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International Analysis on the Traffic Impact of the COVID-19 Pandemic

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INTERNATIONAL ANALYSIS ON THE TRAFFIC IMPACT OF THE
COVID-19 PANDEMIC

By

Fanny Margaretha Kristiansson, E.I.T

A Thesis Submitted to the College of Engineering, Department of Civil Engineering
In Partial Fulfillment of the Requirements for the Degree of
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Abstract

The purpose of this research was to assess, compare, and contrast the impact of COVID-19 activity restrictions on road-based transportation activity in regions of the US, Sweden, and China from January 1st to December 31st, 2020. Roadway traffic volumes were used to relate the progression of reported COVID-19 cases and government directives for social separation in three countries with diverse governmental responses.

Among the contributions of this paper was the illustration of the timeline and level of public responses to closures, lockdowns, and reopening as represented through rapid traffic decreases and increases. Traffic was greatly impacted, showing that the pandemic influenced activity and travel. A Monday-Monday traffic trend show that more normal traffic levels occurred on weekdays and largest decreases on weekends. Urban roads showed a more rapid response to directives than rural roads. At the study period end, only China and Florida returned to pre-pandemic traffic levels, only China reported zero COVID-19 cases. Sweden experienced a similar COVID-19 curve as the US and had fewer cases-per-million than most states. The findings indicate that rapid traffic decrease was associated with delaying initial COVID-19 peak and a longer time to return to normal traffic, likely delayed the second peak.

This research provides insights for practitioners, researchers, and government entities developing and accessing plans for future pandemics. It is also expected that the findings of this study can be built upon by future researchers who continue to study various aspects of the COVID-19 pandemic and assess the public response to governmental actions.

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1.0 Introduction

COVID-19 is a disease caused by the SARS-CoV-2 virus and was first identified in Wuhan, Hubei Province in China, in late 2019. COVID-19 spread throughout the world and has caused enormous global economic and social disruptions. In response to the virus, public officials issued directives to limit person to person contact to constrain the rapid spread of the virus. The government restrictions and actions varied from country to country in terms of type, timing, and nature of the limitations for citizens. The United States (US), Sweden and China, represent the most diverse virus responses taken. China provided an example of an authoritative, centrally planned response, while Sweden represented a classical liberal approach by limiting large public gatherings, but keeping public schools, restaurants, and other business open. The federalist system of the US allowed state governors to choose response measures that were regarded to be most appropriate by local authorities. This resulted in a mixed approach, with most states falling somewhere in between the measures taken by China and Sweden. A good example of this was the dichotomy between New York and Florida, where New York issued significant limitations and Florida was less restrictive.

Many countries around the world closed restaurants, schools, stores, and offices to enforce social distancing. However, Sweden imposed fewer restrictions that were generally viewed as “governmental recommendations” due to a lack of enforcement (Kandaa and Kivimaab, 2020). Sweden’s strategy to control the pandemic was considered more liberal by the international community (Pierre, 2020) and has been both criticized and praised by subject area experts (Lacina, 2020; Nyheter, 2020).

The Chinese government, by contrast, enforced strict control over urban transportation. On January 23, the Wuhan Epidemic Command Center made the first announcement about the

restrictions. Wuhan's public transport, including subways, buses, long-distance buses, and ferries were suspended, along with temporary closures of airports and railway stations (Chen et al., 2020). Soon thereafter, the Chinese government executed a series of large-scale interventions to control the pandemic with a complete lockdown of Wuhan; all travel in and out of the city except medical service transportation was prohibited (Yuan, et al., 2020). The rest of China soon followed with similar restrictions and nationwide travel limitations. Most of the provinces in China ordered an emergency Level 1 response that enforced strict population mobility control measures, such as a travel ban restriction, "stay at home" order, school, entertainment, and business closures, and a ban on public gatherings in late January 2020. By April, most of the provinces in China had lowered their emergency from Level 1 to Level 2 or Level 3 and that relaxed travel bans while reopening schools and businesses.

During the initial stages of the pandemic in the US, a nationwide national emergency was declared on March 1, 2020 followed by state-level emergency declarations in the weeks that followed (Executive Office of the President of the United State, 2020). This did not restrict the movement or gathering of people but created the legal foundation for such measures to be put in place. In a federalist system, only state governors could declare emergencies and in doing so, provided the governmental authority by which to enforce limitations and restrictions, such as limiting large gatherings, closing privately owned businesses, and restricting public activities. While each state was different in responding to the pandemic, most eventually saw the closure of "non-essential" businesses, public schools, sporting events, theme parks, movie theaters and concerts.

By January 2021, the COVID-19 pandemic was not over, and the assessment of significant and complex impacts will go on for years. There is a need for immediate and prompt assessment

of outcomes and efforts as they continue to happen. Public acknowledgment and compliance with government recommendations for social distancing and separation is one of the most critical to assess. The relationship between the government restrictions and COVID-19 cases can bring valuable insights for dealing with future pandemics. It is complicated to understand the impact of government mandated limitations on temporal and spatial responses of the public, given the near-infinite possibility for person-to-person interaction and the difficulty to systematically monitor the movement of individuals. One such method to assess personal interaction and virus transmissions is contact tracing which is a widely used method (Dhillon and Srikrishna, 2018). Unfortunately, during the onset of the pandemic, this method was not feasible because there was a limited capability to get timely and accurate test results, where many infected individuals were largely asymptomatic (Kretzschmar et al. 2020).

Information about travel patterns, more specifically vehicular roadway travel can also provide insight into the activities of a collective region. Generally, travel in and of itself, is not considered an activity but is a means to accomplish an activity. Collective increases and decreases in travel are generally associated with economic productivity and can provide an indication of the activity desires of a populous. Recent studies by Parr et al. (2020; 2021) collected traffic volume data during the initial period of the COVID-19 pandemic. Traffic volume data presented a low-cost, comprehensive, reliable, readily available, and consistent source of data that shows different levels of public activity and movement. Such data can be used as a representation of public movement and the general interaction at collective levels, even if it cannot describe travel purpose and cannot disaggregate the activities of the individual traveler. The most valuable part of traffic volume data is that it gives location-specific conditions by roadway class and over time.

This paper describes research utilizing traffic volumes to show changes in individual activity patterns and the development of COVID-19 cases in 10 US states (Florida, Illinois, Indiana, Massachusetts, Montana, Michigan, New Hampshire, New York, Ohio, Vermont.), two Chinese Provinces (Hubei and Zhejiang), and across Sweden. Positive COVID-19 cases were selected as the basis of analysis instead of deaths and hospitalization because cases are more directly connected to exposure and travel and reflect the spread of the virus. Deaths and hospitalizations are arguably more dependent on complex health factors and include a more unpredictable timeframe. This research is unique and valuable because it assesses the COVID-19 infections and behavioral reactions using the same consistent measure of roadway traffic across three counties that represent the extreme range of pandemic response of any countries in the world. The impact of travel on decreases and increases of COVID-19 cases, as government mandated restrictions were executed and then reduced across the US, China, and Sweden is demonstrated by this paper.

The thesis includes four main sections that summarize and highlight the primary components of the research. The first section is a brief review of similar efforts and reports to analyze the travel and health outcomes of governmental-mandated restrictions during the beginning of COVID-19. This is followed by a section that describes the data and methods that were used in this study. It also includes a description of the COVID-19 databases and traffic count data systems, and how they were used in this research. The section that follows is a demonstration and discussion of the analytical testing that was performed on the data, together with the findings. Finally, the last section of the thesis is a conclusion with a discussion of what the data and findings may be implying.

2.0 Review of Relevant Literature

2.1. Social Distancing

Viruses have a larger impact on health outcomes in crowded areas. Yousey-Hindes and Hadler (2011) found that the likelihood of children being hospitalized with influenza doubled in crowded neighborhoods. Social distancing is one of the strategies that can limit social contact in the community, but crowding is hard to control within a residence. Compliance with social distancing guidelines is impacted by many factors, such as culture (Huynh, 2020) and socio-demographics (Murray-Tuite and Hotle, 2020, and references therein). Social distancing can help reduce the spread of the virus, delay and decrease the size of the peak, in turn helping to reduce the strain on the health care system (Fong et al. 2020). Many countries have pandemic plans that include school closure to reduce social contacts between its populations (Sadique et al. 2008). School, work, and other closures were implemented worldwide in response to COVID-19. A study on the effects of COVID-19 provide evidence that lower COVID-19 infection and mortality rates are linked with increased levels of social distancing and reduced levels of travel—especially by public transit modes (Mahmoudi et al 2021).

2.2. Mobility

COVID-19, closures, and other measures have had significant impacts on general mobility. In the Netherlands, 80 percent of people had an overall trip reduction of 55 percent due to a reduction in outdoor activities (de Hass et al. 2020). A study in Australia showed that household trips were reduced by more than 50 percent across all modes of travel. Transit trips were reduced from 14 percent pre-lockdown to only seven percent (Beck 2020). Traffic volumes in Florida dropped by 47.5 percent looking at roadway detectors across the state (Parr et al. 2020). Other studies examined the association between COVID-19 spread and mobility reductions. A study in

Italy found that the trips conducted three weeks earlier related to daily new COVID-19 cases. Carteni et al. (2021) conducted another study in Italy using a multiple linear regression model to show the similarity between positive Covid-19 cases and transportation accessibility in an area. Accessibility contributed about 40% in weight to new COVID-19 cases, and weighted heavier than the other variables. The greater the transport accessibility is of an area, the easier it is for the virus to reach the population. The authors stated that the study shows that a more sustainable policy for restrictions and lockdowns to containing social interactions, could be to look more closely to the proportionality of transport accessibility in the area of interest. The greater the accessibility is, more restrictive policies on mobility should be implemented (Carteni et al 2021).

Another study in the United Kingdom, described how mobility reductions caused significant decreases in COVID-19 cases (Hadjidemetriou et al. 2020). A study on the relationship between daily trips in the US and the COVID-19 infections in the near future used a time-series forecast models to project future trends from November 2020 to February 2021 (Truong & Truong 2021). The study discovered a closed loop scenario, where people's travel behavior dynamically changes depending on their risk perception of COVID-19 in an infinite loop. A loop that can only be broken if proper and prompt mitigation strategies are put in place to reduce the burden on hospitals and healthcare systems, thus saving more lives.

Mobility reduction has an impact on the spread of COVID-19. Mobility data from Google were applied to the effective reproduction rate, R_t , a measure of viral infectiousness (Noland 2021), to understand the impact from reducing six different trips and activates. The study shows that "Staying at home" is effective in lowering the R_t value. "Activities at parks" appear to not have a significant effect on increase R_t . A return to baseline levels of activity for transit, workplaces, and retail, will increase R_t . 20–40% of mobility reductions are needed to attain an R_t

below 1.0. Noland cautions policy makers with encouraging people to return to normal mobility behavior, particularly when it comes to, transit, workplaces and retail locations.

A study in Japan showed that during the initial stage of the pandemic, no strong restrictions, such as lockdowns, were put in place by the government (Hara & Yamaguchi 2021). Even though there were no major restrictions, the study detected nation-wide behavioral change using mobile phone network mobility data. During the “state-of-emergency” in Japan, results showed a significant reduction in inter-prefectural travel and trips without strong restrictions from the policymakers. Another interesting finding was that the population density index decreased by 20% as people avoided traveling to these densely populated areas. The study showed that after the state of emergency was lifted, people’s behaviors did not immediately return to normal, instead, recovered slowly.

A study in Poland on the overall reduction in travel time after the Polish government introduced administrative measures to slow down the spread of COVID-19. Significant decrease in travel times were observed, with no difference between age groups and gender. The more the respondents experienced a fear of COVID-19, the more he or she shortened their daily travel time and stayed closer to home. (Borkowski 2021).

2.3. Governmental Directives

The impact of policymakers and governmental stringency has a major impact on people’s actions and adherence to social distancing. Yan, Wang (2021) assessed the impact of national culture and government policies from major economies, on social distancing to lower the spread of COVID-19. Government enforcement has a much larger impact on social distancing than what national culture does. There is clear proof that social distancing increase with government stringency. There are two cultural dimensions that matter when it comes to social distance: it

decreases with ‘Long-term Orientation’; and increases for ‘Indulgence’. The results show that it is necessary for policymakers to act decisively instead of blaming the culture (Wang, 2021).

Lower COVID-19 infection and mortality rates have been shown to be linked to stricter enforcement policies and more severe penalties for violating stay-at-home orders (Mahmoudi et al 2021). Policies that allow gradual relaxation of travel restrictions, social distancing and face-mask usage, are connected to lower COVID-19 infection and mortality rates.

As mentioned earlier, Sweden has taken a more recommendation-based approach with fewer restrictions than most governments. Contrary to what has been discussed in public media in regard to the spread of the virus, restrictions and recommendations were effective in Sweden, a study done through monitoring urban noise levels in central Stockholm (capital of Sweden), shows a significant impact on the transport and other human-related activities (Rampler et al 2020). The study connected public movement and mobility to the urban noise level. A higher urban noise level means a higher mobility, while a decrease in urban noise level points to a decrease in transportation and other human-related activities. The noise level reductions are shown to be comparable to those found during the two major public holidays in Sweden with a peak reduction happening in the beginning of April 2020. Sweden’s less restrictive approach to dealing with the pandemic did have an effect in reducing mobility (Rampler et al 2020).

A study on China, constructed a city-based epidemic and mobility model (CEMM) to stimulate the spatiotemporal of COVID-19, using multi-agent technology and big data on population migration. (Wei et al 2021) The urban network perspective model emphasizes the important role of high-speed transportation networks and intercity population mobility. The model was able to simulate the initial stage of the inter-city spread of COVID-19 with high precision. The simulation showed that the total number of infectious cases in China would have

been 4.46 times higher, 138,824 cases in February 2020, if the city lockdown decreasing population mobility did not occur.

2.4. Other Modes of Traffic Impacted

Public transportation and shared use mobility have been greatly impacted. Air travel has experienced a 98 percent constraint in passenger revenue (Suau-Sanchez et al. 2020) and the airline workforce is expected to see an unemployment rate increase of seven to 13 percent (Sobieralski 2020). Cruise ship passenger landings were also significantly reduced as a result of the pandemic (Ito et al. 2020). Shared-use mobility modes (e.g., bus, subway, taxis, mobile phone-based apps, shared bicycles etc.) have suffered a significant decrease in ridership during the COVID-19 pandemic (Hendrickson and Rilett 2020; Teixeira and Lopes 2020). Zhang et al. (2020) further investigated the effect on different transportation modes during the pandemic, discovering that air flights and high-speed train services were related to the number of COVID-19 cases at the travel destination and exposure concerns could contribute to decreased public transit ridership. A study on 3,132 US counties during the lockdown and initial onset of travel restrictions, analyzed the association between COVID-19 deaths and new cases to the proximity of airports, public transport and train stations (Gaskin et al 2021). Counties located within 25 miles from an airport, compared to counties located more than 50miles away from an airport, had 155% more COVID-19 deaths, and 139% more cases (Gaskin et al 2021).

Several factors contribute to high-risk for contamination during public transit ridership (Tirachini and Cats, 2020), such as a high occupancy of infected workers, confined spaces, and multiple surfaces that simply transfer viruses. Tirachini and Cats (2020) suggested that the largest drop in public transit ridership occurred during the highest demand periods, during the previous peak hours. Speculation about the possibility of a travel recovery not materializing is

also concerning (Sung and Monschauer 2020). The notion is that there will be widespread fear of shared modes of transportation and that such modes will be avoided, leading to more people using their cars instead of buses, taxis, subways, mobile apps, shared bicycles etc. (De Vos 2020). The pandemic is also predicted to increase biking and walking (Donné 2020).

Public transport ridership during spring 2020 in Sweden was down by 40-60% across all regions (Jenelius & Cebecauer 2020). The study found that people switched from monthly period tickets to single tickets. Short period ticket sales dropped to almost zero since these ticket types were predominantly purchased by tourists. One-year period tickets and school tickets returned to pre-pandemic levels during April, indicating that travelers that used these tickets are mainly bound to the public transport system.

The pandemic will have both long-term and short-term effect on urban mobility. A study conducted on April 2020 from 5,000 respondents from major cities in China, the U.S. and Western Europe on how COVID-19 will shape urban mobility, in the long and short-term (Bert et al 2020). All transportation modes declined during lockdown, and respondents suspected they would use share mobility and transit less frequently. Instead, they predicted they would walk, bike, and use their own personal vehicle more frequently. More than 60% of the Chinese respondents stated that post-lockdown they would purchase and use their own car. The study concluded that in the long term, respondents stated a willingness to return to the use of public transit and shared mobility, indicating that public transit ridership could return to normal levels.

The viral transmission from commercial air travel stood in the forefront of many discussion during the onset of the pandemic. A study combined air travel data and COVID-19 case data to observe the virus transmission from commercial air travel using the CAT-V tool (COVID-19 Air Traffic Visualization). It was determined that the reported case rate in China was too low for the

number of cases detected in the rest of the world. Actually, cases needed to be roughly 37 times higher than what was reported from China. (Mouton et al 2020). By using the CAT-V tool, five countries were determined to be the highest possibility of contracting COVID-19 from China. By looking at the number passenger planes arriving in the five countries (Thailand, Taiwan, Japan, South Korea, and United States) from China during the beginning of 2020 and using the 503 reported COVID-19 cases in China on January 22nd, only one out of the 5 countries should see a detected COVID-19 case. However, on January 22nd, all 5 countries identified COVID-19. The Chinese case rate reported cannot have been accurate. China must have had 18,700 cases instead of the 503 for COVID-19 to be appearing in each country.

2.5. Reduced Mobility Impact on Traffic Crashes and Fatalities

An investigation in Connecticut, US, studied the impact of COVID-19 stay at home orders on daily vehicle miles traveled (VMT) and motor vehicle crashes (Doucette et al 2021). Looking at the crash severity and number of vehicles involved in crashes from January through April, the study found that the daily VMT decreased by 43%. A decrease in daily counts of crashes was noted, but single vehicle crash rate increased 2.29 times, and single vehicle fatality rates increased 4.10 times. The study concluded that the potential role of reduced police presence, less congested roads, and speeding could contribute to these results. High speed-related fatal crash rate in Japan during the COVID-19 lockdown were higher than pre-lockdown (Inada 2021). The authors reviewed police data on crash fatalities between January 2010 and February 2020 in which motor vehicle drivers were at fault and found that speeding, speed enforcement by the police, and driver behavior during lockdown as leading causes for the increase in crash fatalities.

Looking at traffic crash patterns before and after the outbreak of COVID-19 in Southern Florida for the first half of the years of 2019 and 2020 (Lee and Abdel-Aty 2021), show a considerable reduction during March to June 2020. The total numbers of crashes have decreased with 21%, with the most significant reductions are during morning peak-hour (33.3%), crashes involving alcohol/drug (58.0%), and pedestrian crashes (38.3%). Another study in Florida (Pierre et al 2021), looked at the impacts of the COVID-19 pandemic on traffic crashes on freeway (I-10, I-75, and I-95). The paper showed that since the first confirmed COVID-19 case in Florida, there was a decrease in the total traffic crashes and dropped significantly by up to 45.3%. A decrease in the rear-end crashes and an increase in the run-off-road were observed.

Calderon-Anyosa & Kaufman (2021) conducted studies on external causes of death such as suicide, homicide, and car crashes during COVID-19. The authors wanted to understand how violent and accidental deaths were impacted by the COVID-19 lockdowns. After the lockdown, all forms of deaths suddenly dropped. The largest decrease was seen in traffic related accident deaths, with a reduction of 12.22 and 3.55 deaths per million per month men and women respectively. Homicide and suicide presented a similar decrease in the initial stages of the lockdown for women while homicide in men increased by 6.66 deaths per million men per year.

2.6. Reduced Mobility Impact on Air Quality

Prior research has investigated the environmental impact of the COVID-19 global pandemic, social distancing, and subsequent changes in human behavior on air quality. Local lockdowns within states, cities, or whole countries, helped in improving the air quality (Carteni, A. et al, 2020).

In Italy, an analysis of its carbon footprint indicator, found the country's carbon footprint shrank by approximately 20 percent (Carteni, A. et al, 2020). Lockdown and social distancing

created a decrease in traffic movements, correlated to a direct decline in PM2.5 concentration. (Chauhan, A. and Singh, R. P., 2020). After observing air quality, meteorological parameters, and mobility in six major Italian cities, the authors found that road traffic was reduced by 48-60%, NO₂ reduced by 24-59.1%, and PM2.5 by 17%. O₃ levels remained essentially unchanged or showed a slight increase of up to 11.4-14.7% (Gualtieri, G. et al, 2020). Most studies focused on the impact on PM2.5, NO₂, and ozone. These are criteria pollutants, and they can harm people's health and the environment, and cause property damage.

An analysis of 50 capital cities worldwide found a 12 percent decrease in particulate matter emissions (PM2.5) (Rodríguez-Urrego, D. and Rodríguez-Urrego, L., 2020). An analysis in Wuhan City, China found the average monthly air quality index, improved by 33.9 percent during the lockdown and PM2.5 decreased by 36.5 percent. Nitrogen dioxide (NO₂) decreased by in the city by 53.3 percent. However, Ozone (O₃) increased by 116.6 percent (Lian, X. et al, 2020). An analysis conducted in Rio de Janeiro, Brazil also found increased levels of O₃ while showing decreased levels of NO₂ and carbon monoxide (CO) (Siciliano, B. et al, 2020). An investigation in the continental United States found NO₂ reductions of 25.5 percent and statically significant reductions of PM2.5 (Berman, J.D. and Ebisu, K., 2020).

2.7. COVID-19 Case Date Offset

When exposed to COVID-19, symptoms usually take about 5 days to appear in a newly infected person. Some people experience symptoms as soon as 2 days after being exposed. The majority of people infected show COVID-19 symptoms after 12 days, and most people were sick by day 14. (Nazario 2020). Another study on 181 confirmed cases shows an incubation time of 5.1 days for COVID-19. 97.5% of the study group experienced symptoms within 11.5 days of

being infected by the virus. In some cases, people will develop symptoms after 14 days of being exposed. (Lauer et al 2020).

A study conducted on the COVID-19 reporting in New York City estimated a mean delay in reporting as 5 days, with 15 percent of cases reported after 10 or more days. (Harris 2020). Two other studies conducted by Parr et al (2020, 2021) was temporally offset from the traffic data by two weeks (that is, the COVID-19 case data is reported for the date two weeks prior to its posting). This was done to associate the extent of COVID-19 cases with the traffic conditions during the time when virus infections occurred. The Centers for Disease Control and Prevention (CDC) recommend this period to account for viral incubation and testing time (CDC 2020).

