or analyzed, and results will guide policy makers and researchers in comprehending the magnitude of its impact on this sector. Therefore, this paper is contributing to energy research and social science through the following specific objectives of the study:

- Analyzing the impact of COVID-19 on the global transportation demand
- Assessing the energy savings and GHG emission reductions due to conserved mobility
- Forecasting the transportation demand considering behavioral changes stemming from COVID-19
- Investigating any long-term shifts in transport preferences due to COVID-19

2. Model development and methodology

Mobility and transportation are some of the main essential services of any given city. The fact that all services are interconnected and being heavily populated, inspires cities to develop various transportation solutions. This includes everything from efficient urban planning to using environmentally benign transportation solutions. The impacts of COVID-19 on all transportation modes has been evident throughout the world. Fig. 1 shows the impacts of COVID-19 on different transportation modes globally.

The proposed model assesses the transportation sector using four indicators. Smart transportation is assessed based on the following function [3,8]:

\[ \gamma_{Shmob} = \beta_{TE} \times \beta_{IT} \times \beta_{ITC} \times \beta_{RTC} \]

This domain is explored by assessing a number of indicators including transport efficiency \( \beta_{TE} \), technology integration in the transportation sector \( \beta_{IT} \), traffic congestion rate \( \beta_{ITC} \), and accessibility \( \beta_{RTC} \) in the sector. This framework development is completed as illustrated in Fig. 2. Four indicators are selected to evaluate the transportation sector. Granular-level data is collected for cities worldwide. Once data is available, it undergoes processing from imputation, normalization, weighting and aggregation. This methodology is in line with [9] who highlight the importance of collecting and reporting additional supporting contextual data, reviewing aspects of research design for vulnerability to validity challenges, and building in longitudinal elements where feasible.

Limitations of this model lie in limiting the evaluation of the whole sector based on four data points only. For this model, the objective is to assess the city’s smart transportation capacity from a comprehensive and holistic approach. However, specialists in each field may choose different parameters to evaluate smart transportation as it pertains to their specific niche. The strengths of the methodology stem from its robust design and the selection of measurable parameters, which remove any subjectivity in the assessment.

2.1. Transport efficiency

This indicator assess the level of efficiency for the transportation sector in any given city. A smart city is one where mobility is very efficient, without congestions or delays. The use of technology as well as efficient and effective planning and management should allow for citizens to move around the city in a very smooth, timely and comfortable manner. Therefore, this indicator is a very important one when assessing the smart mobility domain. This indicator is evaluated by determining the commute duration for the employed labour force to their place of employment. Once again, this sample is a reflective sample of the transport efficiency. The commute durations of less than 30 min were determined and compared to the total commuting durations for a given city. The following function is used:

\[ \beta_{TE} = \frac{\sum CD_{<30}}{\sum CD} \]

where \( \sum CD_{<30} \) is the sum of all commuting durations less than 30 min and \( \sum CD \) is the total commuting durations in the sample data.

2.2. Technology integration ratio

The integration of technology and ICT is critical to the prosperity of any city as well as the enhancements of the mobility sector. This indicator assesses the use of advanced or emerging technologies in the transportation sector for a given city. Emerging technologies are those with the potential for rapid growth, significant opportunities, established capabilities, which can make any given city competitive globally. Furthermore, such technologies include the use of advanced materials, artificial intelligence, cyber resilience, space systems, and remotely-piloted systems and autonomous technologies. This indicator is assessed by determining the percentage of advanced technology used in the transportation sector. This indicator is assessed using the following function:

\[ \beta_{ITC} = \frac{\sum EV}{Area} \]

where \( \sum EV \) is the total number of EV charging stations in a city divided by the total city area.

2.3. Traffic congestion rate

A smart city is one that is congestion-free. This indicator measures how bad traffic is in a given city. The congestion level percentages represent the measured amount of extra travel time experienced by drivers across the entire year. To evaluate this indicator, a baseline of travel times during uncongested, free flow conditions across each road segment in each city is established. Then, travel times across the entire year (24/7) for each city is analyzed and compared against free flow periods to derive extra travel time. The following function explains the relationship:

\[ \beta_{ITC} = \frac{\sum Congestion}{\sum FreeFlow} \]

where \( \sum Congestion \) is the amount of extra time in a year [hr/yr] due to congestion within the city while \( \sum FreeFlow \) is the baseline of travel
times during uncongested, free flow conditions across each road segment in each city.

