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Transportation-Related Toxic Emissions Influenced by Public Reactions to the COVID-19 Pandemic

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A novel coronavirus, which has been outbroken since the end of year 2019, is spreading in the world among human society and causing a serious coronavirus disease, which is abbreviated as COVID-19 [1]. By August 10, 2020, the COVID-19 pandemic has caused 19,718,030 total cases and 728,013 total deaths [2] worldwide. The Reproductive Rate (R0) for COVID-19 virus, which is defined as the average number of people infected by one person in a susceptible population, is estimated to be between 2 and 4 [3]. To contain the spread of COVID-19 pandemic, orders for "Stay-at-Home", or called (self-) quarantine, (self-) isolation, or lockdown have been issued in most countries and territories globally. In many places, only essential businesses remain open while other activities are largely limited. For example, educational institutions have been closed in 143 countries by August 11st, 2020, affecting 67.6% of the world's student population [4]. Living styles are greatly changed along with the travel patterns [5] and the associated toxic emissions and energy consumption [6].

COVID-19 may induce indirect effects positively and negatively on the environment [6]. Mobile source, primarily motor vehicles in the transportation system, is the major source of a number of air pollutants and energy consumption through human activity [7]. The impacts of a pandemic outbreak on the motor transportation system are mainly reflected in the change of: (1) travel demand, (2) transportation mode, and even (3) the land use and urban planning. During the COVID-19 pandemic, the "Work-from-Home (WFH)", or called "Teleworking" mode is widely adopted as an efficient working style to contain the disease, while keeping the communities safe and flattening the spreading curve [8]. Some revealed that transportation-related emissions are reducing during the pandemic due to the decreased on-road commuting traffic [9]. Others argue that transportation-related emissions may increase in the long term due to altered travel habits and the possible retaliatory traffic after the pandemic [10]. The social effects of the COVID-19 pandemic can be categorized at three levels: (1) individual, (2) business, and (3) community.

Firstly, the impacts of the pandemic on travel and related emissions for individuals are ambiguous. On one hand, employees do not need to commute to their workplaces, at least not on a daily basis [11], which eliminates many work-based travels, particularly during peak hours, and hence reduces mobile emissions [12]. On the other hand, other types of those commuters' travel demands may increase, at least in part. They may reschedule their saved commuting time for on-site shopping, entrainment, family reunification, fitness, site visits of attractions, etc. Studies indicate that the WFH mode has reduced vehicle-miles traveled (VMT) by 11.5 percent from eliminated commuting trips, with the number of personal trips slightly increased [13]. The overall individual travel demands may be raised or decreased by the pandemic, and the proportions for the types of travel demands are significantly influenced during this pandemic period due to the WFH mode.

Extensively, the pandemic negatively influences the operations of many businesses such as the tourism, catering, airlines, and retailer industries [14]. Several other industries are nevertheless gain revenues such as real estate, e-commerce industries and their related postal services [15,16]. According to a projection by the World Trade Organization (WTO), the air travels, cruises, and accommodations during the COVID-19 pandemic are severely impacted since early 2020, in which, international arrivals declined by 20 to 30% [17]. The prices of agricultural commodities have dropped by 20% because of the depressing hotels and restaurant operation, and other reports showed that the restaurant spending has declined by 50% [18,19]. Retail spending declined by 20 in March 2020 and other services spending declined by 50% [19]. In the meantime, based on an e-commerce related international survey, 20% of the respondents from Germany, France, Canada, Australia, Japan, and the United Kingdom indicated

their increased shopping activities *via* online stores, while more than 50% of the respondents from Vietnam, China, and India utilized more online shopping services than usual [20]. The global e-commerce sales have grown by 209% in April 2020 [21]. The social impacts on businesses vary due to their services and functions. Most businesses that require on-site operations are negatively impacted while those e-commerce businesses are encouraged.

Furthermore, the highly contagious nature of COVID-19 virus also intensively affects community activities [22]. The six-feet social distancing rule limits and even prohibits regular school, residential, and religious activities [23]. In a German musical festival that was held in August, 2020, only 2,000 spectators were allowed for the venue with a 12,000 capacity [24]. When the COVID-19 pandemic began to breakout in the United States, almost all its states ordered or recommended the closure of schools, with at least 55.1 million students in 124,000 public and private schools that were affected [25]. Religious activities were also limited in order to practice social distancing. In the United States, the religious gatherings are limited to ten (in the District of Columbus), 25 (in the State of Oregon), and 50 peoples (in the State of Connecticut), respectively [26]. One interesting thing is that, 19% of Americans indicated their strengthened faith even under such spatially separated situations [27].

As one of the most significant consequences, transportation associated with the social effects introduced above is influenced. Travel patterns under the COVID-19 pandemic have been changed. Due to the WFH mode and less public activities, the work-based travels have been reduced [28]. Non-work-based travels like shopping and delivering are relatively increasing since people prefer or have to shop online [29]. Travels are globally dropping since the outbreak of COVID-19. In the United States during the 4th of July week (i.e. the week for its Independence Day), there were 2.8 billion fewer total trips in 2020 than in 2019 [30]. Trips over 3 miles decreased in the U.S. from December 2019 to April 2020, and slightly increased through April to August in 2020 [30]. The travel demand from January 2020 to June 2020 has decreased by 40% in the City of Taipei, Taiwan, 80% in the City of London, United Kingdom, and even 90% in the City of Milan, Italy [31]. The walking and bicycle demands are, however, increased, for example in Philadelphia, Budapest, Sydney, and Berlin [32]. Travel patterns are mainly related to the social effects on individual level, the changes in travel demand modes are likely to cause sharp differences for travel patterns.