2.8. COVID-19 during Winter Months

Contaminations caused by many respiratory viruses, including influenza and some coronaviruses, increase during winter and decrease during summer (Mallapaty, S. 2020). An increased risk of transmission occurs when people interact indoors and in places with poor ventilation. Studies show that the COVID-19 virus favors dry, cold conditions. The virus degrades faster on surfaces in more humid and warmer environments. During the winter period, people will usually heat their houses and the air is dry and not well ventilated. The Director for Centers for Disease Control and Prevention (CDC) Robert Redfield predicted that the COVID-19 pandemic would take a severe turn for the worse during the winter months. (McEvoy, J. 2020). Robert Redfield stated that January and February will be the hardest time for the US, in all history of public health. Robert Redfield also predicted that the death toll rate would increase by 50,000 every two months, resulting in 450, 000 deaths by the end of February.

CDC released warnings and advised against traveling for Thanksgiving and the holidays. 9 million airport travelers were reported during the holiday period (Newburger, E. 2020). A

coronavirus task force coordinator from the White House, Dr. Deborah Birx, made a statement saying that the U.S. will be seeing a large increase in new COVID-19 cases, deaths and hospitalization in the whole country after the holidays. In Sweden, a second wave and peak are predicted to occur in the middle of December. (Folkhälsomyndigheten, 2020b).

3.0 Methodology

The data and methods used in this research followed similar work completed during the initial onset of COVID-19 in Florida (Parr et al 2020) and across the US (Parr et al 2021). By the late spring of 2020, COVID-19 had been diagnosed in every state of the US, and all countries of the world. From a public health standpoint, the manner and variation of where, when, and how the virus was occurring and spreading was of primary interest. While the virus was overwhelming health care systems in some states in the US and, more specifically some metropolitan regions (like New York City), it was having comparatively far less impact in others (like Montana). Clearly, one explanation for these differences was the high amount and density of the population in these areas. However, factors like the amount of interaction between people, levels of mobility, climate, and the availability of testing were likely also contributing to these differences.

This study compared 2020 daily traffic volumes to corresponding days (matched days of the week) in 2019 using a paired t-test in the US, China and Sweden. There was no distinction between vehicle types, and the traffic counts were aggregated over 24-hour periods. These three countries were chosen because of data accessibility, time availability, and because they all acted differently to the pandemic, giving the study a diverse outlook on the global effects of the pandemic. China is republic and reacted drastically to the pandemic, with uncompromising lockdowns, while Sweden had a more liberal action with more recommendations and advise. USA incorporate a mix of China's strictness and Sweden's leniency.

The comparison period for US and Sweden was one year. This to include the time of initial onset when government restrictions were first being implemented, reopening phases, and the actions taken at the end of the year. These dates were January 1 to December 31, 2020, and January 2 to December 31, 2019. China experienced the COVID-19 pandemic much earlier than

Sweden and the US. The comparison period for China was January 2 to April 30, 2019, and January 1 to April 28, 2020, to include the onset of the pandemic and as far into 2020 as possible. The traffic data for the rest of the year was not available.

A paired t-test was used to compare traffic on matching traffic sensors on matching days of the week 2019 to 2020. The null hypothesis was that there was no change in traffic between these two dates, that the true mean difference between the paired samples is zero. The alternative hypothesis was that the traffic was not equal, that the true mean difference between the paired samples is not equal to zero, and that there was a significant difference at a confidence level of 0.05 (5%). For example, the paired test was used to determine if the daily traffic in Sweden from Friday, May 31, 2019 was significantly different from the same detectors, on Friday, May 29, 2020.

In the US, a sample set of ten states were selected to comparatively assess the range of conditions and COVID-19 cases in this study (Figure 1), Florida, New York, Illinois, Indiana, Michigan, Montana, Massachusetts, New Hampshire, Ohio, and Vermont. While the inclusion of all 50 states would have been ideal to comprehensively illustrate and discuss every case, limitations in data availability and quality; its timeliness and spatial extent; and its ability to “representatively” reflect conditions, made it impractical. Although nearly all the states were in the eastern half of the country, they reflect diversity among relevant characteristics in the study, climate, population density, political parties, etc. Table 1 lists the states and summarizes key population, mobility and even broad political orientation characteristics.

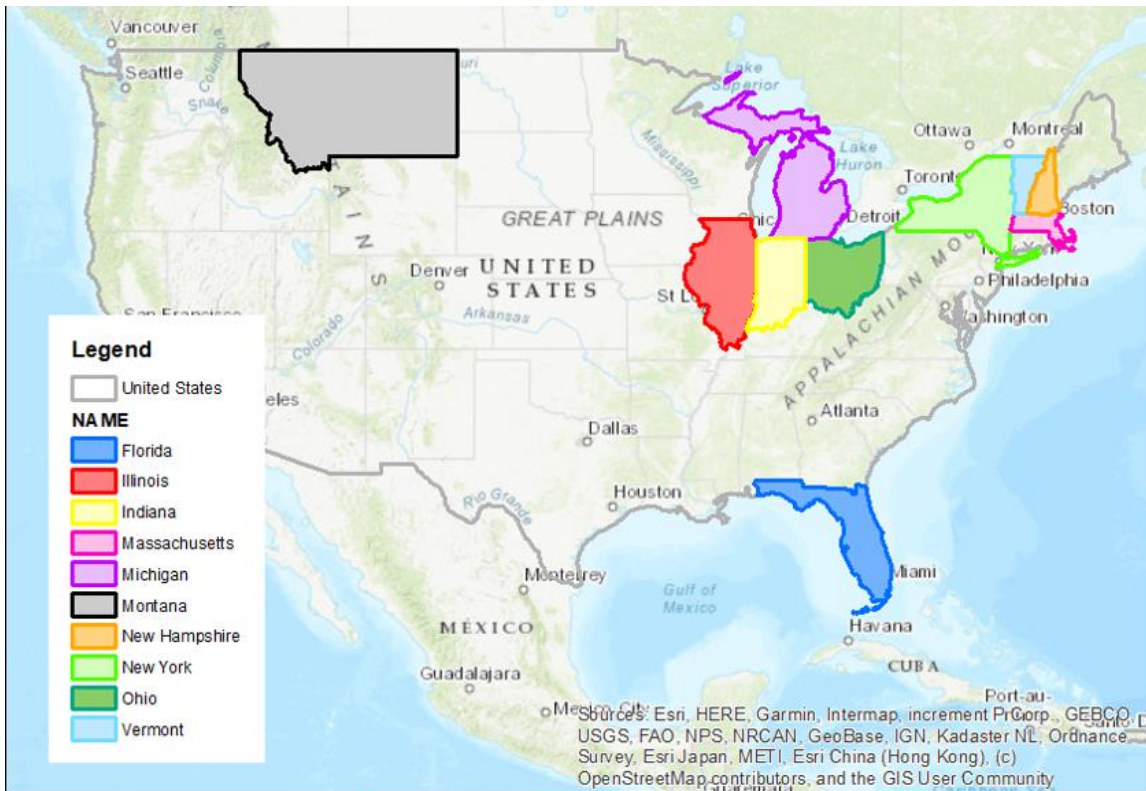


Figure 1 Chosen US States for Study

For China, two provinces were selected for analysis: Hubei and Zhejiang. Hubei was chosen because its capital, Wuhan, was where the COVID-19 was first identified. Zhejiang, with a similar population size, was chosen as a reference province to Hubei. Traffic data from Sweden was aggregated nationwide, because of its relatively small geographical size and population. Table 1 lists the countries and summarizes key population and mobility characteristics.

Table 1 Characteristics of Country Study Pool

Country	State/Province	Population	Population Density (people/mi ²)
USA	Florida	21,477,737 ^a	401 ^d
	Illinois	12,671,821 ^a	228 ^d
	Indiana	6,732,219 ^a	188 ^d
	Massachusetts	6,892,503 ^a	884 ^d
	Michigan	9,986,857 ^a	177 ^d
	Montana	1,068,778 ^a	7 ^d
	New Hampshire	1,359,711 ^a	152 ^d
	New York	19,453,561 ^a	413 ^d
	Ohio	11,689,100 ^a	286 ^d
	Vermont	623,989 ^a	68 ^d
China	Hubei	59,270,000 ^b	825 ^e
	Zhejiang	58,500,000 ^b	1436 ^e
Sweden		10,327,589 ^c	9.8 ^f

^aEstimate by US Census (2019), ^bNational Bureau of Statistics of China NBS (2019), ^cStatistics Sweden SCB

(2019); ^dStatista (2020a), ^eStatista (2020b), ^fStatista (2020c)

3.1. Traffic Data and Statistics

This study includes traffic data collected from US states' Departments of Transportation, the Swedish Transportation Administration, and the Ministry of Transport of the People's Republic of China.

3.1.1. US Traffic Data

The Federal Highway Administration (FHWA) in the United States mandates that every state department of transportation submit annual traffic statistics (FHWA 2014) as part of the National Highway Performance Monitoring System (HPMS). Transportation agencies in every state construct, operate, and maintain permanent traffic monitoring stations with the purpose of collecting traffic count information, among other measures. These stations are referred to as continuous count stations. To meet the federal requirements outlined by the HPMS, the traffic count detectors report hourly traffic counts continuously throughout the year, every year. The

states make their traffic count data publicly available through data requests (FL), through their websites (NY), or have permitted a third-party vendor to share HPMS data publicly online (IL, IN, MA, MI, MT, NH, OH, VT).

In the north-central part of USA, Illinois, Indiana, Michigan, and Ohio is located (Figure 3) and the states has 91, 56, 73 and 182 traffic detectors, respectively. Florida is located in the south east part of the US and has 276 traffic detectors (Figure 2). Montana is located in the north-western part of the US and has 91 traffic detectors (Figure 5). New York, New Hampshire, Massachusetts, and Vermont are located in northern part of the US on the east coast (Figure 4) and they have 137, 52, 82, and 32 traffic detectors respectively. The number of urban and rural detectors can be seen in Table 2.

Table 2 US States Urban and Rural Detectors

State	Urban Detectors ^a	Rural Detectors
Florida	120	95
Illinois	54	25
Indiana	14	30
Massachusetts	43	7
Michigan	31	34
Montana	14	73
New Hampshire	22	26
New York	17	118
Ohio	105	65
Vermont	5	24

^aAreas with a population that is greater than 5,000 is classified as urban (FHWA, 2018). All areas that do not fall into this category by the FHWA, or is classified as urban areas for the Census, are considered rural areas.

Number of Urban and Rural detectors are taken as the median number of observations during the study period.

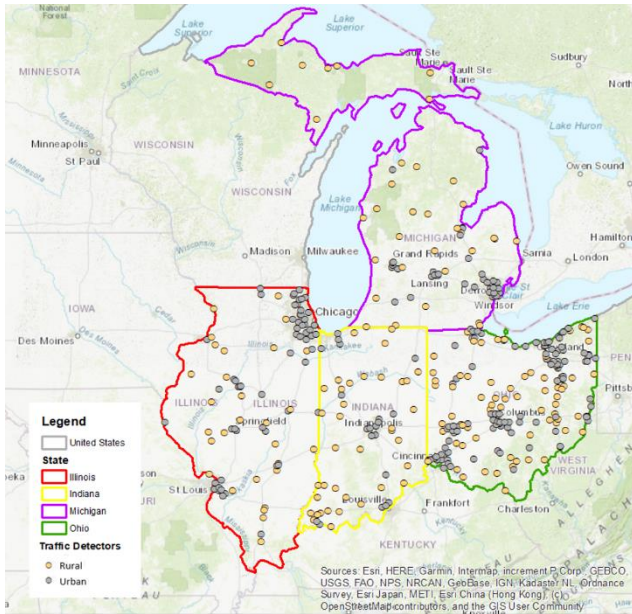


Figure 3 Illinois, Indiana, Michigan, and Ohio Traffic Count Stations

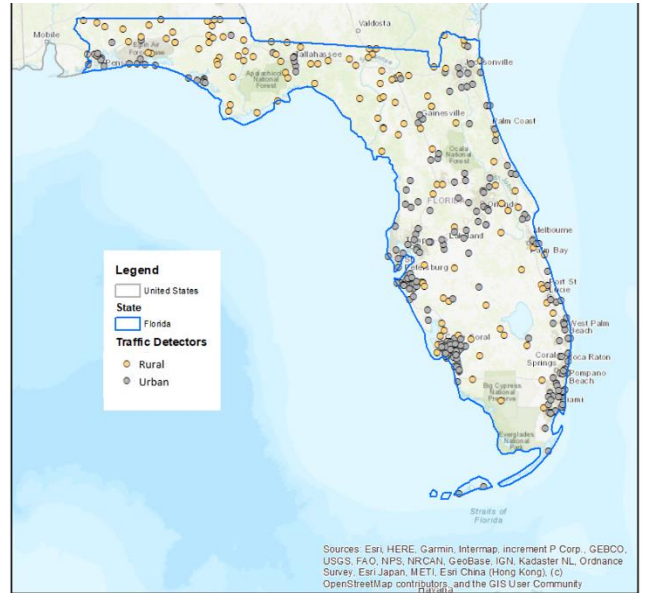


Figure 2 Florida Traffic Count Stations

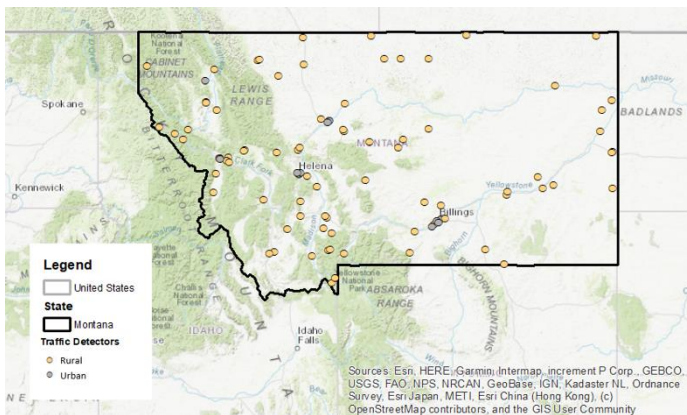


Figure 5 Montana Traffic Count Stations

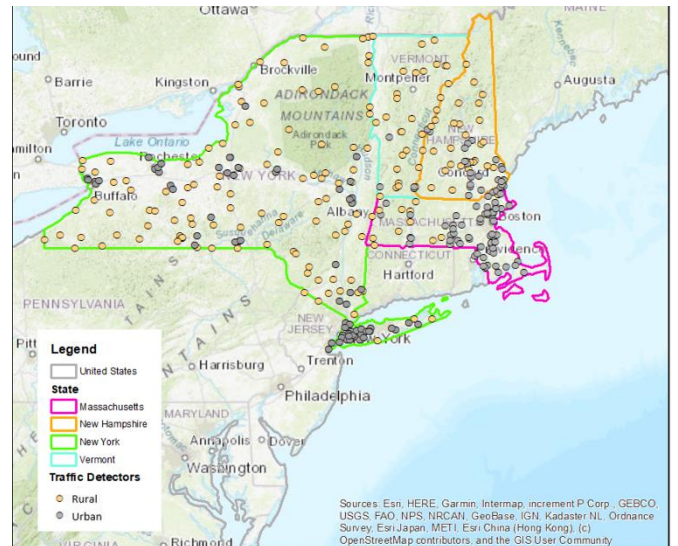


Figure 4 Massachusetts, New Hampshire, New York, and Vermont, Traffic Count Stations

3.1.2. Sweden Traffic Data

The Swedish Transportation Agency provides publicly available traffic count data. Similar to the US system, permanent count detectors record traffic continuously. The permanent count detector system consists of 92 detectors throughout Sweden (Figure 6) including five detectors in urban areas. An urban area in Sweden is by definition an area where a collection of houses consists of at least 200 habitants with less than 200 meters (656ft) between the houses.



Figure 6 Sweden Traffic Count Detectors

3.1.3. China Traffic Data

Traffic count data for Hubei and Zhejiang, China were obtained from the Ministry of Transport of the People's Republic of China (MOT). The MOT is an executive agency under the State Council and is responsible for road, water, and air transportation in China (Chinese Government Network, 2014). The MOT oversees a vast array of permanent highway traffic toll stations, which functions similar to traffic count stations, across China. The location of the traffic toll stations/count stations in Hubei and Zhejiang can be seen in Figure 7. Hubei consists of 256 traffic detectors, and Zhejiang has 425 detectors.

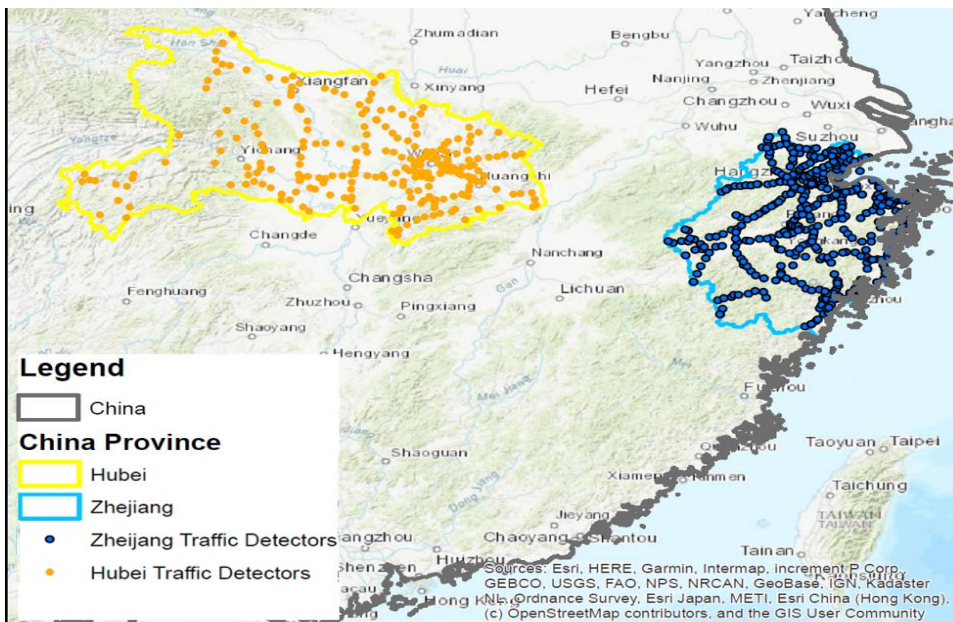


Figure 7: Hubei and Zhejiang Province Boundaries and Traffic Count Detector Locations

3.1.4. Traffic Data Error

A common error found in the traffic data from the US and Sweden, was missing data which was reported as a zero value from the station. The reason for the zero value may be road closures due to scheduled maintenance, incidents, or malfunctioning sensors. When missing data occurred in the dataset, the sensor was removed from consideration for that day, but still included in the analysis for other days when data was available. Some days were shown as “NaN” or “Null” values. These were similarly removed but later considered in the analysis when the data was available. This resulted in the daily number of observations varying. Only stations with paired data were included in the daily t-test analysis. There was also an error in some states where traffic data was completely missed from a full day. Those cases were not included in the paired t-test analysis but interpolated from the day before and the following day when comparing traffic volumes from 2019 and 2020. This occurred in New York, Michigan, and Vermont. When performing the paired two-sided t-test, the significance level of 0.05 was used for rejection of the null hypotheses. There were also cases where the t-test failed to reject the null hypotheses, suggesting that, on those days, the compared traffic in 2019 and 2020 was similar.

With regard to the data provided by the Ministry of Transport for China’s traffic detectors, missing data, data errors, and detectors reporting zero traffic were all reported as blank. Sensors that reported blank values on days when other nearby sensors reported high traffic counts were considered as data errors and/or missing data and were removed from consideration. The remaining blank values were assumed zero traffic counts and inputted as such when performing the paired t-test.

3.1.5. Urban/Rural Analysis

Sweden and the US have classified their count stations as either being located in Urban or Rural areas, no such data was available for China. These were sorted out from the data sets mentioned above, and then traffic counts were represented by 100 000 vehicles per day. On figures 2-6, the urban traffic detectors can be seen marked in gray and rural traffic detectors can be seen marked in orange. Data was sorted by rural traffic levels from 2019, rural traffic levels 2020, urban traffic levels from 2019 and urban traffic levels 2020. Florida and New York (State) did not classify their urban and rural areas for their count stations. A separate map with urban and rural areas were utilized (FDOT 2019 & NYDOT 2020) to categorize the traffic detectors. They were plotted using ESRI ArcGIS with the Latitude and Longitude given in the same dataset as mentioned above. Figure 8 shows New York (state) and Figure 9 shows Florida. Areas in yellow are urban areas. If the count stations were located within the urban area on the Urban Rural Map, they were classified as urban detectors. If they fell outside the urban area, they were classified as rural detectors. The daily traffic volumes for urban and rural roads, later shown in this thesis, are represented as 7-day moving averages (the average of the last 7 days) to eliminate daily irregularities and smooth out the data to provide a better understanding of weekly trends.

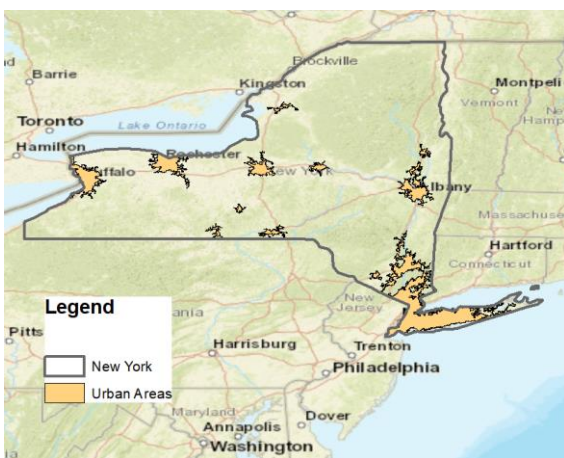


Figure 8 New York (State) Urban Area Map



Figure 9 Florida Urban Area Map

3.2. Health Data and Statistics

The coronavirus health-related data for China was obtained from the daily updates from Johns Hopkins University (Dong et al. 2020). The US Center for Disease Control reported the number of COVID-19 cases and deaths for all US states. The reasons for selecting this data set are scope, update regularity, and widespread use. The range of data used for US was January 22, 2020 to January 9, 2021 for the US. In China, the dates used were January 15, 2020 to March 8, 2021. The COVID-19 case data for Sweden was collected from the Swedish Health Agency (Folkhälsomyndigheten, 2020a) and the dates used were March 15, 2020 to January 13, 2021. The health case data periods included the earliest data that was available in 2020, all of 2020 cases, and a few days into 2021 to account for data offset.