2.4. Accessibility ratio

Accessibility in transport planning refers to a measure of ease of reaching destinations or activities throughout the city. The level of accessibility in a given city tells a much larger story about that city. In fact, the economic prosperity of cities in part, depends on people being able to move around in an efficient, inclusive and sustainable manner. Fast development in cities ignite and inspite mobility solutions that are more accessible and efficient. For this indicator, the Deloitte City Mobility Index is used to quantify accessibility for a given city. The following function is used to assess this indicator:

Fig. 1. Overview of the COVID-19 impacts on the transportation sector.

Fig. 2. Overview of the smart transportation assessment methodology.

Fig. 3. Proposed model for assessing the transportation sector.
where $\sum \text{AccessibleRoute}$ represents the total length of the accessible routes in (km) compared to the total length of the transportation system in any given city. Fig. 3 outlines the main indicators proposed to analyze the transportation sector for cities.

3. Results and discussion

The COVID-19 global crisis is extraordinary in its magnitude. Therefore, the consequent impacts are also unparalleled. Global mobility has halted since the pandemic outbreak and the utilization of transportation means for passenger and freight purposes has been limited due to restrictions imposed by authorities throughout the world. Fig. 4 shows the Citymapper Mobility Index results for selected cities.
Table 1
Monthy aircraft movements, by civil and military planes, airports with NAV Canada towers (Data from: [11]).

|                       | Dec-19  | Jan-20  | Feb-20  | Mar-20  | Apr-20  | Average | % Decrease |
|-----------------------|---------|---------|---------|---------|---------|---------|------------|
| Total civil movements | 301,273 | 293,256 | 336,921 | 283,797 | 90,393  | 310,483 | −71%       |
| Commercial movements  | 208,941 | 203,544 | 212,563 | 179,577 | 49,376  | 208,349 | −76%       |
| Private and other movements | 15,167 | 13,722  | 17,992  | 17,341  | 14,629  | 15,627  | −6%        |
| Local movements       | 77,165  | 75,990  | 106,366 | 86,879  | 26,388  | 86,507  | −69%       |
| Total military movements | 1,095  | 1,363   | 1,651   | 1,366   | 1,291   | 1,370   | −22%       |
| Military movements    | 955     | 1,115   | 1,269   | 1,116   | 893     | 1,113   | −20%       |
| Military local movements | 140    | 248     | 382     | 250     | 108     | 257     | −58%       |

Fig. 6. Mobility changes in American cities in response to COVID-19 (Data from: [10]).

Fig. 7. Mobility changes in English cities in response to COVID-19 (Data from: [10]).
across the world. These cities were selected in specific because they are considered major cities and because of data availability on the transportation sector for these cities. The Citymapper Mobility Index is calculated by comparing trips planned in the Citymapper app to a recent typical usage period.

The mobility reductions of 50% is observed from China and Japan prior to March 2020. The wave triggered the rest of the world after that of China’s. Thus, the mobility is rapidly reduced throughout the world as of the start of March 2020. During that week, many jurisdictions halted public transport and other means of non-essential transportation, resulting in a severe depression in the mobility index to unprecedented low levels. The transportation sector was virtually non-existent for the months of March, April and May, after which restrictions loosened and cities started to resume public transport with extra precautions and care. Fig. 3 also shows how the mobility index of China never went below 30%, whereas the rest of the world went to near 0%. This is attributed to effective management of the wave and accurate timing for transport closure and restriction. As the rest of the world just shut down their transportation, China started to revive and increase its mobility. As of June 2020, Hong Kong, followed by Moscow and Istanbul are the cities with the highest mobility index worldwide. It is also observed that loosening of the transportation restrictions in Moscow and Hong Kong is happening incrementally and gradually, whereas other cities are following a more gradual and steady rate. Fig. 5 shows the mobility trends in response to COVID-19 in major Canadian cities.

In fact, Canadian aviation is especially impacted due to these regulations. Table 1 shows aircraft movements by both civil and military planes for the months between December 2019 and April 2020. This shows that civil aviation activities declined by 71%, compared to business as usual, whereas military aviation activities declined by 27%.