The operation of public transit is significantly influenced by the WFH mode and social distancing policy [5]. The monthly ridership of public transit including local bus and light rail in Houston, Texas has reduced by 43% month on month in June 2020 [33]. The City of Wuhan, China shut down its public transport to halt the outbreak of the pandemic on January 23, 2020 until the bus services were resumed on March 25, 2020 with restrictions [34,35]. The metro system in Shanghai, China received regular disinfection during the pandemic period, and an altered riding schedule for metros and buses in Shanghai was implemented after the outbreak of COVID-19 [36]. In the City of New York, the ridership of subways has reduced by more than 90% since the outbreak of the pandemic, the subway stations were shut down overnight for regular cleaning from May 2020 [37]. The reduction in passenger numbers of public transit has also taken place in London, hand sanitizers were provided on buses, tubes and rail stations during the pandemic period [38]. The Tokyo Metro has assigned workers to spray silver compounds in its cars to repel viruses from the surface since the lift of city lockdown from May 2020 [39]. The ridership of Metro bus in Montreal has dropped by 80% and regular weekday bus service has reduced by 45% in March 2020 [40]. Due to the practice of social distancing and the awareness of the higher infection risks in public spaces, the worldwide public transit is negatively affected by the pandemic, while the overall ridership is greatly reduced. The general demands for freight transportation is greatly reduced due to the overall decrease in business activities. Based on statistics, the railway freight volumes are declined by 20%, and ocean transportation is down by 25% [41]. Owing to the changed shopping mode for increased e-commerce, the ground freight traffic volumes in the United States, however, increased by 30% in 2020 [41].

Along with the changing travel demands, land use and urban planning are further impacted. The deployment of warehouses and associated land use types will be reshaped now or later [42]. To reduce the risk of a future pandemic, the United Nations Convention to Combat Desertification (UNCCD) suggests keeping the land use in natural balance by protecting and restoring livestock farming land [43]. A related study on Chinese land use indicates the increase in livestock density and animal consumption during the COVID-19 pandemic [44]. The housing locations are also affected by the WFH mode [45] as the distance to work is not a dominant consideration and flexible housing locations in more dispersive areas with lower rates tend to be more attractive [46]. This however may cause longer commuting time after the pandemic in the long run. Lower interest rates, convenient virtual openings, and the need for more personal spaces at homes are propelling the change of home building and sales [47]. For example, the real estate property sales and single-family home sales in Houston increased by 25% and 23% in July 2020 while compared to July 2019 [48]. It is anticipated that social distancing and many other relevant health-related factors will be incorporated into the urban and transportation planning process in the future.

As a result in terms of the pollution, the changes in travel demand, travel patterns, and even land use and urban planning will all eventually impact the toxic emissions (e.g, nitrogen oxides (NOx), hydrocarbon (HC), carbon monoxide (CO)), greenhouse gases, and energy consumption [49]. Such emissions and fuel consumption can be estimated by using the MOVES model developed by the United States Environmental Protection Agency (EPA) [50], with the estimated speed, acceleration rate, vehicle's specific power (VSP), VMT, and other factors from travel demand-based transportation planning models [51]. For the operational traffic, vehicle emissions and fuel consumption can also be measured directly using the onboard Portable Emission Measurement System (PEMS) [52].

In particular, the WFH mode that is widely adapted during the pandemic may reduce emissions due to the reduced commuting demand. However, some types of emissions (particularly, N_2O and CH_4) may increase because of the added home-based travels [53,54]. The depressed tourism, catering, and retailer industries may result in lower electrical and fossil energy consumption, and toxic emissions [55], while retaliatory emissions and consumptions may increase after the pandemic [56]. The industries that are positively related to the pandemic such as the e-commerce related postal services may increase mobile source emissions [57]. While the school and religious related toxic emissions and energy consumption are decreased due to the WFH mode, the at-home energy consumption rises [58,59]. Thus, the total toxic emissions during pandemic period are inexplicit. Related studies should be focused on specific cases since the pandemic impacts on pollution vary with the nature of industries in discussion.

It is the best hope that the pandemic caused by COVID-19 will be contained with the birth of effective vaccines and medicines. However, the pandemic virtually impacts on every aspects of social activities from individuals to communities. Among the consequences of the

impacts, transportation shows more variation tendencies. On one side, the travel demand may be reduced by the WFH and other types of restrictions of social activities. On the other side, the travel demand may increase by the public's new lifestyle. Furthermore, the changes on land use and urban planning may last for a long time and further influence the travel demand. For example, the Facebook company starts to plan for permanent remote working style [60], and some of its employees are even considering moving their homes from the expensive San Francisco Bay Area to locations with lower living costs such as Houston and Dallas in Texas. The mobile source toxic emissions due to these activities might be changed positively or negatively in the long run, which should be carefully analyzed in details on case by case basis, so that the stakeholders and authorities of transportation sectors can make preventative decisions for advance preparation.

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