The raw data for the US, China, and Sweden, from different sources, provided the cumulative number of reported COVID-19 cases. To obtain the daily number of reported cases, the differences between consecutive days were calculated. There were a few data inconsistencies identified in the Florida dataset. May 10, May 15, May 28, and November 27, 2020, all showed negative COVID-19 cases. These were assumed adjustments for previous day errors since you cannot have a negative number of COVID-19 cases. To adjust for these anomalies and produce the state total, the previous day's data was subtracted with these negatives, and then an average was distributed between these two dates. A similar error was encountered for NY on April 7, 2020 and corrected similarly.

In Illinois on September 4, 2020, Massachusetts June 1, 2020, and Michigan June 5, 2020, the COVID cases showed an abnormal increase compared to adjacent days. Illinois showed more than the double in number of cases, Massachusetts showed over 3000 more cases and Michigan

showed thousands more cases. These were considered to be reporting errors and adjusted by interpolating the case data for that day with adjacent days.

In China, the COVID-19 cases were not given for the full study period for the individual providences. For Hubei, the data was missing from January 15 to January 19. As a surrogate, COVID-19 case data from China was utilized since the pandemic started in Hubei; it was assumed that was where the COVID-19 cases occurred during early January. In Zhejiang, data was missing from January 15 to January 20. To fill this missing data, the numbers of COVID-19 cases were assumed to be zero. Even if there may exist a few cases during these dates, they would not affect the analysis, nor the peak of the COVID-19 curve.

In the graphs shown later in this paper, the daily COVID-19 cases are represented as seven day moving-averages to eliminate the day-to-day reporting and testing variations. They are represented as cases per million of population to better be able to compare countries and states to each other.

3.2.1. COVID-19 Case Offset

The health data has also been temporally offset from the traffic data. The reason for this was to associate the extent of cases to traffic conditions during the approximate time when the infection occurred. There are many other exposure possibilities that are not connected to vehicular travel and have been acknowledged.

To determine the number of days to offset reported new COVID cases for each individual state and country, a correlation analysis between number of daily cases and decrease in traffic from 2019 to 2020 was conducted. Correlation is the linear relationship between two sets of data. Correlation is measured by a value between +1 to -1, with ± 1 being the highest value of

correlation. When the correlation is +1, it means the two sets of data have a positive correlation and both of the data sets increase at the same rate. Whereas, when the correlation is -1, it means the two sets of data have negative correlation and one variable decrease while the other increases. Traffic decreases preceded a drop in COVID-19 cases. This traffic/COVID-19 relation is offset in time. By moving the COVID case curve, a date can be found where it correlates more to the traffic decrease, and this relation can be shown more clearly. The difference between that date and the reported date of COVID cases, is the number of days offset.

The correlation analysis was done by taking the percent decrease of traffic from first day of decrease until traffic reaches “bottom”, the lowest point of decrease. The same number of dates of Daily reported COVID cases were also gathered. These two were analyzed and a correlation value was obtained. Next, the COVID case data was offset by one day and these were then compared to decrease in traffic values to obtain a new correlation value. This was repeated by offsetting a total of 28 days, creating 29 different correlation values (including 0 days offset). The correlation value that was closest to -1, was the day offset that was used for that specific country or state. For example, Michigan’s first day of traffic decrease occurred on March 13, 2020. The state reached its traffic “bottom” on April 4, 2020. This gave 23 data points of traffic decrease. New COVID cases reported from March 13, 2020 to April 4, 2020 was the second data set. These datasets represent a 0-day offset and gave a correlation value of -0.778. Next, to offset 1 day, traffic decrease from March 13, 2020 to April 4, 2020 were compared to COVID cases from March 14, 2020 to April 5, 2020 and gave a correlation value of -0.797. This was repeated until 28-day offsets were conducted comparing traffic decrease from March 13, 2020 to April 4, 2020 to COVID cases from 10 April to 2 May 2020. The correlation value closest to -1, was -

0.916 for a 7-day offset. 7-day offset was then used for the whole study period in Michigan and represented on the graphs later in this thesis.

3.2.2. Initial Pandemic Cases

Before the COVID-19 virus was a public concern, the first three COVID-19 cases in the US, Sweden, and China, occurred well in advance of the other cases. Table 3 shows the dates of the first three COVID-19 cases in the study group. This distribution of dates for the first infection differed between countries. China’s cases appeared first (in January) and all three cases were identified on the same day for each province. Sweden’s first case appeared at the beginning of February and the second and third case occurred at the end of February one day apart. The first case in the US states occurred in Illinois at the end of January. Massachusetts got their first case at the beginning of February but did not have their second and third case until beginning of March. All other States had their first case in the first third of March with their second and third case occurring within the next couple of days. Last was Montana with its first COVID case March 11 and its third case March 15.

Table 3 First Three Confirmed COVID-19 Infection Dates

Country	State/Province	First COVID-19 Case	Second COVID-19 Case	Third COVID-19 Case
USA	Florida	2-Mar	3-Mar	5-Mar
	Illinois	24-Jan	30-Jan	1-Mar
	Indiana	6-Mar	8-Mar	9-Mar
	Massachusetts	1-Feb	3-Mar	6-Mar
	Michigan	10-Mar	10-Mar	12-Mar
	Montana	11-Mar	15-Mar	15-Mar
	New Hampshire	2-Mar	3-Mar	8-Mar
	New York	2-Mar	3-Mar	4-Mar
	Ohio	10-Mar	10-Mar	10-Mar
	Vermont	8-Mar	12-Mar	14-Mar
China	Hubei	17-Jan	17-Jan	17-Jan
	Zhejiang	21-Jan	21-Jan	21-Jan
	Sweden	4-Feb	26-Feb	27-Feb

3.3 Governmental Directive Dates

Data on Governmental directives, closures, and re-openings were gathered from news articles, press conferences, executive orders, and official websites. The dates in the US for State of Emergency (SOE) declarations, statewide closures of schools (Sch. Closed) and restaurants (Rst. Closed) reopening phases (Phase 1 through 5), and further restrictions (Restrict)) are shown in Table 4. Some states did not have all 5 phases of reopening as part of their reopening plan; therefore, those are represented as N/A in Table 4. Florida did not make any new restrictions after reopening phases, which is also represented by N/A.

Table 4 Key COVID-Related Closing and Opening Dates in the US

State	SOE	Sch. Closed	Rst. Closed	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Restrict
Florida	9-Mar	13-Mar	20-Mar	18-May	5-June	25-Sept	N/A	N/A	N/A
Illinois	9-Mar	13-Mar	17-Mar	1-May	29-May	26-june	N/A	N/A	26-Aug: Restrictions 20-Nov: Restrictions
Indiana	6-Mar	19-Mar	16-Mar	4-May	22-May	11-june	26-sept	N/A	15-Nov: Restrictions 10-Dec: Restrictions
Massachusetts	10-Mar	17-Mar	17-Mar	18-May	8-June	6-July	N/A	N/A	6-Nov: Restrictions 13-Dec: Phase 3 22-Dec: restrictions
Michigan	10-Mar	16-Mar	16-Mar	7-May	1-June	10-June	N/A	N/A	2-Oct: Phase 2 27-Oct: Restriction
Montana	12-Mar	16-Mar	21-Mar	27-April	1-June	N/A	N/A	N/A	18-Nov: restriction.
New Hampshire	13-Mar	16-Mar	16-Mar	18-May	15-June	29-june	24-aug	N/A	15-Oct: restriction
New York	7-Mar	16-Mar	16-Mar	8-June	19-June	6-july	20-july	N/A	9-Oct: restriction. 13-Nov: restriction 14-Dec: restriction
Ohio	9-Mar	16-Mar	16-Mar	12-May	22-June	25-aug	N/A	N/A	19-Nov: Restriction
Vermont	13-Mar	18-Mar	17-Mar	17-April	22-May	8-june	10-july	18-sept	17-nov: restriction

The Chinese Emergency System defines four levels of emergency. Level 1 is an “extremely serious incident”. Under a Level 1 emergency, the government implements the strictest control measures, such as travel restrictions, “stay at home” orders, school and entertainment venues closures, and public gathering bans. Provincial governments must implement the control measures under the national government’s command. Level 1 was considered when there were positive COVID-19 cases and corresponds to Response Stage 1 (R.S.1). Level 2 is a “serious incident”. The provincial governments coordinate all prevention and control measures. Restrictions are slowly being lifted, and people can return to work. The provincial governments coordinate all prevention and control measures. This occurs when there have been no confirmed COVID-19 cases for a week and corresponds to Response Stage 2 (R.S.2). Level 3 is a “relatively serious incident,” and the municipal governments (city) coordinate all prevention and control measures. This occurs after Level 2, when there has been a longer period of no new COVID-19 cases. The dates of response stages and severity level can be found in Table 4 (National Health Commission of the People’s Republic of China, 2020).

Table 5 Key COVID-Related Response Stages and Severity Levels in China

Province	Response Stage 1		Response Stage 2	
	Start from	Level	Start from	Level
Hubei	1/22, 1/24	II, I	5/1	II
Zhejiang	1/23	I	3/3	II

The Swedish governmental directives were generally recommendations and advisory and not enforceable, unless otherwise noted (Folkhälsomyndigheten, 2020c). In 2020, the major announcements were as follows.

- March 11: Public gatherings were limited to no more than 500 people. WHO declared COVID-19 as a pandemic
- March 14: Nonessential travel to countries outside Sweden was not recommended
- March 16: Companies that can, should work from home
- March 17: Academic institutions, high schools, college, and universities were advised to do distance learning
- March 19: All non-essential travel into Sweden was forbidden except members of European Economic Area (EES) who wished to return to their home country or was exempt from restrictions. Non-necessary travels within Sweden were advised to be canceled
- March 24: Restaurants, cafés and bars received new guidelines and rules, adhering to social distancing.
- March 27: Public gatherings were limited to 50 people
- April 1: Recommendations were issued against public gatherings and to maintain social distance. People over 70 years old and in the risk-group were advised to stay home. The number of people in stores, and shopping malls were limited so that social distancing could be performed. Athletic organizations were advised to hold practice outside with limited fans. Public transport continued but limited the number of passengers so social distancing could be maintained.
- June 14: Sports competitions and games were permitted. Trips within Sweden for athletes to games were permitted.

- June 15: The recommendations for distance learning were withdrawn.
- June 30: Travel restrictions to countries within the EU, EES and Schengen were lifted.
- October 29: Decision to strengthen recommendations for the public in certain districts in Sweden
- November 3: New recommendations to restaurants and cafes
- December 3: High schools go virtual for rest of semester
- December 18: Stores are recommended to refrain from sales event during holidays
- December 22: Social gathering limited to 4 people
- December 26: 2nd strain of COVID found in Sweden
- December 27: First dose of vaccine administrated
- December 30: Facemask are recommended to be worn while traveling on public transit

4.0 Findings

The pandemic infections and the traffic volume trends during the first year of the pandemic in the US, China, and Sweden, were analyzed both on individual and collective like-combinations of metrics. These results are presented and discussed statistically and graphically. The graphical comparisons are discussed in the following section and figures. The figures illustrate comparative levels of impact and overall trends in the three countries, including all three key parameters in the study: traffic volumes, COVID-19 cases, and governmental directives. The general hypothesis in this paper was that government restriction would reduce travel, which would reduce person-to-person interaction. Then this decrease would slow the progression of the virus, as shown by the traffic and COVID-19 metrics. Since some holidays are bound by a specific date, and not the day of the week, these dates tend to show major increases and decreases of the difference in traffic volumes.

4.1 COVID-19 Case Data Offset

The correlation analysis produced correlation values for each states' and country's' 0 to 28 days offset. The highest correlation value (C) can be seen in Table 6 together with the corresponding number of days offset. The closer the correlation value is the -1, the higher the correlation between the COVID-19 cases and a decrease in traffic. The highest correlation value was for New York (State) with -0.947 for 5 days offset. The lowest correlation value was Sweden with -0.336 for 13 days offset. Among the individual state/countries, highest correlation value and average of 5-days offset and median of 6-days offset were determined. The days offset with the highest correlation value, as seen in the table, is the day that is further used for the individual country/state in the figures and results outlined in this section. The health data collected for each state and country is offset by the result outlined in Table 6.

Table 6 Individual Days Offsets & Correlation Values

State/Country	Days Offset	Highest C
Montana	0	-0.559
Illinois	0	-0.945
Zhejiang	0	-0.804
Vermont	2	-0.838
Florida	5	-0.781
New York	5	-0.947
Ohio	6	-0.945
Indiana	6	-0.874
Massachusetts	6	-0.883
Michigan	7	-0.915
Hubei	8	-0.832
New Hampshire	9	-0.835
Sweden	13	-0.336
Average Days Offset	5	-0.807
Median Days Offset	6	-0.838
Highest Correlation (New York)	5	-0.947

Figure 10 shows the highest correlation value corresponding to the days offset for the individual states and countries. The x-axis shows days offset, the y-axis shows number of states/countries. Three states/countries showed 0 days offset, three other states/countries showed six days offset for highest correlation value, and two countries/states showed five days offset. The rest of the states and countries were spread out individually across two days, seven days, eight days, nine days and 13-days offset.

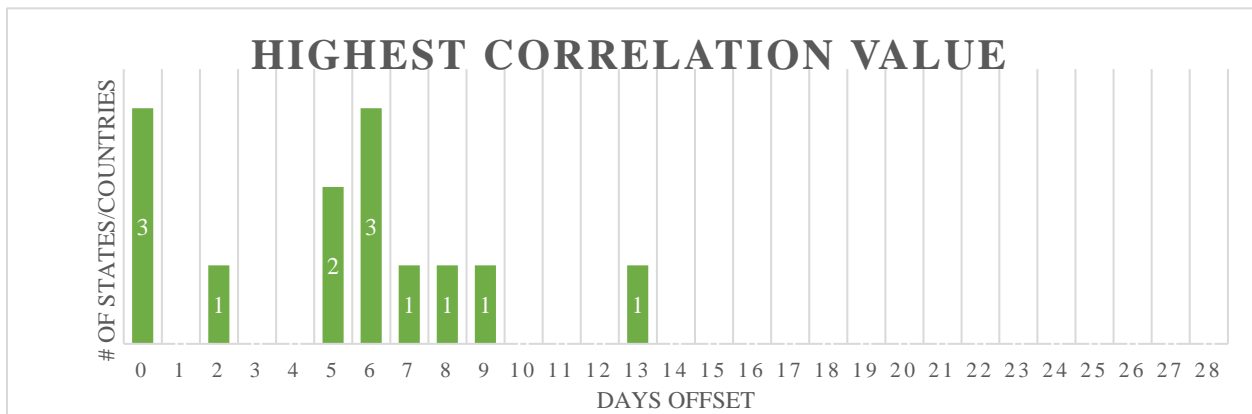


Figure 10 Highest Individual Correlation Value

When looking at the total result across all states, providences and countries, 0-days to 28-days offset, the correlation values varied as seen in Figure 11. Here the average (light green) and median (dark green) correlation value (y-axis) for each day offset (x-axis) have been plotted. The highest correlation for the average values were detected at 1-days offset at a value of -0.705. The highest correlation for median values was detected at 5-days offset at a value of -0.781. Comparing the median and the average values, the highest correlation occurred at a 5-day offset for the median values.

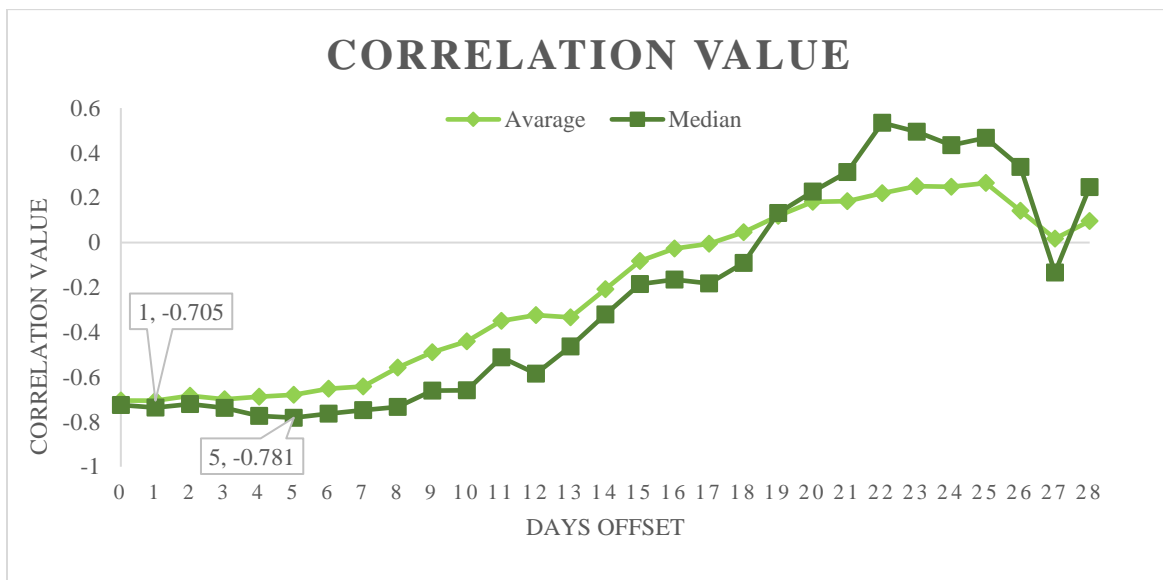


Figure 11 Average & Median Correlation Value

4.2 Daily Traffic 2020 vs 2019, New COVID-19 Cases, & Directives

Figure 12 through Figure 18 represent the percentage change in traffic observed between 2020 and 2019, for corresponding days-of-the-week in Sweden, China and the US. A paired t-test, with significance level of 0.05, indicated the dates on which traffic was significantly different between years. Significantly, different days are shown with orange asterisks, and similar days are shown with green circles. The lower right corner of each figure shows the minimum (Min), maximum (Max), median (Med), and standard deviation (StDev) for the traffic

detectors (Obs.) used in the daily *t*-test analysis. The percent change in vehicles between 2019 and 2020 is shown on the primary y-axis while the number of daily COVID-19 diagnosed cases per million people is provided on the secondary y-axis. The diagnoses are offset by a number of days following the correlation analysis result in Table 6, shown in the secondary y-axis label, to account for testing time and viral incubations, and represented as seven-day moving-averages.

4.2.1. Sweden 2020 vs 2019 Daily Traffic, New COVID-19 Cases, & Directives

Sweden (Figure 12) showed a persistent and even increasing number of COVID-19 infections until reaching the first peak in April. Traffic did not show a sustained and consistent decrease until March 14, when school and business restrictions were advised. The major decrease occurred after the Swedish Health Agency published a travel advisory. Eventually traffic reduced to just 50 percent of the prior year's level, on April 10. However, traffic never really stabilized but fluctuated. Several days (April 17, April 20, May 28, May 29, June 5, June 9 and June 11) showed that traffic was not significantly different between years. COVID-19 cases reached a second peak on June 5, and then slowly started to decrease. When the cases started to decrease traffic returned to 2019 levels and similar days, except for a few instances during Saturday and Sundays (June 27 & 28, July 4 & 5, July 11 & 12, July 25 & 26, August 22 & 23, and August 30). At the beginning of September COVID-19 cases started increasing again, reaching a third peak December 15. When the cases had reached new record high, local recommendations were once again enforced, and public gatherings limited to eight people, traffic started decreasing once again reaching negative 29 percent traffic values compared to 2019. At the end of the study period, traffic had not return to normal levels and showed a 21 percent decrease before the holidays started.

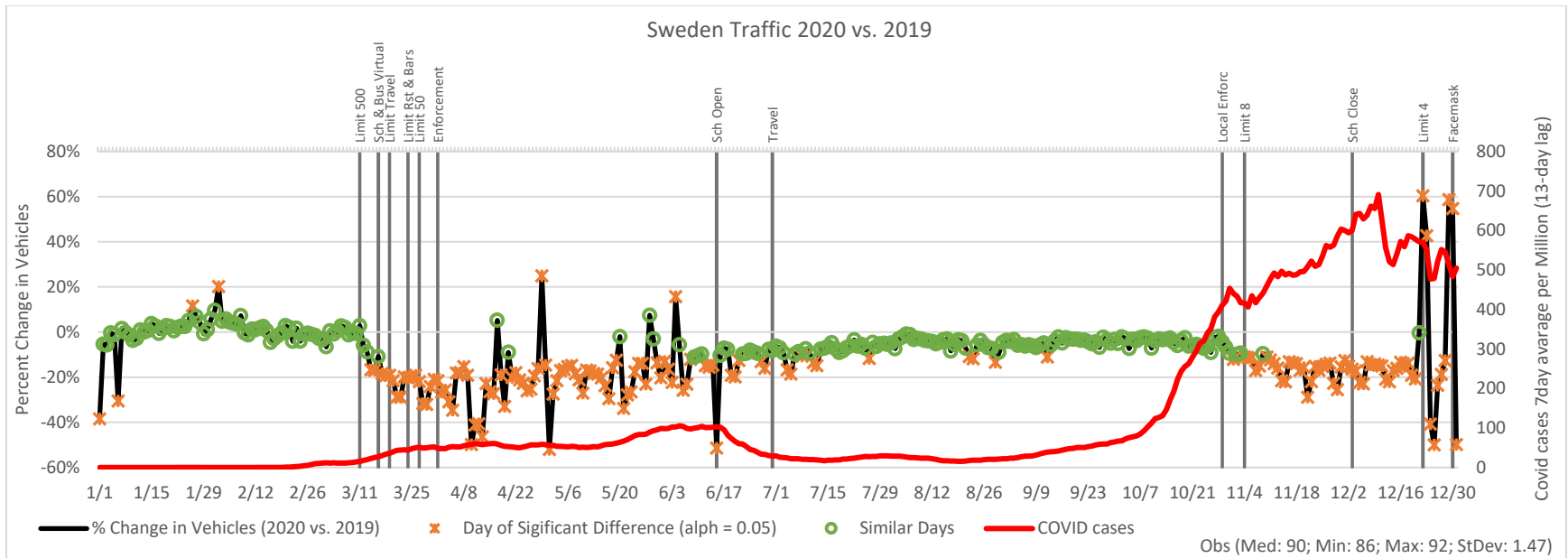


Figure 12 Sweden Daily Traffic 2019 vs 2020, New COVID-19 Cases, Directives

4.2.2. China 2020 vs 2019 Daily Traffic, New COVID-19 Cases, & Directives

In Hubei province, the COVID-19 cases increased significantly beginning in January and reached a peak on February 5 (Figure 13). In Hubei, a Level 2 “Serious Incident” was declared on January 22. On the next day, a significant and sustained drop in traffic across the province began. On January 24, the Level 2 incident was upgraded to a Level 1 “Extremely Serious Incident” and traffic levels continued to decline. By January 30, traffic across the province dropped to nearly zero. While the figure only shows percent change, the raw data show little if any traffic moving in Hubei province by the start of February. Traffic remained at or near zero until mid-March, when a small rise in traffic was observed. This increase was short lived, as the traffic volume again fell to near zero. This short-term raise followed by a drop of traffic maybe due to the missing of data during March to May in Hubei Province as there could be a raise of traffic data since March 20, 2020. Hubei reported zero new cases since Mar 19, 2020 and all the cities in Hubei province except Wuhan lifted lockdown on March 25, 2020. Large traffic increases were seen in both Chinese provinces by the end of the study period. Traffic did not return to Hubei until May 1, when the Level 1 incident was downgraded to a Level 2, and by May 16, traffic appeared to have returned to pre-pandemic levels.