Similar to the global trendline, Canadian cities halted all public transport activities as of mid-March, reducing the mobility index to its lowest levels to ever be recorded. They resumed in mid-May with restricted use and access of public transport along with heavy emphasis on social distancing and staying at home. In all three cities, Toronto, Vancouver and Montreal, the gradual restart of public transport would
oscillate increasingly. As of the end of June, the mobility index for these cities is well below 50%. Fig. 6 shows the mobility trends in major American cities, amidst the COVID-19 pandemic. The American cities follow a similar trajectory as Canadian cities, where closures took effect mid-March. However, restart of public transport is still limited until the end of June. Seattle’s closures were earlier, perhaps due to their coastal proximity and the impact of the COVID-19 wave on them, slightly earlier than the rest of the American cities. The rest of the cities relatively had an immediate closure around the same day.

Fig. 7 shows similar results for English cities, which follow a closer trajectory to Canadian cities than American cities, especially with resuming public transport in mid-May. As of end of June 2020, cities with higher than 50% mobility index include Brussels, Singapore, Stockholm, Lyon, Paris, Moscow, and Hong Kong with the highest mobility index of 76%. The mobility index measures the percentage of the city moving compared to usual movement, based on recorded data from thousands of end users across the world. [10].

On the other hand, Istanbul, Madrid, Vienna and Barcelona have mobility indexes ranging between 40% and 43%. Canadian cities such as Toronto, Montreal and Vancouver are at 30% mobility. English cities such as Manchester, London and Birmingham have mobility indexes ranging between 20% and 27%. Finally, American cities have the lowest mobility indexes as of end of June with mobility indexes lower than 20% [10]. To compare trends of transportation by air versus transportation by land, Fig. 8 illustrates the change in percentage for the transportation activity by mode for the United States, China, Europe, India and the World.

The trends clearly show a reverse relationship between the Chinese activity, compared to the rest of the world. While the world was experiencing business as usual for land and air mobility, China’s transportation sector was hit in January and February. This depression was lagged for the rest of the world due to the wave’s transmission period. As road and air transportation worldwide started to halt, Chinese transportation sector was revived. Air transportation in China plateaued at around 60%, whereas road transportation keeps increasing gradually and linearly towards business as usual (BAU). As discussed earlier,
while there have been global crises in the recent past, including health crises, the COVID-19 pandemic is by far the most severe. Prior to this pandemic, the most severe health epidemic impacting the transportation sector was the 2003 Severe Acute Respiratory Syndrome (SARS) crisis, which reduced the demand for passenger air transport in the affected regions by about 35% at the height of the crisis (IATA, 2020). In fact, the demand remained below BAU for six months after the ease of the epidemic, which resulted in an annual decrease of revenue by 8%. Other health epidemics following SARS include the Avian Flu outbreaks of 2005 and 2013, as well as the Middle Eastern Respiratory Syndrome in 2015. Although these two viruses caused disruption in the transportation sector, air travel recovered fairly quickly. Fig. 9 shows the impact of other health epidemics on the transportation sector worldwide.

Therefore, it is expected and reasonable to assume that the public’s

### Table 2

| Month    | Average GHG Emissions (Mt CO₂-eq) | % Decrease due to Closure |
|----------|-----------------------------------|---------------------------|
| January  | 14.5                              | 0                         |
| February | 14.5                              | 0                         |
| March    | 14.5                              | 80                        |
| April    | 14.5                              | 80                        |
| May      | 14.5                              | 80                        |
| June     | 14.5                              | 50                        |
| July     | 14.5                              | 50                        |
| August   | 14.5                              | 50                        |
| September| 14.5                              | 30                        |
| October  | 14.5                              | 30                        |
| November | 14.5                              | 30                        |
| December | 14.5                              | 30                        |
response to COVID-19 will exceed that of SARS as the scale of the impacts and the perceived risks of contagion are much greater compared to other health crises. According to a recent international poll, featuring 28,000 participants from across 14 countries, between April 16–19, majority of respondents in eight of the 14 countries are against opening the economy if the virus is not completely under control [13], with the Britons and Canadians being the biggest supporters of keeping the economy and businesses shut until COVID-19 is fully contained. In fact, seven out of ten Britons say that they will be nervous about leaving the house after the lockdown eases. This suggests that the turnaround for the transportation sector will not be as fast as anticipated. Fig. 10 shows the responses for each country to the statement: *We should restart the economy and allow businesses to open even if the virus is not fully contained?*