Reported COVID-19 cases in Zhejiang province (Figure 14) showed a similar pattern to Hubei. The first cases were reported on January 21, prompting a Level 1 “Extremely Serious Incident” declaration on January 23. COVID-19 cases reached a province-wide high on February 3, 2020 and then began a precipitous decrease. By the end of February, the 7-day rolling average of reported COVID-19 cases was near zero, and with a few brief periods of new cases, reports of COVID-19 infections remained relatively low for the remainder of the analysis period. Traffic in Zhejiang began a downward trend on January 11, but substantial changes in traffic were not

observed until January 21. By the start of February, traffic was down 94 percent, reaching a minimum on February 7, when traffic was reduced by over 98 percent from 2019. Traffic steadily increased throughout February, where it then stabilized at an approximately 60 percent reduction for much of March and April. On March 3, the incident level was downgraded to Level 2 and by April 25, traffic had exceeded pre-pandemic levels.

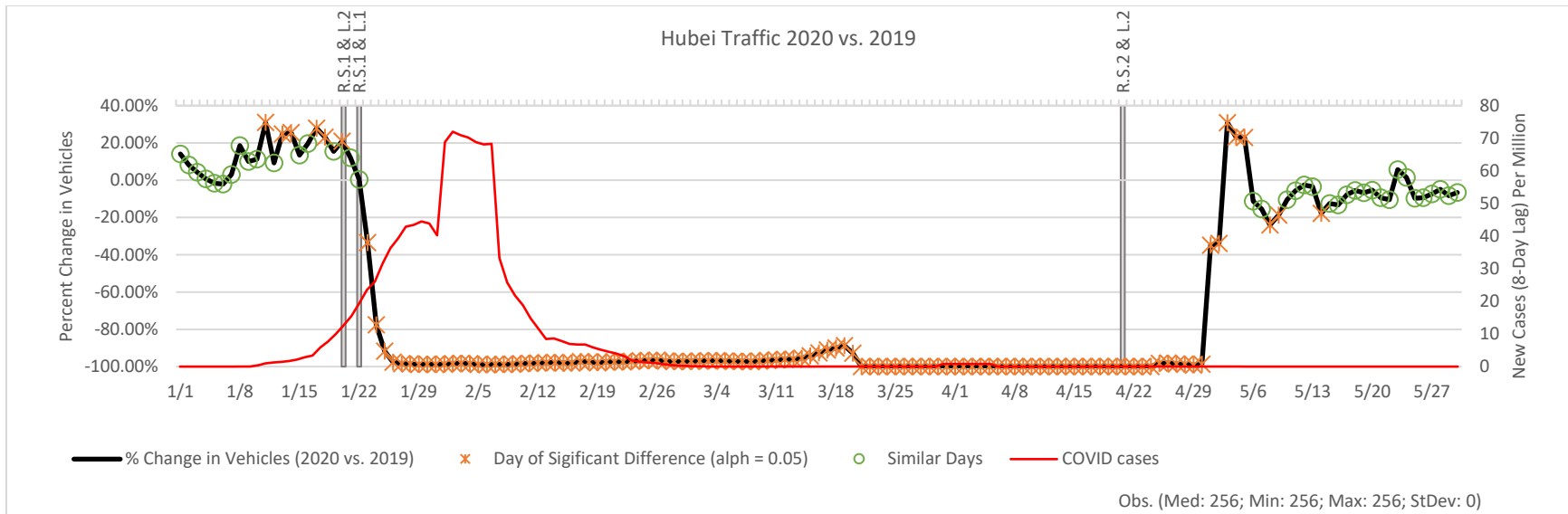


Figure 13 Hubei, China, Daily Traffic 2020 vs 2019, New COVID-19 Cases, and Directives

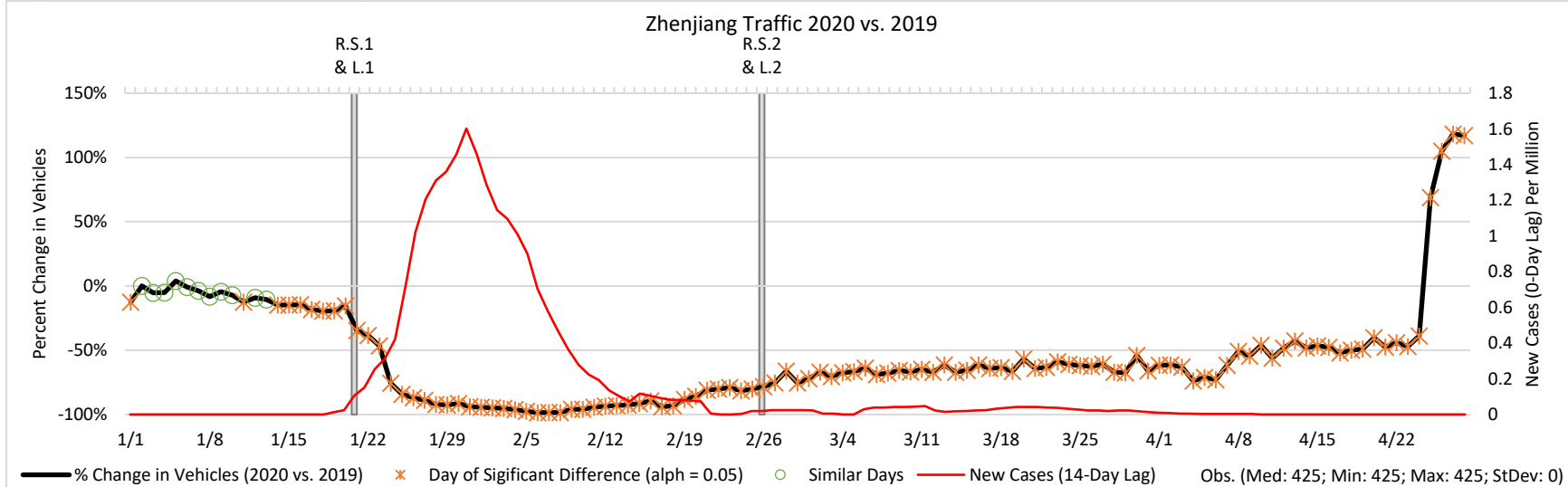


Figure 14 Zhenjiang, China, Daily Traffic 2020 vs 2019, New COVID-19 Cases, Directives

4.2.3. US 2020 vs 2019 Daily Traffic, New COVID-19 Cases, & Directives

The result for the 2020 vs 2019 daily traffic in the ten states in the US are shown in Figure 15 through Figure 18 . Figure 15 shows the south-east state, Florida, Figure 16 shows the north-east states, New York (a), Massachusetts (b), Vermont (c), New Hampshire (d), Figure 17 shows the north states, Indiana (a), Michigan (b), Ohio (c), and Illinois (d), and Figure 18 shows the north-west state, Montana.

4.2.3.1. South-East US: Florida

Figure 15 showed that sustained traffic reductions across Florida began March 18, 2020. Public schools were closed on March 14 and restaurants followed on March 20, as traffic was reduced by 27 percent. Traffic in Florida reached a minimum value on April 5. After which traffic began to increase across that state. On May 18, Florida entered Phase 1 of reopening, which was followed, 10 days later, with a sharp increase in daily COVID-19 cases. At the beginning of June, traffic returned to normal levels and soon thereafter they reached the second peak of COVID-19, a peak that was remarkable larger than any other state or country, on July 11. As COVID-19, cases once again started decreasing and traffic returned to normal levels in the beginning of August and remained similarly to 2019 levels until the end of the study period. Beginning of October Covid-19 cases started increasing once again, reaching a third peak at the end of December, and seem to still be climbing. Florida was the only US state that remained at normal traffic levels and did not experience a decrease in traffic at the end of the study period. Florida was also the only state/country that did not initiate any more restrictions or lockdowns when the COVID-peak at the end of the year started.

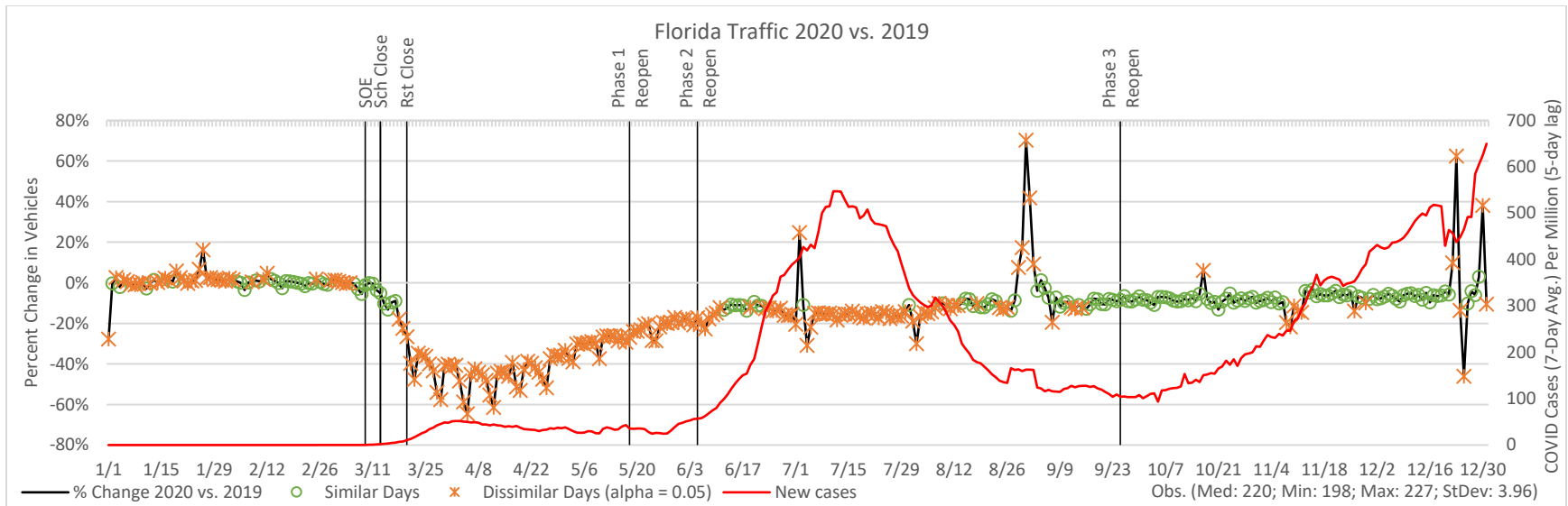


Figure 15 Florida, US, Daily Traffic 2020 vs 2019, New COVID-19 Cases, and Directives

4.2.3.2. North-East US: New York, Massachusetts, Vermont, New Hampshire

Figure 16 a showed that New York State sustained a significant change in traffic beginning March 14, 2020. This occurred just prior to school closures on March 16 and by March 18, when restaurants were ordered closed, traffic statewide was reduced by 25 percent from prior year levels. Traffic reached its minimum (62 percent reduction) on Sunday, April 4 and appeared to begin to increase starting April 14. Daily COVID-19 cases reached their maximum on April 5 and then began a sharp and sustained decline. A general trend of increased traffic persisted, and traffic reached above a 20 percent decline soon after Phase 1 and Phase 2 reopening was initiated in mid-June. After Phase 4 reopening on July 20, traffic was still showing a significant difference, but the decrease was only around 10-20%. Traffic reached normal 2019 levels beginning of October. Once this happened, COVID-19 levels started to increase, and New York initiated more enforcements and restrictions. This did cause traffic to decrease and only a few days in November and December showed normal levels. At the end of the study period, COVID-19 cases were still increasing and reaching record high levels similarly to Florida.

Figure 16 b shows the traffic trends in Massachusetts. Third COVID case was detected at the end of February but didn't start increasing rapidly until end of March. Traffic started decreasing on March 12, 2 days after the state of emergency. Traffic reached bottom on March 29, with a decrease of 67 percent compared to 2019 levels. COVID reached its first peak on April 7, and steadily started decreasing after that. Traffic slowly increased and when it was only down 15-20 percent at the beginning of June, COVID cases started increasing again. Massachusetts reached a small second peak August 8, and a small additional decrease in traffic was noted. Beginning of September COVID-19 cases started gradually increasing, with a rapid increase starting at the end of October. Massachusetts initiated restrictions on November 6 resulting in traffic decreasing and

a slight plateau in the COVID-19 cases curve. End of November COVID-19 resumed its increase in cases and Massachusetts reached a third COVID-19 peak on December 3. Traffic remained around a 30% decrease compared to 2019 levels with only a few irregular days of normal levels, a trend that remained until the end of the study period. COVID-19 cases seem to continue to increase after the third peak reaching new records similarly to New York and Florida.

Figure 16 c shows the traffic and COVID-19 case trends during 2020 in Vermont. Vermont detected their first COVID-19 case on March 6 and enforced a state of emergency on March 13. On the same day, traffic started decreasing reaching its bottom on March 29 with a 66 percent decrease. The first COVID peak happened on April 8, and once cases were rapidly decreasing, Phase 1 Reopening was initiated (April 27) and traffic started increasing. After Phase 2 Reopening on June 1, Traffic started reaching above a 20 percent decrease and COVID reached slightly higher levels, with a 2nd peak on June 8. Phased reopening continued to occur and traffic slowly climbed higher and higher. A few days of normal levels occurred at the beginning of September, and a few sporadic once from October throughout the study period. During this period, traffic was only down a few percent and COVID-19 cases started climbing once again. Restrictions were enforced on November 17, leading to a decrease in traffic and a halt to the increase in cases. Soon thereafter cases started increasing again, reaching a third COVID peak on December 6. COVID-19 cases started decreasing after that. At the end of the study period started increasing again, but to lower cases than the third peak. At the end of the study period traffic had not returned to normal but showed a negative 13 percent decrease compared to 2019 levels

Figure 16 d represents New Hampshire during the study period. First COVID case was detected on February 22 and first traffic decrease occurred on March 10, a few days prior to the state of emergency (March 13) and Closure of schools and restaurants (March 16). After these

government directives traffic dropped considerably reaching a bottom on March 29 (62 percent decrease). COVID-19 cases peaked a month later on April 28 as traffic levels were still below 40 percent decrease. On May 18, Phase 1 Reopening was initiated, and traffic increased above 1 20 percent decrease and continued to increase as Phase 2 Reopening occurred and Phase 3 Reopening. COVID started slightly increasing after Phase 3 Reopening (June 29) reaching a small second COVID-19 peak on July 19. After that, COVID-19 cases resumed to decrease. On August 24, New Hampshire initiated Phase 4 Reopening and traffic resumed similar levels to 2019 for until mid-September. Beginning of October also experienced a couple of days of similar traffic levels. After Phase 4 reopening, cases started once again increasing, and on October 15 further COVID-19, restrictions were put in place. A slight decrease in traffic can be noted on the figure after these directives, but COVID-19 continued to increase. COVID-19 reached its peak on December 4 and traffic went down to a 20 percent decrease and no longer showed any similar days of traffic throughout the rest of the study period. After the peak, new cases were declining until mid-December and then picked up again. At the end of the study period cases were close to the third peak levels once again

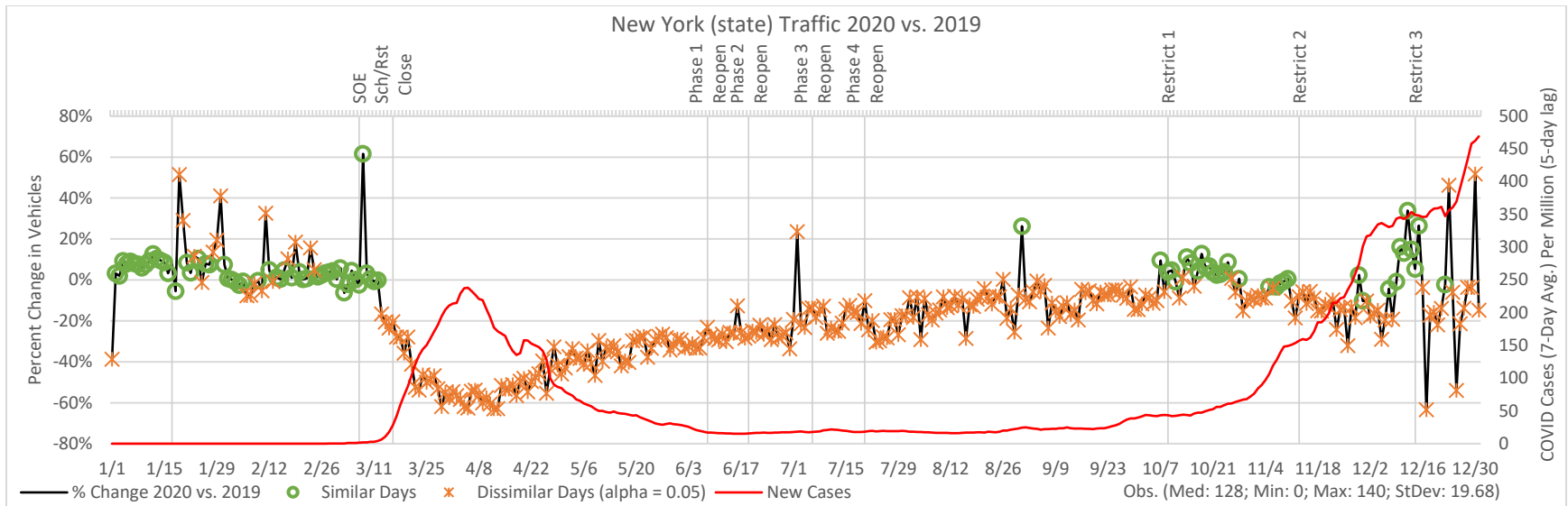


Figure 16 a North-East US: New York, Daily Traffic 2020 vs 2019, New COVID-19 Cases, Directives

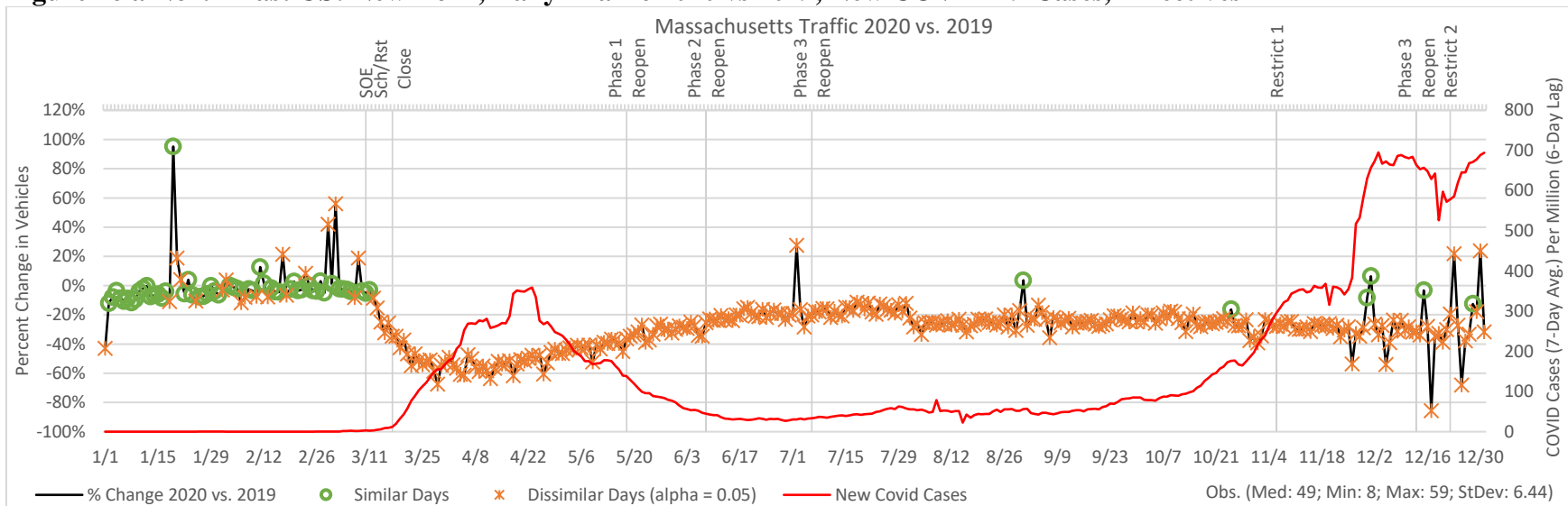


Figure 16 b North-East US: Massachusetts, Daily Traffic 2020 vs 2019, New COVID-19 Cases, and Directives

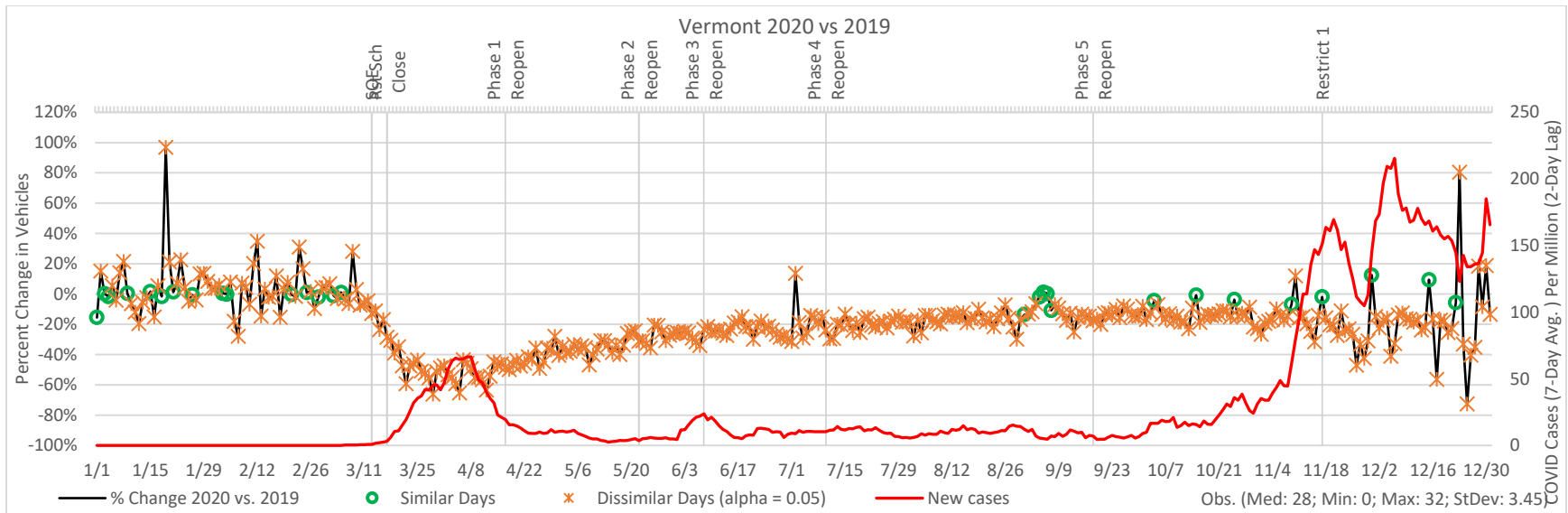


Figure 16 c North-East US: Vermont, Daily Traffic 2020 vs 2019, New COVID-19 Cases, Directives

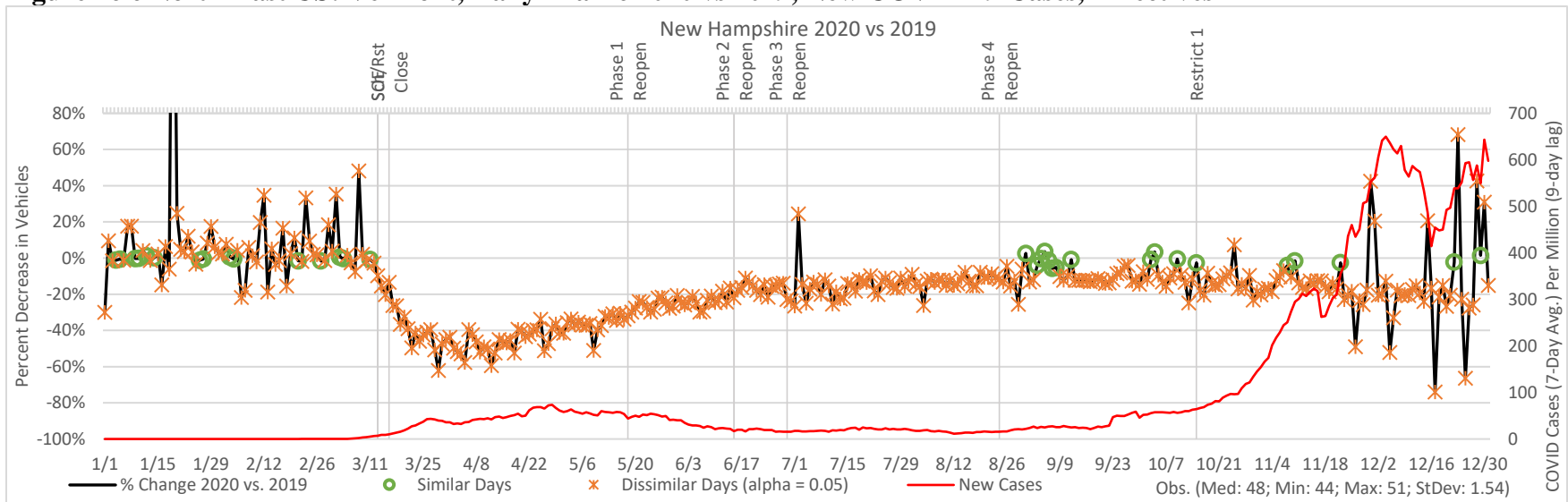


Figure 16 d North-East US: New Hampshire, Daily Traffic 2020 vs 2019, New COVID-19 Cases, Directives

4.2.3.3. North US: Indiana, Michigan, Ohio, and Illinois

Indiana Traffic and COVID-19 cases are shown in Figure 17 a. Indiana detected their third COVID-19 case on March 3 and imitated a state of Emergency on the same day. Traffic started decreasing on March 10 and reached its bottom on April 12 with a 59 percent decrease. The first COVID peak happened on April 27, and then started to decrease. Traffic started increasing and even more so when Phase 1 Reopening was imitated (May 4). After Phase 2 Reopening on May 22, Traffic started reaching above a 20 percent decrease and COVID reached slightly higher levels, with a 2nd peak on June 8. Phased reopening continued to occur and traffic slowly climbed higher and higher as COVID decreased. After Phase 3 reopening on June 11, Traffic was only down with about 10 percent and COVID cases started increasing again. Beginning of August traffic experienced a few days of normal traffic levels and a second COVID peak on August 24. Phase 4 Reopening happened September 26 and COVID-19 levels started rapidly increasing. A few sporadic days of normal traffic levels were noted until November 15 when Restrictions were put in place across the state. A slight decrease in traffic can be seen with a few days showing a 20 percent decrease. COVID-19 cases also started decreasing, but a few weeks later picked up again, for a third COVID-19 peak on November 30. After that, COVID-19 started decreased and remained decreasing after more restrictions were put in place. The end of the study period showed traffic with 17 percent decrease and 2 instances of normal traffic.

Figure 17 b represents Michigan during the study period. The first COVID-19 case in Michigan was detected on February 26. It took until March 10 for a state of emergency to be declared and traffic did not start decreasing until March 13. Traffic reached bottom on April 4 with a 65 percent decrease, a few days after the first CPVOD-19 peak (April 1). Traffic remained low until end of April when it started increasing. Once Phase 1 reopening occurred on May 7,

traffic increased more and reached above a 20 percent decrease after Phase 3 reopening (June 10). At this point COVID-19 cases started increasing instead of decreasing, reaching a second peak on August 21. Leading up to this point traffic had remained significantly different from 2019, but September forward, sporadic instance of similar days of traffic occurred. Beginning of October COVID-19 cases were rapidly increasing, and Michigan returned to Phase 2 Reopening (October 2). This resulted in a small decrease in traffic, but still a few days with normal levels. On October 27, Michigan issued further restrictions and Traffic started decreasing more, reaching a 39 percent decrease at the end of November. COVID-19 reached its third peak on November 26, and with the continued large decrease in traffic, number of new COVID-19 cases was declining. At the end of the study period, traffic levels had not returned to normal, and a slight increase in COVID-19 cases can be seen, but levels still lower than their third peak.

Traffic and COVID-19 cases in Ohio are shown in Figure 17 **cFel! Hittar inte referenskälla..** First COVID-19 case was detected on March 4 and a few days later state of emergency were declared (March 9). The day after, traffic started decreasing reaching bottom on April 5 (59 percent decrease). The first peak of COVID occurred on April 1, and after that, cases started to decrease. A light increase in traffic can be seen at the end of April, but after Phase 1 reopening on May 12, traffic increased rapidly. End of May COVID-19 cases started climbing again reaching the second peak of COVID on 28 of June, 6 days after Phase 2 Reopening occurred (22 June). At this point traffic had less than 20 percent of a decrease. COVID-19 started decreasing and traffic levels remained the same until Phase 3 Reopening on August 25. The traffic was only at about a 10 percent decrease and at the beginning of September COVID-19 cases once again started increasing. COVID-19 reached a third peak on November 23, 4 days after Ohio enforced further restrictions in the state. After that, COVID-19 cases and traffic

decreased. Traffic hit a 36 percent decrease, the lowest it has been for almost 3 months. COVID-19 continued decreasing throughout the study period with a slight increase at mid-December, and traffic volumes stayed low. Ohio was the only state that did not experience any days of similar traffic volumes to 2019. Michigan and Massachusetts are the only states that are similar to Ohio, but they experienced a few sporadic days of similar traffic volumes.

Illinois Traffic and COVID-19 cases are represented in Figure 17 d. Illinois experienced their first COVID-19 case on January 24 and initiated a state of emergency little more than one week after, on March 9. Traffic started decreasing that same day, reaching bottom on March 22 at 65 percent decrease. COVID-19 reached its initial peak on May 4 a few days after Phase 1 reopening (May 1). Illinois was the state that started their Phased reopening first and COVID-19 cases did not start decreasing until end of May. After Phase 1 reopening, traffic showed a slight increase, climbing from below a 40 percent decrease to over a 20 percent decrease. Traffic continued to increase as Illinois initiated Phase 2 reopening (May 29) and Phase 3 reopening (June 26). After Phase 3 reopening traffic started showing days with similar traffic and only about a 10 percent decrease on adjourning days. COVID-19 started to increase, and Illinois initiated new restrictions on August 26. COVID-19 reached a second peak of new cases on September 5, but the showed a slight decrease. Traffic levels started showing more consecutive days of similar levels to 2019; almost all of September was similar in 2020 to 2019 traffic. Beginning of October, COVID-19 cases started increasing and the number of similar days of traffic became less frequent. COVID-19 hit a third peak on November 17 and rapidly decreased after new restrictions were put in place on November 20. Traffic levels showed a few sporadic days of similar levels. However, traffic remained around a 10 percent decrease throughout the rest of the stud period with COVID-19 cases continuing to decrease.

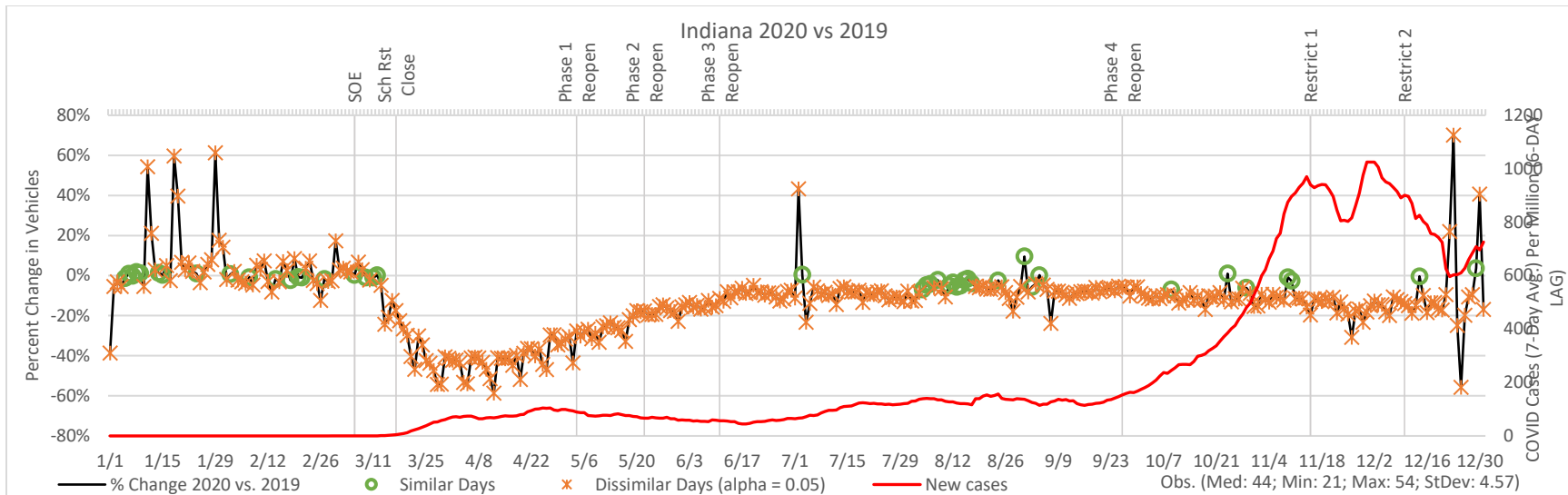


Figure 17 a North US: Indiana, Daily Traffic 2020 vs 2019, New COVID-19 Cases, and Directives

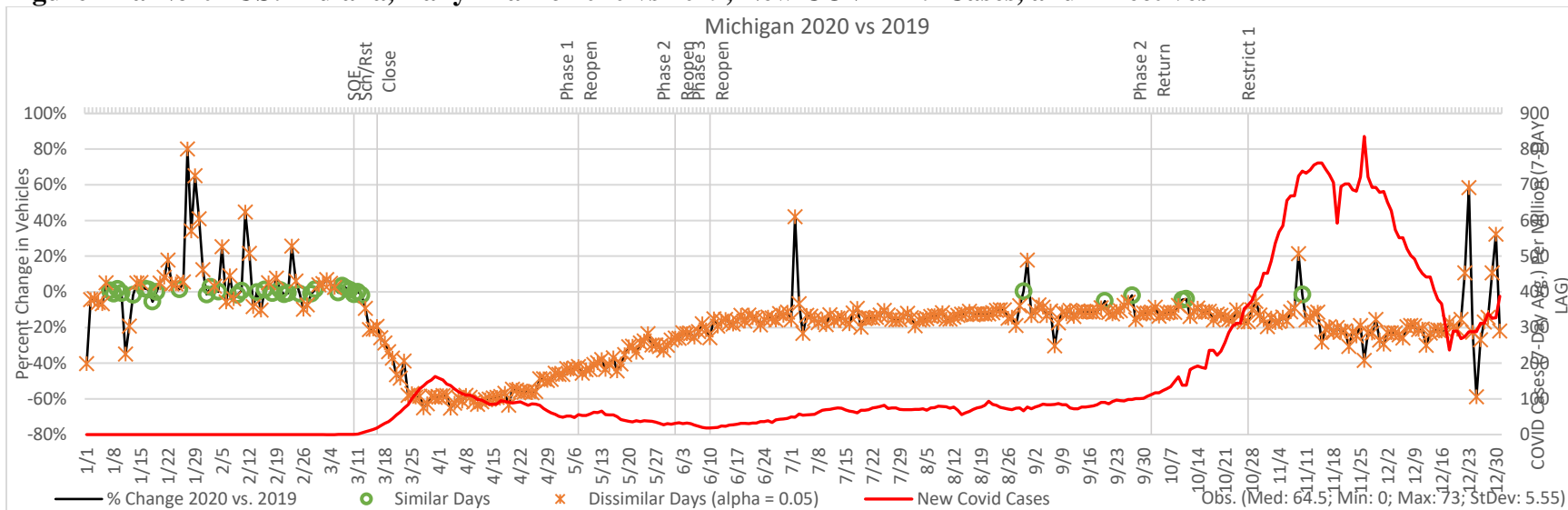


Figure 17 b North US: Michigan, Daily Traffic 2020 vs 2019, New COVID-19 Cases, and Directives

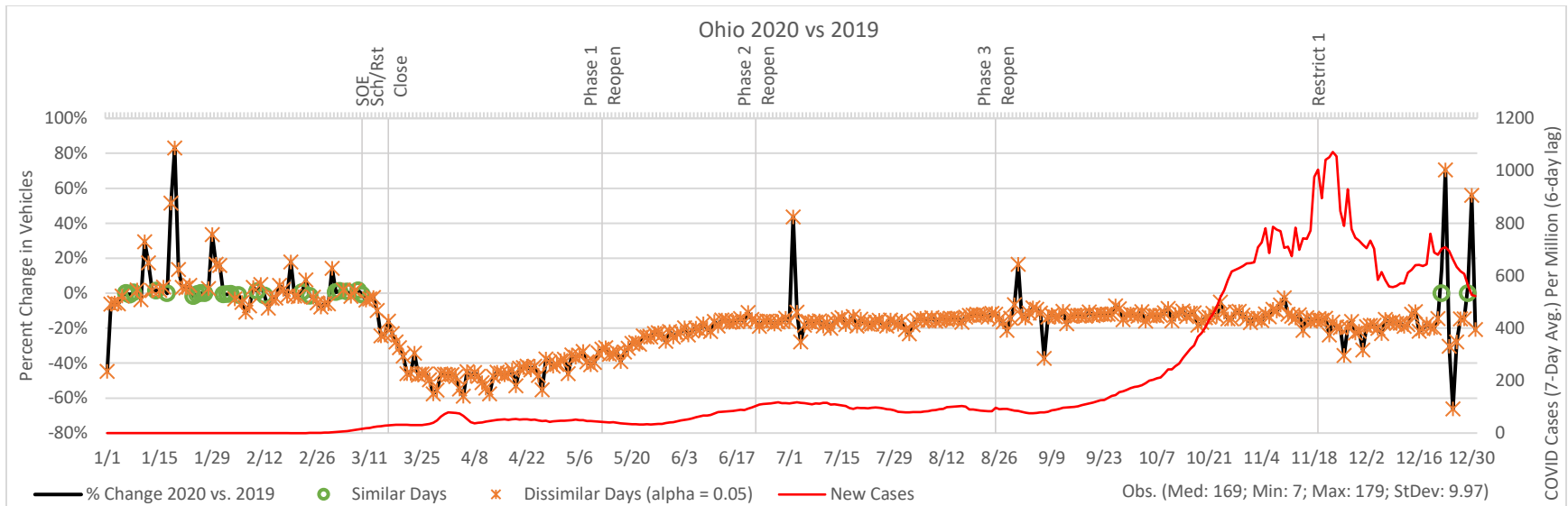


Figure 17 c North US: Ohio, Daily Traffic 2020 vs 2019, New COVID-19 Cases, and Directives

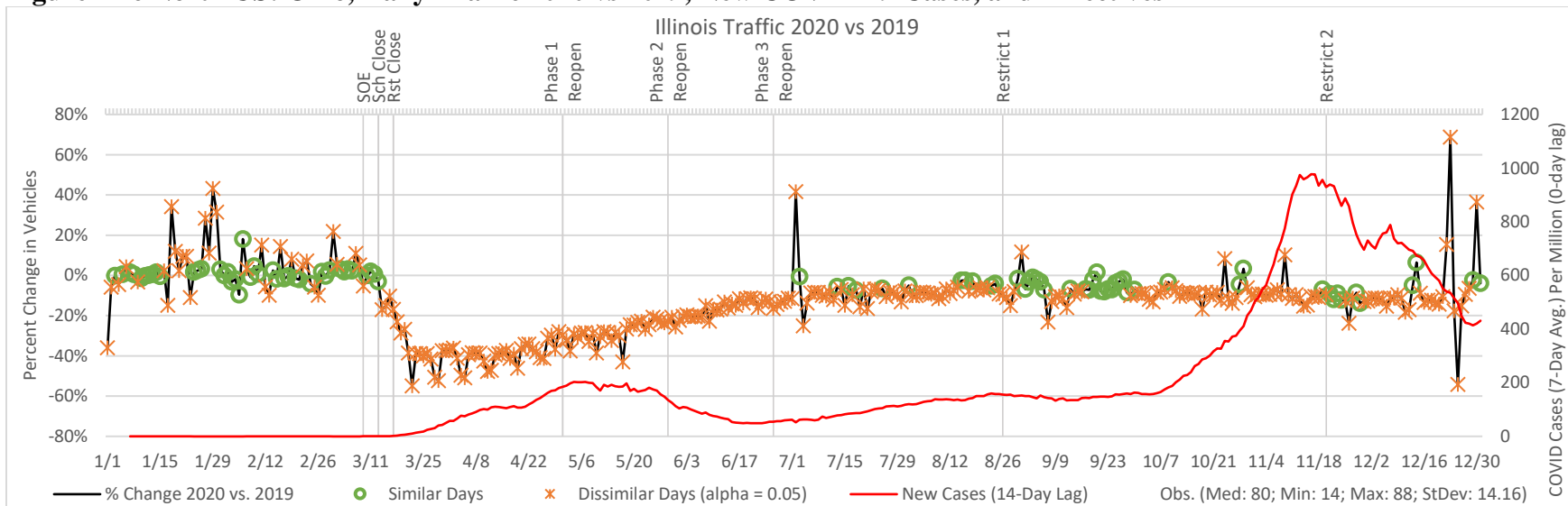


Figure 17 d North US: Illinois, Daily Traffic 2020 vs 2019, New COVID-19 Cases, and Directives

4.2.3.4. North-West US: Montana

Figure 18 represent the traffic and COVID trends during 2020 in Montana. Montana detected its first COVID case on March 11, which increased steadily until reaching a first peak on April 1. Traffic started decreasing on March 13; the day after state of emergency had been initiated. Traffic reached it bottom on April 11 at a 60 percent decrease. Soon thereafter traffic started increasing and once Phase 1 reopening was announced traffic went above a 20 percent decrease. Traffic returned to normal levels a few days at the beginning of July and the surrounding days only had a few percent of decrease. COVID-19 levels started increasing once again during this period, reaching a second peak on July 29. At the end of August normal traffic levels was once again noted, a trend that continued until beginning of November. As traffic was back to normal, COVID-19 levels started rapidly increasing, reaching a peak on November 20. Montana initiated a Restriction November 18 and traffic started showing more significant difference in traffic volumes, but a very little decrease (~5%) before the holidays. A trend that lasted throughout the study period with COVID-19 cases steadily decreasing.

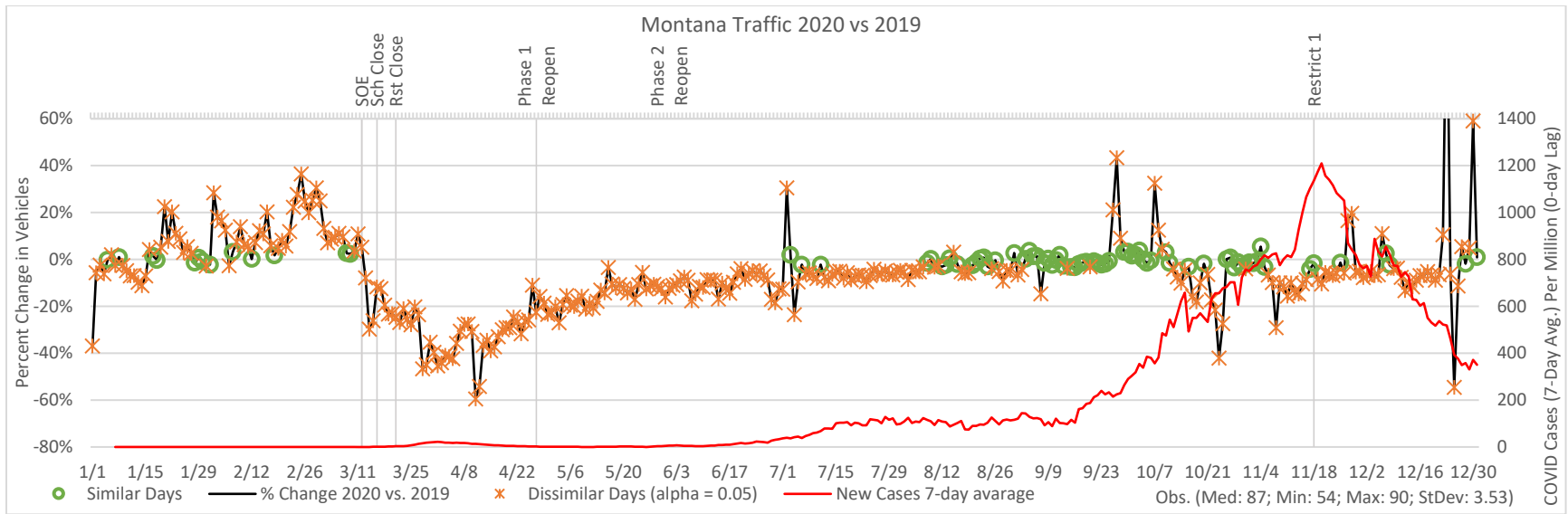


Figure 18 North-West US: Montana, Daily Traffic 2020 vs 2019, New COVID-19 Cases, and Directives

4.2.4. Major Findings from Daily Traffic, New COVID-19 Cases, and Directives,

Of the Countries and states, only China and Florida showed a return to pre-pandemic traffic levels. The rest of the US and Sweden continued to show decreases in traffic at the end of the study period. Some states showed a few days of similar traffic but decreases remained consistent. Lowest traffic decrease at the end of the study period was Massachusetts with levels close to 30 percent. Sweden, Indiana, New Hampshire and Ohio had levels near 20 percent decrease.