On the contrary, the Chinese, Russians, Indians, and Italians find it vital to restart the economy. This is reflective of the transportation activity and policy in these countries as illustrated in earlier Figures. Similarly, countries with public discontent on the strategy of reopening businesses before full containment of the virus such as Australia, Canada, USA and Mexico have limited activity and more careful reopening of the transportation sector. Fig. 11 shows the survey results to the following statement: *Even if the businesses are allowed to reopen and travel resumes, I am going to be very nervous about leaving my home.*

Results show that the majority of the world is in a state of mental distress and will experience nervousness and anxiety issues post-COVID-19. This sentiment is strongest in India (78%), Japan (77%), China (72%), the U.K. and Mexico (71%) and Brazil and Canada (68%) (IPSOS, 2020). Thus, turnaround on the transportation sector will be limited and slow. People less nervous about leaving home are in Russia (37%), and France and Australia (32%). Furthermore, an IATA-conducted survey shows that 60% of recent travellers anticipate a return to travel within one to two months of containment of the COVID-19 pandemic but 40% indicate that they could wait six months or more [14].

The GHG emissions within the Canadian transportation sector increased by 19% from 2000 and 2017. Specifically, emissions from passenger light trucks and freight trucks have continued to rise due to an increased number of vehicles. Freight emissions have also experienced an increase due to many factors such as an increase in trade and globalization, and online shopping [5]. Total GHG emission have increased from 146 Mt CO₂-eq in 2000 to 174 in 2017. Passenger transportation contributes 54% to total emissions, freight emissions are 41% of total and off-road is 5%. Energy efficiency improvements in the transportation sector resulted in 763 PJ of energy savings and almost $20.8 billion in energy costs in 2016. Fig. 12 shows historical GHG emissions between 1991 and 2019 with modeled 2020 values based on BAU for various Canadian transportation modes.

The trucking industry is the main contributor to the GHG emissions of the Canadian transportation sector, accounting for more than 62% of the total emissions in 2019. Passenger cars account for approximately 20% of the annual emissions in 2019. Forecasted GHG emissions of the transportation sector in Canada is illustrated further in Fig. 13.

The modeled GHG emissions as well as the BAU scenario for 2020 were determined by taking the 5 year average between 2012 and 2017. The COVID-19 impact consideration on the 2020 GHG emissions follows a gradual and incremental increase in the transportation sector as outlined in Table 2.

The 2021 GHG forecast factors in that the transportation sector will be operational at 75% compared to BAU, whereas in 2022, it will be 80% and 2023, it will be 85%. This is given historical precedence learning from previous health crises such as SARS. It is evident that COVID-19 pandemic has resulted in favourable environmental impacts by lowering the GHG emissions of the transportation sector. The closure of the transportation sector for the months of March, April, May and June will have saved approximately 45 Mt CO₂-eq. In fact, the annual 2020 GHG emissions of the Canadian transportation sector is evaluated to be 93 Mt CO₂-eq, which is a substantial reduction that is unheard of in the past two decades.

### 4. Conclusions

This is a novel research paper with focus on the transportation and the global trend given the COVID-19 pandemic. The paper also introduces a proposed model to assess the transportation sector for any given smart city. Globally the transportation sector has been halted for the past few months, resulting in significant GHG reductions and energy savings, as the transportation industry accounts for 60% of global oil demand. Historical analyses of past health crises indicate that the transportation sector will take a long time before full recovery. This is validated by an international survey that highlights the levels of anxiety and nervousness that people are experiencing worldwide. GHG emissions of the Canadian transportation sector has been modeled for 2020 to 2023 given historical data and COVID-19 impacts. Results show substantial energy savings and GHG reductions associated with the pandemic. Future research can focus on the utilization of pandemic trends in developing more sustainable and reliable transportation trends and policies. Policymakers should adopt the current GHG performance as the new baseline for future years. This will help cap emissions from this sector. With physical distancing in effect, the transportation sector will experience high demand as it approaches 100% operational capacity. Therefore, expanding the fleet with environmentally benign solutions would be a lucrative opportunity. Finally, the transportation sector must identify other sources of revenue to be able to remain profitably operational, without fare increases or financial burdening on passengers.

### 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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