In China, both Hubei and Zhejiang experienced the largest decrease in traffic of all study groups, reaching near zero levels. By the end of the study, China's daily reported COVID-19 cases stood at or near zero (National Health Commission of the People's Republic of China, 2020), while the US and Sweden were still reporting cases. In most instances reporting an increased number of cases. Only Montana, Ohio and Illinois are showing a decrease in cases. Florida, New York and Massachusetts were reaching higher COVID-19 levels than their third peak on the last day of the study period. A trend that was seen across all states and countries is that when lockdowns and government restrictions were put in place, traffic did decrease. It is therefore likely that government restrictions and fear of the pandemic influenced travel behavior by limiting discretionary trips. Combined with social distancing and other preventative measures, these trip cancelations likely led to fewer person-to-person interactions, which in turn could have led to the decreases in daily COVID-19 cases after the first peak.

The figures suggested that regions with consistently lower traffic volumes reported fewer COVID-19 cases offset by some time period. Florida was the state in the US that started increasing traffic the fastest after the major decrease in the e beginning of the study period. Florida was also the one state that experienced a major second peak of COVID-19 while New York was the only one that did not experience a second peak. As phased reopenings started

occurring, traffic showed rapid increase across all states and countries, showing trend of normal traffic levels in all countries Massachusetts, Michigan and Ohio. Ohio was the one with the most significant result of this, not having a single day of traffic being similar to 2019.

Florida was the only state that did not enforce any restrictions at the end of the study period when the third COVID-19 peak started happening. In the rest of the states and Sweden, traffic decreased immediately after restrictions were put in place, showing that once again government restrictions influenced travel behavior. In Montana, Ohio and Illinois, COVID-19 cases declined rapidly after the restrictions were put in place. These states also continued showing a decrease in COVID-19 cases at the end of the study period. Massachusetts and Vermont were not able to decrease COVID-19 cases, but after restrictions they managed to delay their third peak and a clear plateau in new cases can be seen.

Another interesting general traffic volume trend was that traffic conditions demonstrated periodic patterns of change relative to 2019 levels, particularly weekly Monday-to-Monday stepped increases. While most days of the week in 2020 were less than the corresponding 2019 days, weekend traffic decreases, (Sundays in particular) were more pronounced across most states during the analysis period. This was especially clear in Sweden during June to August when traffic resumed similar levels to 2019, but a significant decrease was still noted on Saturdays and Sundays. This is likely because weekend discretionary travel was impacted most acutely by the closure orders. A similarly notable trend in the graphs is the inverse relationship between traffic volume and COVID-19 infections.

4.3. Initial Peak of COVID-19

The first peak in COVID-19 diagnoses, shown as a seven-day rolling average of new cases, varied across a broad range of periods (Table 7). The period is labeled from “Early” in the COVID case increase period to “Late” in the COVID case increase period. Fastest to reach the COVID-19 peak from third COVID-19 case was Zhejiang (13 days), and they had the lowest number of COVID-19 cases per million of population, only 1.6. In the US, Montana was the only one to reach their COVID-19 peak in less than 20 days. Longest to reach their peak was Illinois (64 days), New Hampshire (60 days) and Indiana (55 days). Sweden was also one of the countries that took longest time, reaching its peak in 63 days. Highest number of COVID-19 cases per million of population was Massachusetts with 359 cases, New York also reached high levels (238 COVID cases per million population) as well as Illinois (202).

Table 7 Initial Peak of COVID-19 Case Growth

Country	State/Province	Third COVID-19 Case	7-day Moving Avg. Peak	Days Between	Peaking Pattern	Peak of Cases Per Million Population
USA	Florida	29-Feb	2-Apr	33	Early	52
	Illinois	1-Mar	4-May	64	Late	202
	Indiana	3-Mar	27-Apr	55	Late	104
	Massachusetts	29-Feb	7-Apr	38	Middle	359
	Michigan	5-Mar	1-Apr	27	Early	158
	Montana	15-Mar	1-Apr	17	Early	22
	New Hampshire	28-Feb	28-Apr	60	Late	73
	New York	29-Feb	5-Apr	36	Early	238
	Ohio	4-Mar	1-Apr	28	Early	79
	Vermont	12-Mar	8-Apr	27	Middle	66
China	Hubei	9-Jan	5-Feb	27	Early	72
	Zhejiang	21-Jan	3-Feb	13	Early	1.6
	Sweden	14-Feb	17-Apr	63	Middle	61

To examine the initial onset period more closely, Table 8 shows the initial date in each state on which 2020 traffic volume was statistically different from 2019. In the US, all fell within the same narrow 10-day window from March 9 to 18. In Sweden it occurred on March 14, and in China it occurred on January 11 (Zhejiang) and January 23 (Hubei). The difference between the third diagnosed COVID-19 case and the first significant traffic decline ranges from negative 10 days in Zhejiang to 29 days later in Sweden. For Hubei, it took 14 days to change. In the US, it ranges from negative 2 days in Montana, to 18 days in Florida.

Table 8 Initial Peak Period –COVID-19 Case and Traffic Volume Changes

Country	State/Province	Third COVID Case	First Traffic Decrease	Days to Change
USA	Florida	29-Feb	18-Mar	18
	Illinois	1-Mar	9-Mar	8
	Indiana	3-Mar	10-Mar	7
	Massachusetts	29-Feb	12-Mar	12
	Michigan	5-Mar	13-Mar	8
	Montana	15-Mar	13-Mar	-2
	New Hampshire	28-Feb	10-Mar	11
	New York	29-Feb	14-Mar	14
	Ohio	4-Mar	10-Mar	6
	Vermont	12-Mar	13-Mar	1
China	Hubei	9-Jan	23-Jan	14
	Zhejiang	21-Jan	11-Jan	-10
	Sweden	14-Feb	14-Mar	29

Closures of business and cancellation of activities with high person-to-person interaction led to decreases in traffic volume and likely decreases in the rate of COVID-19 infections.

Reduction in spread rates was not instantaneous, however. Even taking the COVID-19 case offset adjustment into account; it was non-uniformly related across the countries. This further suggests that other mechanisms of virus spread, aside from interactions reflected through travel, also accounted for initial infection increases. In some cases, traffic decreased before the third

COVID-19 case was reported. This indicates that the fear of the virus, affected people's actions even before the spread of the virus had reached them.

4.3.1 General Trends and Observations between Traffic Volume and Viral Progression

All states in the sample experienced a gradual increase of traffic volume toward 2019 levels in late April and May. The largest difference between the states, however, was the path of the infections over the analysis period. Table 9 summarizes the period for virus and traffic changes revealed during the time from the initial "peak" in cases to the greatest traffic decline. Montana was the only states where the time for the virus cases to peak was shorter than the time for traffic to reach its bottom point (as measured by change from 2019 levels). Figure 19 plots the number of days to reach the first peak on the x-axis, and the days to reach "bottom" on the y-axis for each state/country. The figure shows an indication that for these relatively diverse ten states and Sweden, the more rapid the declines in traffic volume, the slower the growth in COVID-19 virus cases. The two states in the US where it took longer than 60 days to reach the COVID-19 case peak were also the two states with the some of the fastest decline to the vehicle volume "bottom." Since "flattening the curve" and delaying the peak was a primary purpose of social distancing, these findings suggest that overall, governmental directives, as reflected through rapid traffic decreases, served their purpose.

Table 9 Initial Peak Periods for COVID-19 Cases and Traffic Volume Decline

Country	State	Initial Peak			
		COVID-19		Traffic Volumes	
		1 st Peak Date	Days to Reach 1 st Peak	Traffic “Bottom” Date	Days to Reach “Bottom”
USA	Florida	2-Apr	33	5-Apr	18
	Illinois	4-May	64	22-Mar	13
	Indiana	27-Apr	55	12-Apr	33
	Massachusetts	7-Apr	38	29-Mar	17
	Michigan	1-Apr	27	4-Apr	22
	Montana	1-Apr	17	11-Apr	29
	New Hampshire	28-Apr	60	29-Mar	19
	New York	5-Apr	36	4-Apr	21
	Ohio	1-Apr	28	5-Apr	26
	Vermont	8-Apr	27	29-Mar	16
Sweden		17-Apr	63	10-Apr	27

Days to Reach Peak – Time from third COVID case occurrence to highest rolling seven-day average cases.

Days to Reach “Bottom” – Time from initial traffic decline to largest traffic volume change from 2019 to 2020.

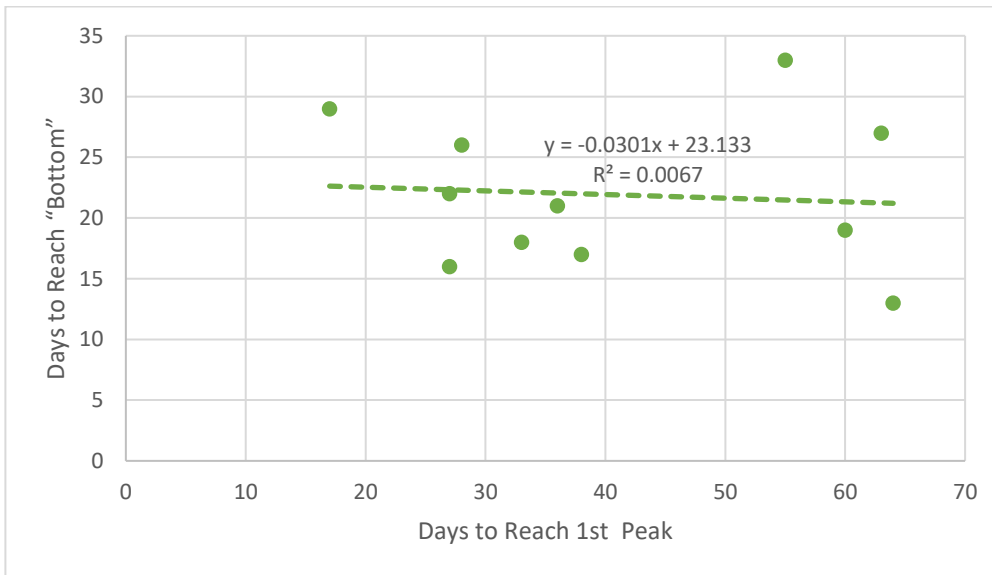


Figure 19 Comparison of Days to 1st Peak Rolling Seven-Day Average COVID Case Count and Time to the Largest Decrease in Traffic between 2019 and 2020

4.4. Second peak of COVID-19

After the initial peak of COVID-19, all countries followed a similar pattern with traffic increasing from the traffic “bottom”. When Phased reopening occurred, traffic increased more rapidly across the board, and so did COVID-19 cases. China’s COVID-19 cases remained at zero for the rest of the study period until end of March. For Sweden and the US, everyone except New York experienced a second COVID-19 peak. The second peak in COVID-19 diagnoses, shown as a seven-day rolling average of new cases per million of population, varied across a broad range of periods (Table 10). The period is labeled from “Early” in the COVID case increase period to “Late” in the COVID case increase period. Earliest peaks occurred in Sweden (June 5), Vermont (June 8) and Ohio (June 28). Latest peaks occurred in Michigan (August 21), Indiana (August 24), and Illinois (September 5).

Table 10 2nd Peak Period –COVID-19 Case and Traffic Volume Changes

Country	State/Providence	7-Day Moving Avg. 1 st Peak	7-day Moving Avg. 2 nd Peak	Days Between	Peaking Pattern	2 nd Peak of Cases Per Million Population
USA	Florida	2-Apr	11-Jul	100	Middle	547
	Illinois	4-May	5-Sep	124	Late	192
	Indiana	27-Apr	24-Aug	119	Late	156
	Massachusetts	7-Apr	8-Aug	123	Middle	79
	Michigan	1-Apr	21-Aug	142	Late	93
	Montana	1-Apr	29-Jul	119	Middle	116
	New Hampshire	28-Apr	19-Jul	82	Middle	25
	New York	5-Apr	N/A	N/A	N/A	N/A
	Ohio	1-Apr	28-Jun	88	Early	117
	Vermont	8-Apr	8-Jun	61	Early	24
	Sweden	17-Apr	5-Jun	49	Early	105

Florida's second peak of COVID-19 was noticeably higher than for the other states and countries, reaching 547 cases per million population. Lowest second peak was for Vermont (24 New COVID-19 cases per million population) and New Hampshire (25 new COVID-19 cases per million population). A similarly notable trend in the graphs as seen for the initial peak, is the relationship between traffic volume and COVID-19 infections. As traffic increase so did COVID-19 cases, and when traffic decreased so did COVID-19 cases.

4.4.1. General Trends and Observations between Traffic Volume and Viral Progression

All states in the sample experienced a gradual increase of traffic volume toward 2019 levels in late April and May as more reopenings started happening. The largest difference between the states, however, was the path of the infections over the analysis period with differences in number of cases and onset of the peaks. Table 11 summarizes the period for virus and traffic changes revealed during the time from the initial "peak" to the "second" peak in cases to return from traffic "bottom" to normal levels. Massachusetts, Michigan, Ohio and Vermont were the only states that did not experience a trend of traffic returning to normal levels. Vermont was the state with the lowest number of COVID-19 cases per million population during the second peak. Both Massachusetts and Michigan had some of the lowest COVID-19 cases and some of the longest times to reach their second COVID-19 peak. Sweden returned to normal traffic levels the fastest and was the one with the earliest second peak (June 5) and reached it in the shortest time (49 days). Figure 20 indicates that for these US states and Sweden, the longer it took traffic to return to normal levels, the longer it took the second peak of COVID to occur.

Table 11 2nd Peak Period for COVID-19 Cases and Traffic Volume Decline

Country	State/ Providence	Second Peak			
		COVID 19		Traffic Volumes	
		2 nd peak date	Days To Reach Peak	Trend of Similar Days of Traffic	Days To Reach Normal
USA	Florida	11-Jul	100	12-Jun	68
	Illinois	5-Sep	124	13-Jun	83
	Indiana	24-Aug	119	4-Aug	114
	Massachusetts	8-Aug	123	N/A	N/A
	Michigan	21-Aug	142	N/A	N/A
	Montana	29-Jul	119	8-Aug	119
	New Hampshire	19-Jul	82	31-Aug	155
	New York	N/A	N/A	2-Jul	95
	Ohio	28-Jun	88	N/A	N/A
	Vermont	8-Jun	61	N/A	N/A
Sweden		5-Jun	49	10-Apr	61

Days to Reach Peak – Time from 1st peak to 2nd peak occurrence to highest rolling seven-day average cases.

Days to Reach Normal – Time from largest traffic volume change from 2019 to 2020 to trend of similar days of traffic.

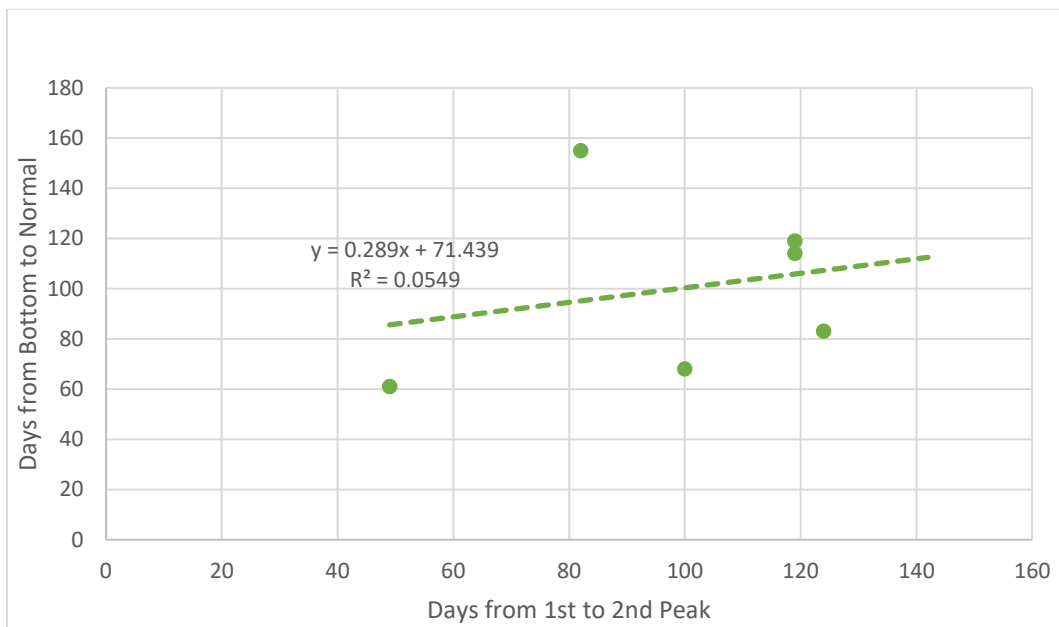


Figure 20 Comparison of Days between 1st and 2nd Peak Rolling Seven-Day Average COVID Case Count and Time from the Largest Decrease in Traffic between 2019 and 2020 to Normal Traffic Volumes

4.5. December Peak of COVID-19

Across all states in the US, and in Sweden, COVID-19 cases started rapidly increasing in October. Florida was the only state that did not enforce any restrictions, even Sweden started with stricter recommendations and even more mandatory enforcements not seen before. During the restrictions and increased COVID cases, traffic started decreasing for everyone, with Florida being the only state where traffic remained at normal volumes similar to 2019. A few states showed some sporadic days towards the end of the study period with a few days of similar traffic (Massachusetts, Montana, Illinois, New York, New Hampshire), but no clear indication of trend with complete normal traffic volumes compared to 2019. Massachusette, New York and Florida showed increased level of COVID-19 cases at the end of the study period, increases that were higher levels of new COVID-19 cases compared to the third peak. New Hampshire, Indiana, and Vermont also show increase after the third COVID peak, but they did not reach levels higher than their previous peak. The highest number of COVID-19 cases per million of population occurred in Montana with 1210 cases. Indiana and Ohio also reached levels over one thousand cases per million of population. Lowest peak occurred in Vermont with 215 cases per million population.

Table 12 December Peak Period of COVID-19

Country	State/Providence	Third COVID peak	Cases per million
USA	Florida	18-Dec	517
	Illinois	17-Nov	977
	Indiana	30-Nov	1025
	Massachusetts	3-Dec	695
	Michigan	26-Nov	836
	Montana	20-Nov	1210
	New Hampshire	4-Dec	650
	New York	26-Dec	391
	Ohio	23-Nov	1072
	Vermont	6-Dec	215
	Sweden	15-Dec	691

Figure 21 shows the COVID-19 case curve for all US states and Sweden. Interesting to see are the similarities between all study groups. The only one that stands out is Massachusetts with a large initial peak, Illinois and Indiana with delayed initial peak, Florida, with a large second COVID-19 peak, New York with no second COVID-19 peak, Montana with an early large increase in cases for the third peak. Sweden, with its liberal and less restrictive recommendations, shows a similar COVID-19 curve compared to US states, and even had lower cases in peaks than most.

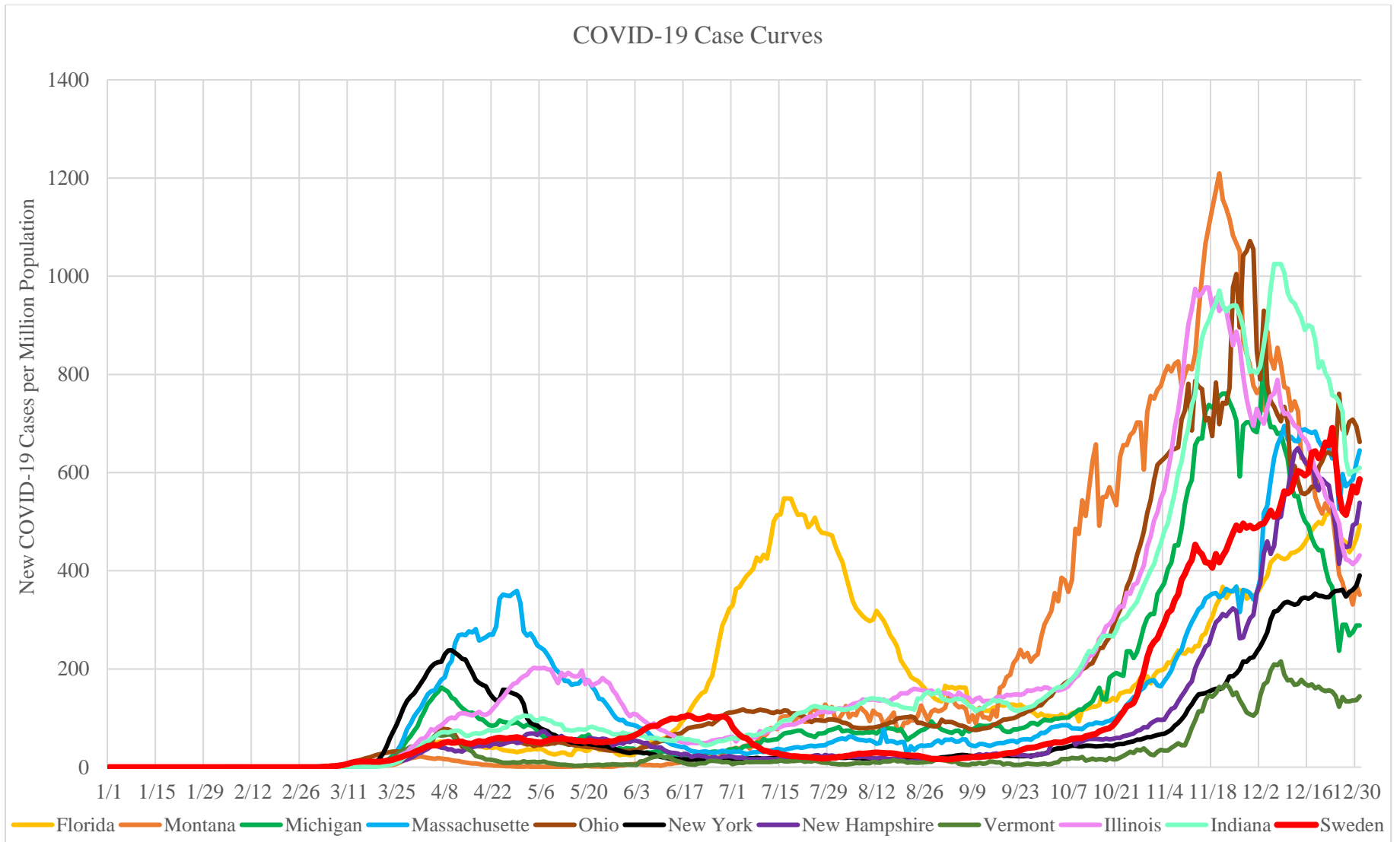


Figure 21 COVID-19 Case Curves

4.6. Urban VS Rural Daily, Traffic Volumes 2020 vs 2019 & Directives

Figure 22 through Figure 32 shows the daily vehicle counts per 100,000 vehicles observed in 2020 and 2019, in urban and rural areas, in Sweden and the US. Traffic in urban areas during 2019 are shown as a dashed black line, and during 2020 in blue colors. Traffic in rural areas during 2019 are shown as a full black line, and during 2020 in green colors. A paired t-test, for corresponding days of the week, with significance level of 0.05, indicated the dates on which traffic was significantly different between years. Similar days are shown with circles in either blue (urban) or green (rural) colors. Sections that do not show circles on similar days are days with a significant difference in traffic. The lower right corner of each figure shows the minimum (Min), maximum (Max), median (Med), and standard deviation (StDev) for the traffic detectors (Obs.) used in the daily t-test analysis for both urban and rural detectors. The percent daily vehicle volumes per 100,000 vehicles in 2019 and 2020 is shown on the primary y-axis.

4.6.1. Sweden, Urban VS Rural

Figure 22 shows the urban and rural traffic in Sweden. Sweden has the majority of its traffic detectors in rural areas, a median of 83 rural observation compared to 3 urban observations. The majority of the traffic occurs on the rural roads with levels reaching above 700,000 vehicles, and only 50,000 vehicles on urban roads. During the full study period, urban roads only showed a significant difference in traffic levels on one day in the beginning of January, the rest remained similar volumes compared to 2019. However, no statistical conclusion can be made about urban travel in Sweden due to the low number of observations in these areas. Rural roads days with significant difference and similar volumes correspond to Figure 12 that shows urban and rural roads combined in the analysis.

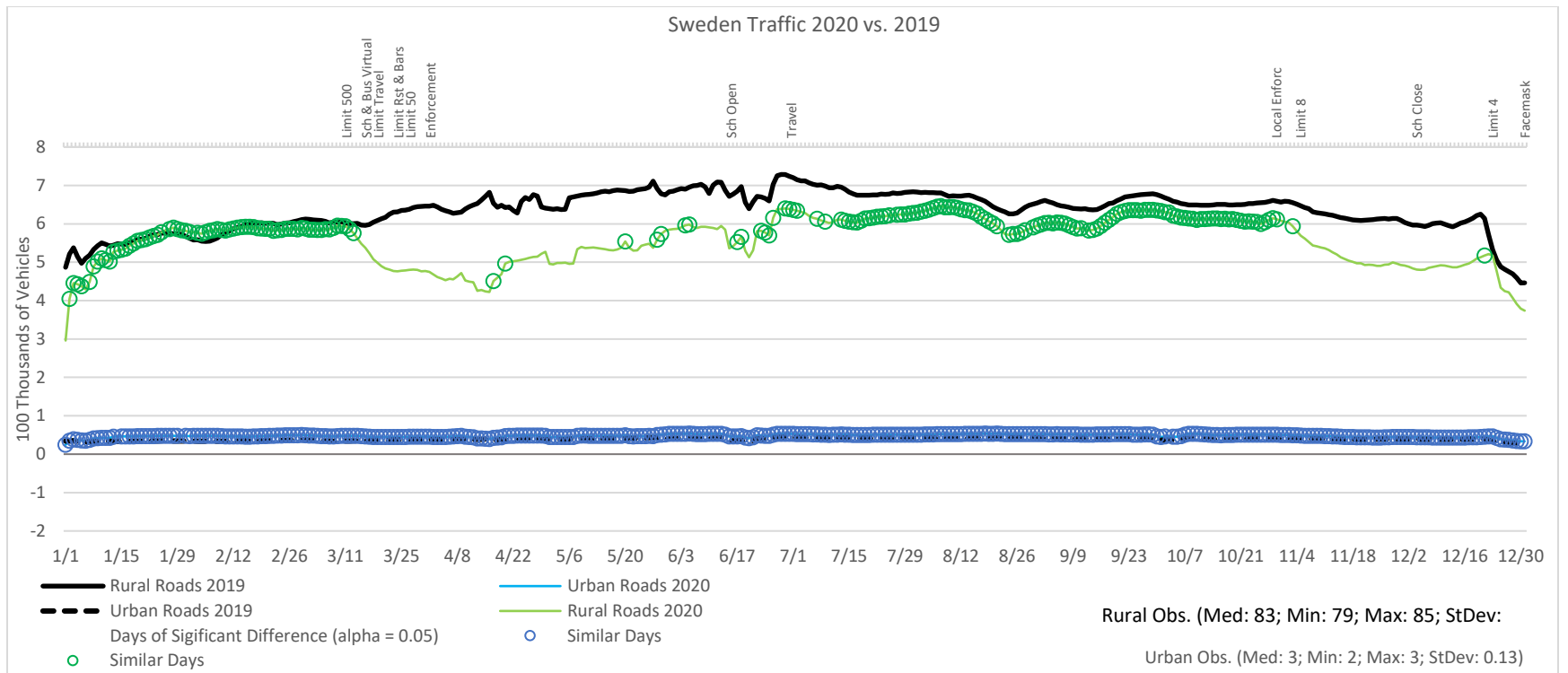


Figure 22 Sweden, Urban VS Rural Daily Traffic

4.6.2. US, Urban VS Rural

Montana in Figure 23 and Vermont in Figure 24 US, Urban VS Rural Daily Traffic, are both similar to Sweden, where most of their traffic occurs on rural roads. In Montana rural detectors make up a median observation of 73, and urban detectors make up a median observation of 14. Vermont has a median of 24 rural detectors and 5 urban detectors.

In Montana when traffic decreased in beginning of March as seen in Figure 18aa decrease can be seen in both urban and rural areas. Urban roads return to similar days of traffic volume faster than rural roads, showing a trend in beginning of June, suggesting that the Phase 1 reopening had a larger effect on activities and traffic in urban areas than rural areas. Rural areas trend of normal traffic occurred around Fourth of July weekend, indicating that more people travel on rural roads on their way home or to visit family away from school and work in urban areas. The secondary trend of normal days of traffic in August to October occurred both in rural and urban areas. After Restriction 1 in November, Urban roads had more instances of significant differences in traffic, while rural roads had more similar days of traffic, indicating that urban areas were more affected by the government directives and traffic reduction associated with those activists while rural roads remained generally unchanged.

Vermont showed a decrease in traffic on both urban and rural detectors in March, similar to Montana. Although Rural areas does not show a return back to normal traffic levels until end of August, urban returned to normal levels in the end of May when Phase 1 Reopening occurred. The trend of similar days of traffic on urban roads remained throughout the whole study period with some instances of significant difference in traffic, but no noticeable consistent periods. When restrictions occurred in November, a decrease in both urban and rural locations can be noted.

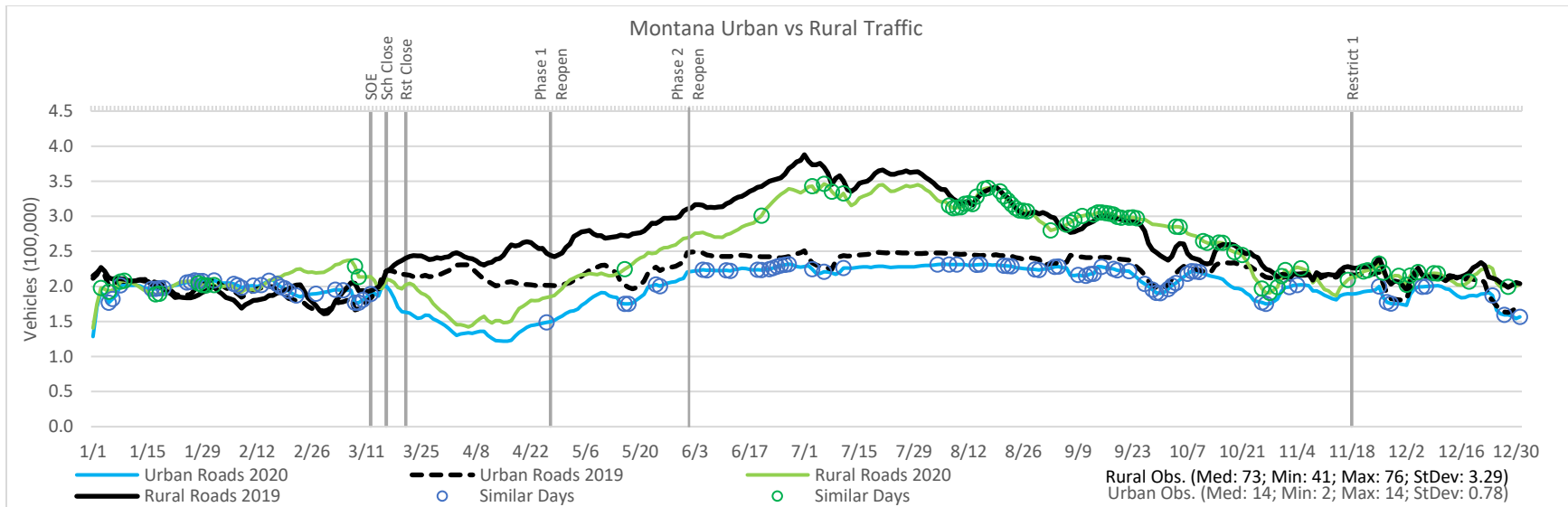


Figure 23 Montana, US, Urban VS Rural Daily Traffic

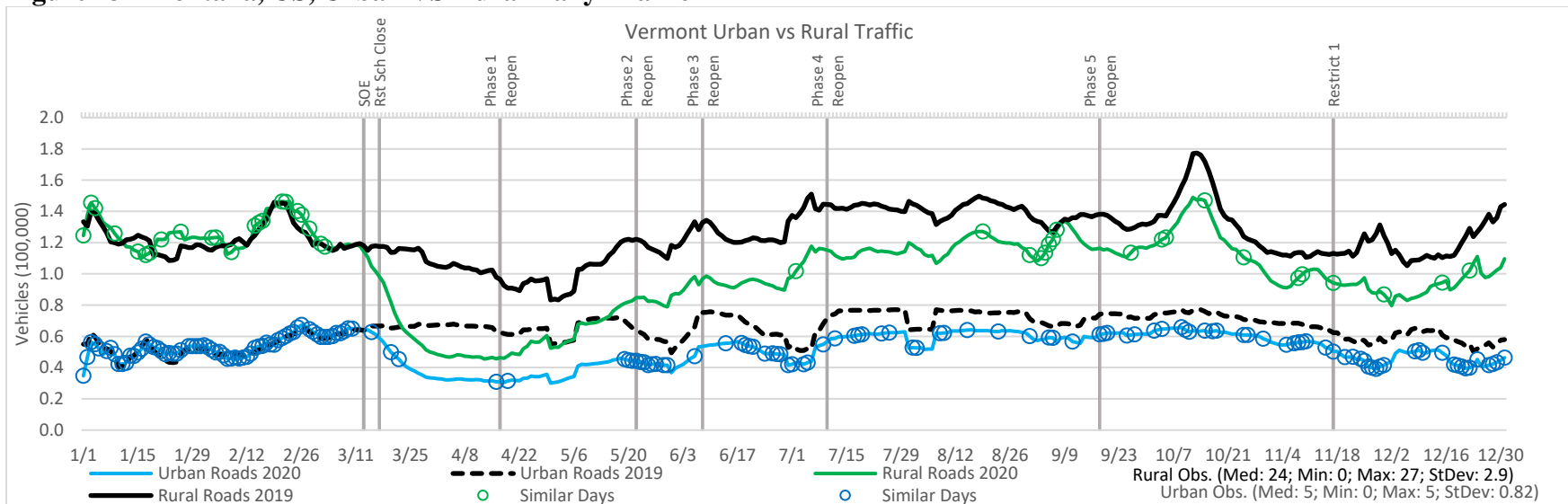


Figure 24 Vermont, US, Urban VS Rural Daily Traffic

New Hampshire (Figure 25), and Ohio (Figure 26) both had larger traffic volumes on urban roads than rural roads. These three states showed similar trends on both rural and urban roads corresponding to earlier figures and analysis. Ohio had a median of 104.5 detectors on urban roads and 64.5 detectors on rural roads. New Hampshire showed 22 detectors on urban areas and 26 on rural areas. Traffic started decreasing on both rural and urban roads around the same time period, and traffic remained significantly different during the whole study period in Ohio. Rural roads experienced two days of similar traffic September 4 and November 10. In New Hampshire Urban roads showed more significant difference the rural roads after restrictions were put in place, rural roads remained generally unchanged.

Michigan (Figure 27) and Indiana (Figure 28) are similar to New Hampshire because urban roads have higher volume than rural roads. In Michigan, median observations are 34 on rural roads, but 31 on urban roads. Indianan has 30 median observations of detectors on rural roads, and 14 on urban roads. Even if urban roads have fewer detectors, they have higher traffic. For both the states traffic decreased in March similarly to Figure 17 b (Michigan) Figure 17 a (Indiana) in the above section. A notable difference to these figures is that rural areas are experiencing normal levels of traffic (similar days) during mid-August to mid-October in Michigan, and from mid-June to end of November in Indiana. The other figures with combine urban and rural traffic are not showing the same period of similar days. Urban roads better match those figures, but there are a few instances where there are similar days instead of significantly difference, a result of rural roads being similar. This indicates that rural roads were not as affected by the COVID-19 pandemic, with traffic levels returning to normal levels much faster than urban roads. During state of emergency, rural roads did decrease, showing an affect from government directives and activity restrictions.

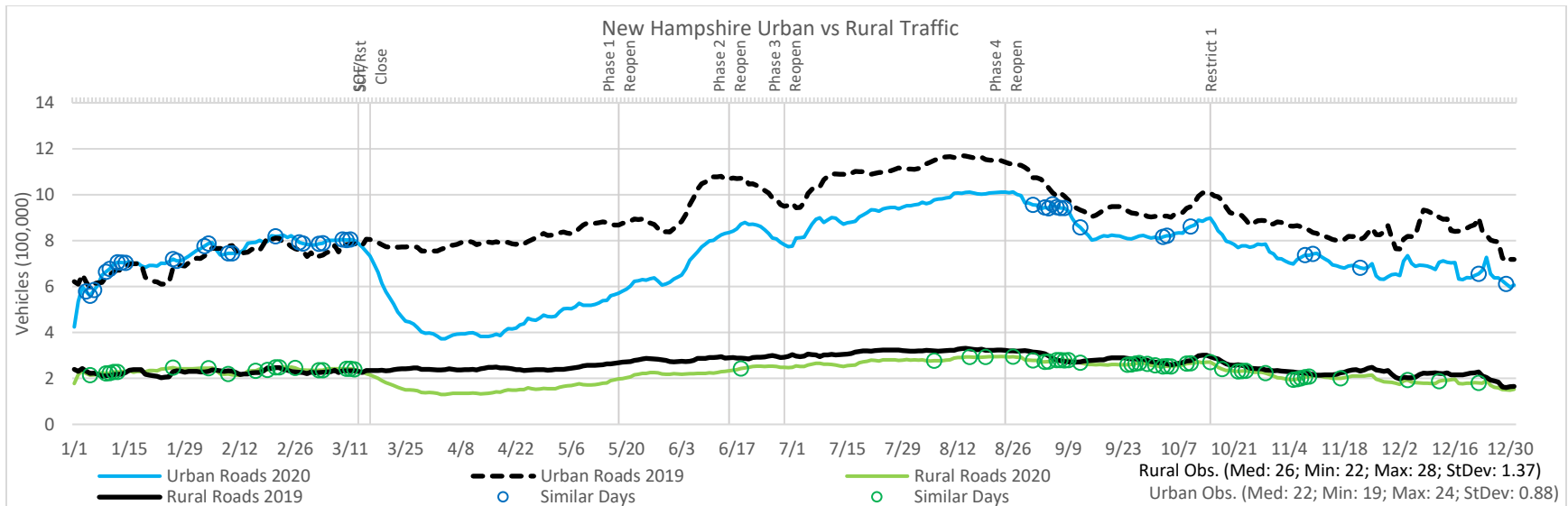


Figure 25 New Hampshire, US, Urban VS Rural Daily Traffic

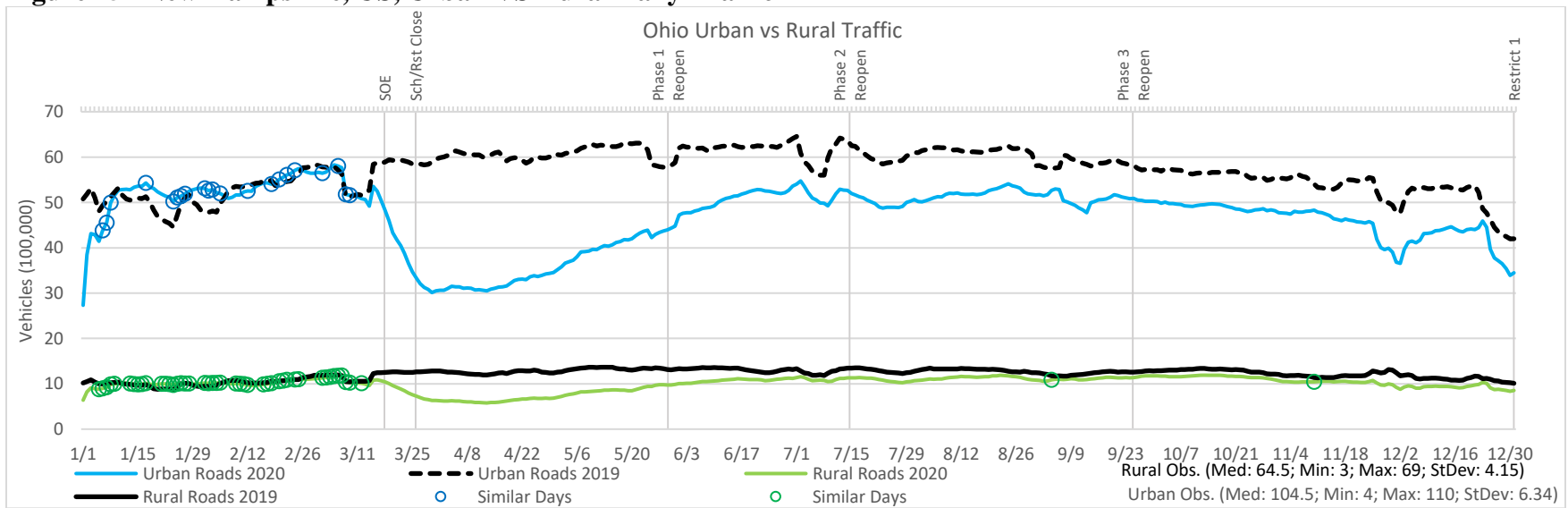


Figure 26 Ohio, US, Urban VS Rural Daily Traffic

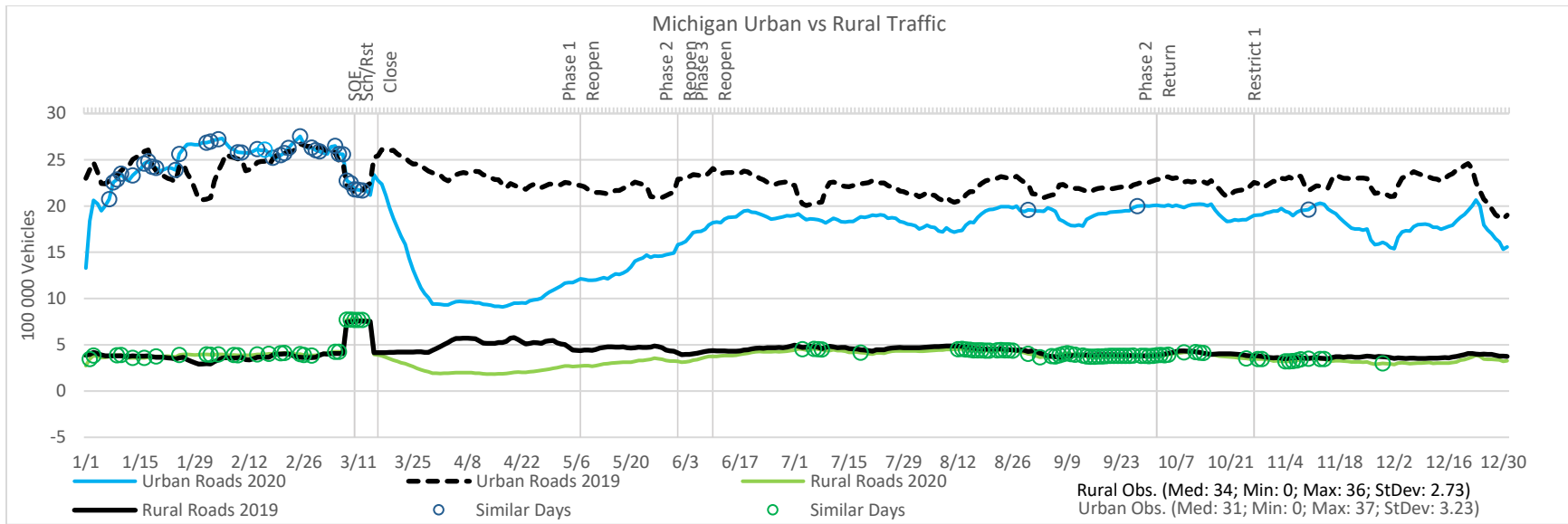


Figure 27 Michigan, US, Urban VS Rural Daily Traffic

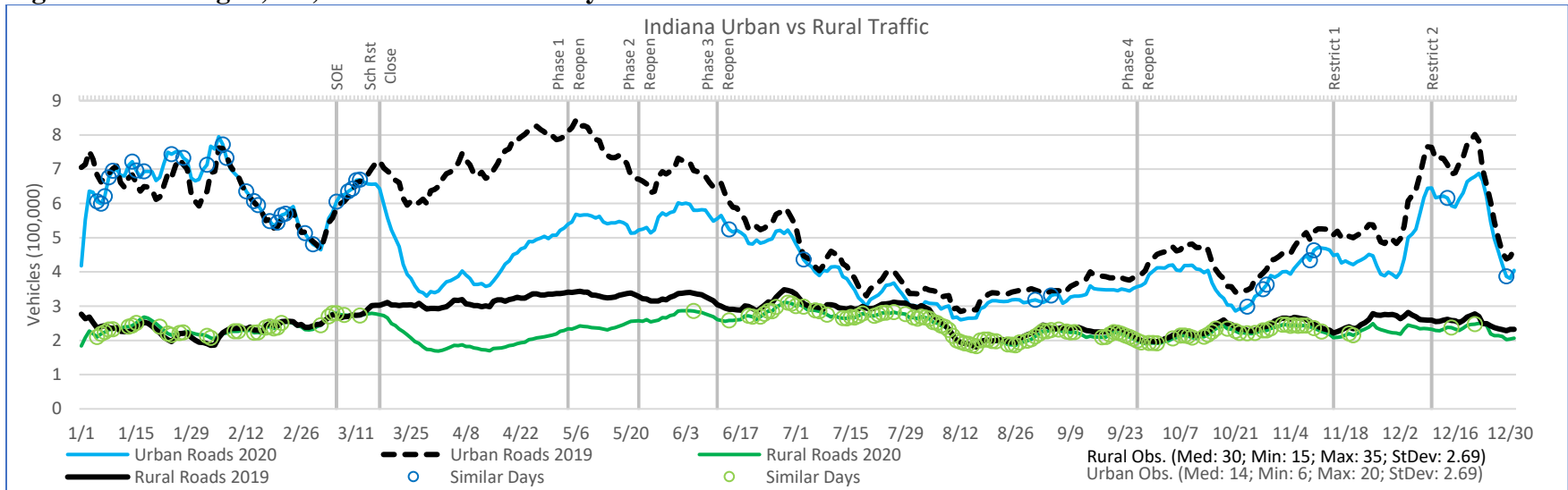


Figure 28 Indiana, US, Urban VS Rural Daily Traffic

Massachusetts, Figure 29 , is similar to Indiana and Michigan in the sense that majority of traffic occur on Urban roads. A difference is that Massachusetts has a significant larger number of observations on urban than rural detectors, 43 and 7 median observations, respectively. Massachusetts is the only state that showed no significant decrease on rural traffic detectors during the initial onset of the COVID-19 pandemic in March. Urban roads decline similar to Figure 16 b. Rural traffic volumes remained similar throughout the stud period with only a few instances of significant difference. Urban roads remain significant different throughout the whole study period, with a few sporadic days of similar volumes occurring seven times during August, October and September.

New York Urban roads shows a similar result like Massachusetts and can be seen in Figure 30 . Although a few days of significant difference occurs during the traffic bottom at the end of March, beginning of April, these are not continuous. After that, the study period on rural roads are similar days with only a few instances if significant difference int traffic volumes. Urban detectors only show a median observation of 17 detectors, while rural has 118 median. What is a very interesting difference between the urban and rural traffic compared to all traffic on Figure 16 aFigure 16 a is that urban roads start showing a trend of normal traffic volumes starting at end of June and continue throughout the study period. This overlap rural days showing similar traffic volumes, yet Figure 16 a, with traffic combined shows significant difference in traffic leading up to October where a trend of similar days of traffic begins.

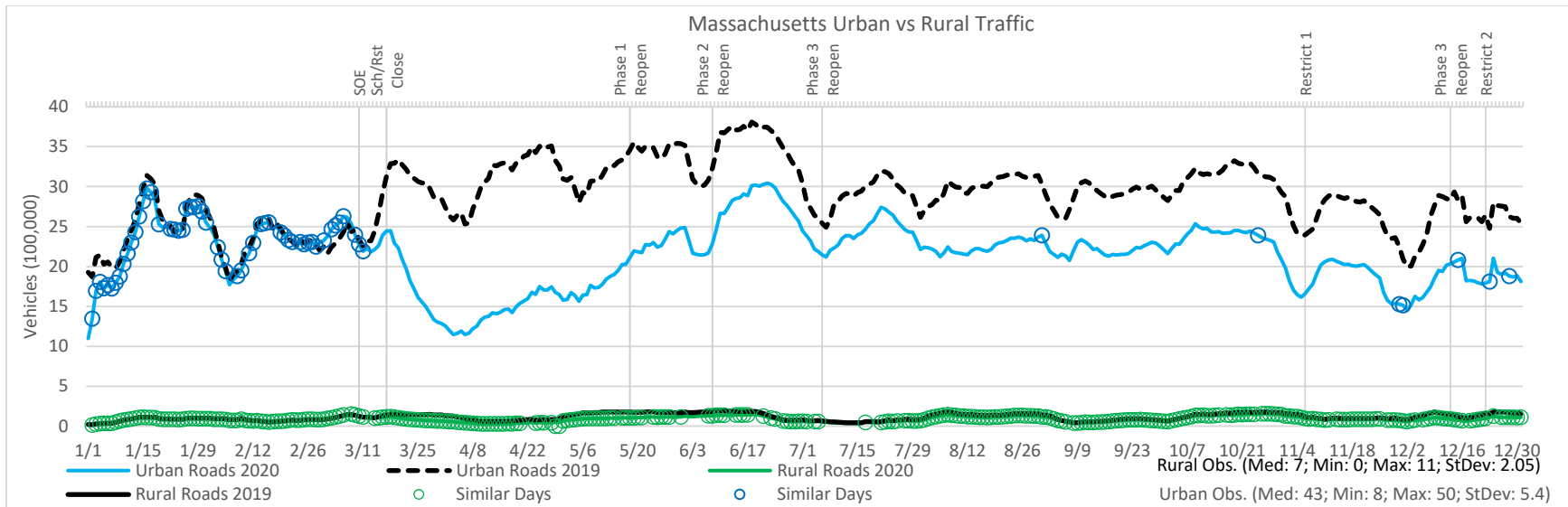


Figure 29 Massachusetts, US, Urban VS Rural Daily Traffic

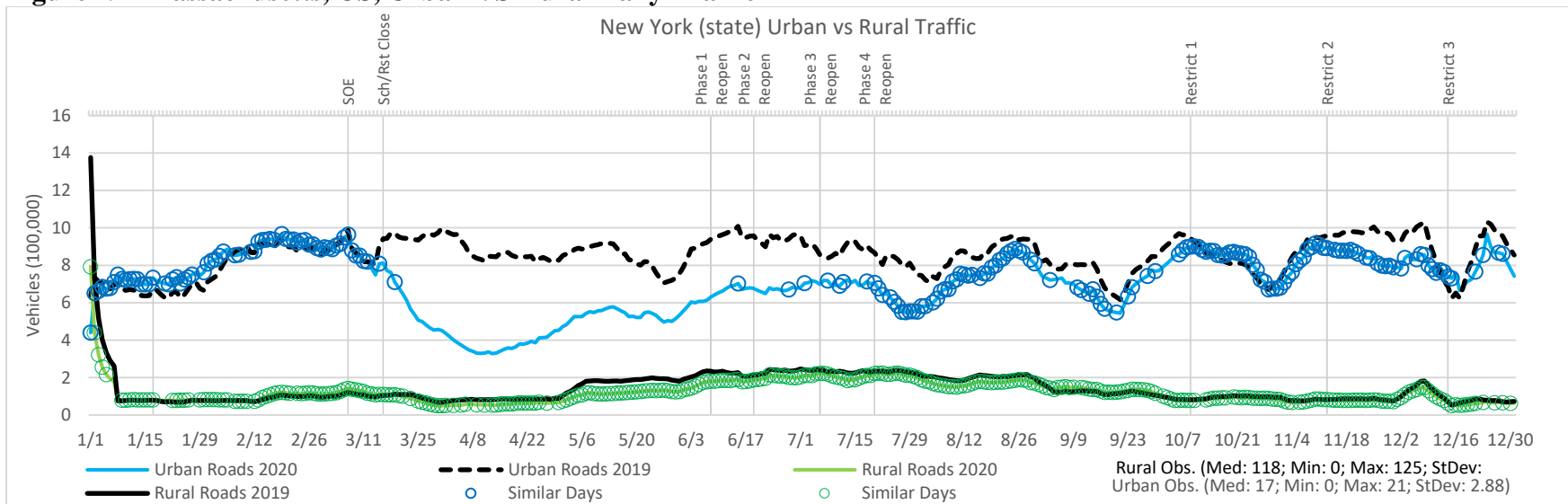


Figure 30 New York, US, Urban VS Rural Daily Traffic

Illinois (Figure 32) resembles Michigan urban and rural traffic trends with the only difference being that Illinois has more observed median of detectors on urban roads (54) than rural roads (25). A decrease on both urban and rural roads occurs during the initial pandemic peak in March. When Phase 1 reopening starts at the end of April, Illinois starts a trend of similar days of traffic volume on rural roads. This is consistent through the end of the study period, with only a few instances of significant difference. Urban roads showed mostly significant different traffic volumes through the stud period, only having 9 days of similar traffic levels. Even if Illinois in Figure 17 d show a trend of similar traffic days in July to August, these are caused by rural traffic and not urban traffic. Urban had not returned to normal level at the end of the study period.

Florida Figure 31 is similar to Illinois traffic trends. Both urban and rural areas decrease in March during the initial onset of the pandemic. Urban remains significantly different traffic volumes throughout the study period, with a few normal traffic days in the beginning of December. Rural roads show a traffic trend returning to normal levels at end of June and beginning of august carrying through the study period. In Florida, a median observation of 95 rural detectors were noted, and 120 traffic detectors in urban areas. Figure 15 with combined urban and rural traffic volumes, show similar days of traffic trend starting in August and carrying on throughout the stud period. Similar to Illinois, this is caused by rural traffic and not urban traffic.

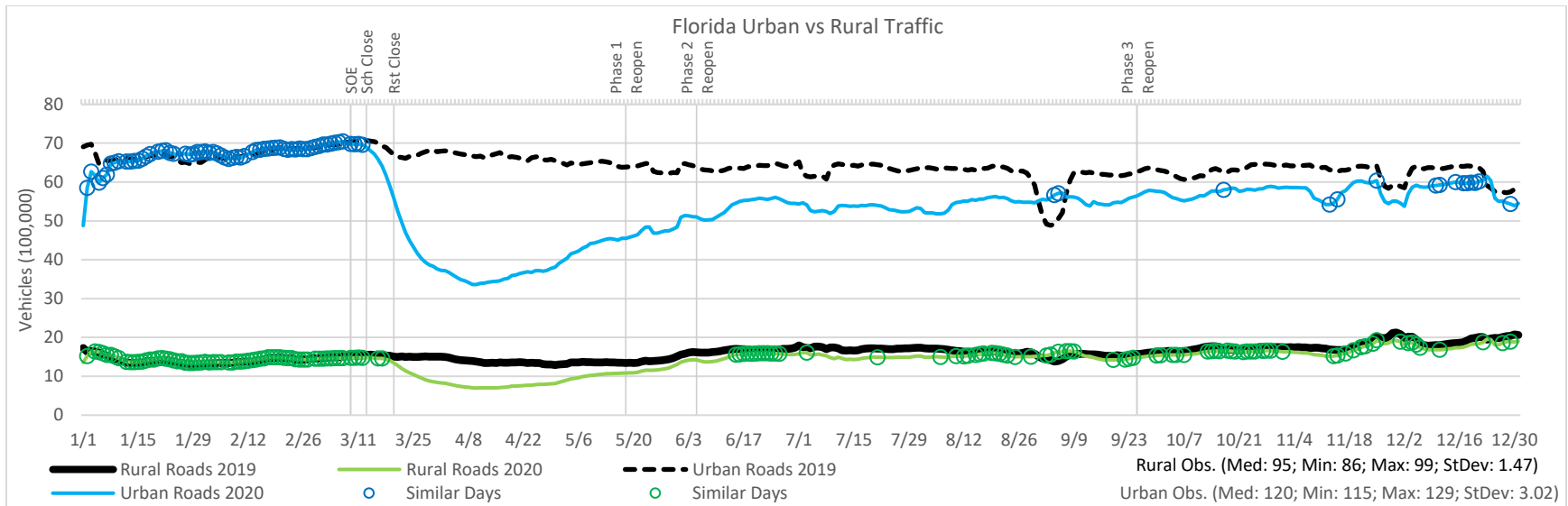


Figure 31 Florida, US, Urban VS Rural Daily Traffic

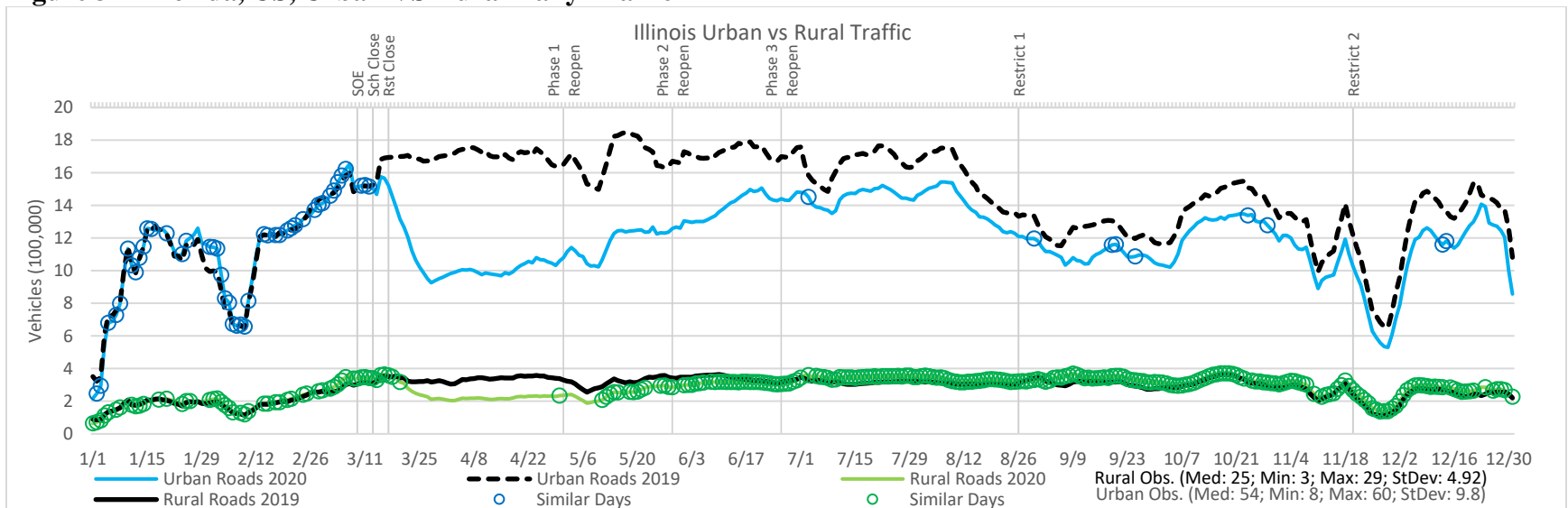


Figure 32 Illinois, US, Urban VS Rural Daily Traffic

4.6.3. Major Findings from Urban VS Rural Analysis

Sweden, Montana, and Vermont were similar in the sense that the majority of their daily traffic occurred on rural roads. The difference is that Sweden had such a low amount on traffic on urban detectors, it was relatively unchanged during the study period, while Vermont and Montana experienced significant differences and similar days in traffic on urban detectors. The rest of the states in the US had majority of traffic volumes on urban detectors. A common trend is that traffic on both Urban and Rural showed a decrease during initial lockdowns, besides at states/countries where traffic was so low on one of the classifications it did not show an impact (Sweden, New York, Massachusetts). Traffic volumes on urban roads indicate to seem to be more affected by governmental directives, showing an instantaneous increase or decrease.

At the end of the study period only Florida showed trends of returning to normal traffic levels on both rural and urban roads. Vermont showed a trend of returning to normal levels on urban roads, but not on rural roads. Montana, Massachusetts, New York, and Illinois showed trends of similar days of traffic on rural detectors at the end of the year but not on urban detectors. Ohio, New Hampshire, Michigan, and Indiana were still showing significant differences on both rural and urban roads at the end of the study period. An interesting finding is Illinois and Florida. During a period in July and August, on the figures showing total daily traffic change between 2020 and 2019, these days were showing a trend of similar days of traffic. When looking at Urban VS Rural, rural detectors showed similar days of traffic during this period, but urban detectors showed a significant decrease in traffic. The trend of similar days of traffic was caused by rural detectors and not urban detectors.

5.0 Conclusion

While it is clear that the COVID-19 pandemic will continue to evolve for some time into the future as the vaccine is spread widely through the world's population, this research presents a narrative of the critical first year of the event. This research shows how the virus initially spread throughout the world, and what happened when lockdowns were initiated, and as the world started reopening. Specifically, this research relates COVID-19 cases to highway traffic during the first year of the pandemic in the US, Sweden, and the first six months in China. Moreover, showing how governmental decisions and actions to limit personal interaction among its citizens influenced vehicular travel and, perhaps more critically, the course of the virus. This research also offers insights and perspectives to how the different timing and extent of public responses around the world to these governmental actions related to the onset and/or delay of viral spread of COVID-19.

In terms of the maximum decrease of traffic in each country, the data showed a clear pattern that related the level of governmental restriction and traffic. China, with the most-strict lockdown orders had a 100 percent decrease in traffic in Hubei and 98 percent decrease in Zhejiang. The US, while varied among individual states, also had comparatively strict lockdown as well (although less encompassing than China). Sweden had almost no mandated lockdowns, but experienced decreases in traffic up to 50 percent. This is logical, however, since many of the Swedish governmental recommendations targeted activities and business that would normally generate and attract vehicle trips. Sweden followed the same general shape of the COVID-19 spread, with an initial, secondary, and larger third peak, but in most cases fared better than most US states in terms of new cases per million in population, even with its more liberal approach.

The major takeaway from this study is that unless a country enforces a lockdown to the same extreme that was seen in China, it does not really matter at what level of lockdown is enforced. Sweden is considered as having less strict lockdown and US had a medium strict lockdown, if compared to China. Yet, both Sweden and US experienced similar COVID-19 case trends, indicating that US lockdowns were futile, and they could have possibly gotten the same result if they did less lockdowns, similarly to Sweden. China was the only one that managed to reach zero new daily COVID-19 cases, with a strict rigorous lockdown.

Among the most notable of the COVID-19 trends related to the vehicular travel was that all countries experienced decreases in traffic as the number of COVID-19 cases increased, even before government-mandated announcements. This suggests that public apprehension related to COVID-19 played a significant role in influencing individual travel making. As traffic decreased, the rate of COVID-19 cases slowed across all three countries. This was most notable in China, where no new COVID-19 cases were reported within just a few weeks following the drop in traffic. As lockdowns and government restrictions were put in place at the beginning of the study period, traffic did decrease more rapidly. It is therefore likely that government restrictions and fear of the pandemic influenced travel behavior by limiting discretionary trips. Combined with social distancing and other preventative measures, these trip cancellations likely led to fewer person-to-person interactions, which in turn could have led to the decreases in daily COVID-19 cases after the first peak. For US and Sweden, the result shows an indication that the more rapid the declines in traffic volume, the slower the growth in COVID-19 virus cases. Since “flattening the curve” and delaying the peak was a primary purpose of social distancing, these findings suggest that overall, governmental directives, as reflected through rapid traffic decreases, served their purpose.

In the US and Sweden, once traffic started increasing and Phased reopenings started occurring, COVID-19 cases started to increase despite low traffic volumes, ultimately reaching a peak 2nd peak in every state/country besides New York, with Florida experiencing the largest peak. Florida was the state in the US that started increasing traffic the fastest after the major decrease in the beginning of the study period. As Phased reopenings started occurring, traffic showed rapid increase across all states and countries, showing trend of normal traffic levels in all countries Massachusetts, Michigan, and Ohio. Ohio was the one with the most significant result of this, not having a single day of traffic being similar to 2019. This may indicate that for these US states and Sweden, the longer it took traffic to return to normal levels, the longer it took the second peak of COVID to occur.

Another interesting general traffic volume trend was that traffic conditions demonstrated periodic patterns of change relative to 2019 levels, particularly weekly Monday-to-Monday stepped increases. While most days of the week in 2020 were less than the corresponding 2019 days, weekend traffic decreases, (Sundays in particular) were more pronounced across most states during the analysis period. This was especially clear in Sweden during June to August when traffic resumed similar levels to 2019, but a significant decrease was still noted on Saturdays and Sundays. This is likely because weekend discretionary travel was impacted most acutely by the closure orders. A similarly notable trend in the graphs is the inverse relationship between traffic volume and COVID-19 infections. Another trend that can be seen in the figures are large increases and decreases during the holidays. This occurred since most holidays happens during a specific date and not day of the week. Since our analysis compared matching days of the week 2019 to 2020, these huge increases and decreases can be seen in all study groups. They were not incorporated in the analysis and can be disregarded for the purpose of this study.

By the end of the study period both Sweden and the US are experiencing a large third peaks. In most instances reporting an increased number of cases. Only Montana, Ohio and Illinois are showed a decrease in cases. Florida, New York, and Massachusetts were reaching the highest number of new COVID-19 cases than observed during December 2020.

Florida was the only state that did not enforce any restrictions at the end of the study period when the third COVID-19 peak started happening. In the rest of the states and Sweden, traffic decreased immediately after restrictions were put in place, showing that once again government restrictions influenced travel behavior. In Montana, Ohio and Illinois, COVID-19 cases declined rapidly after the restrictions were put in place. These were the states that also continued showing a decrease in COVID-19 cases at the end of the study period. Massachusetts and Vermont were not able to decrease COVID-19 cases, but after restrictions they managed to delay their third peak and a clear plateau in new cases can be seen.

Of the Countries and states, only China and Florida showed a return to pre-pandemic traffic levels. The rest of the US and Sweden continued to show decreases in traffic at the end of the study period. Some states showed a few days of similar traffic but decreases remained constant. Lowest traffic decrease at the end of the study period was Massachusetts with levels close to 30 percent. Sweden, Indiana, New Hampshire, and Ohio had levels near 20 percent decrease.

Traffic on both Urban and Rural showed a decrease during initial lockdowns, besides at states/countries where traffic was so low on one of the classifications it did not show and impact (Sweden, New York, Massachusetts). An interesting finding is that traffic volumes on urban roads were more affected by governmental directives, showing an instantaneous increase or decrease. That shows that the directives were more targeted towards activities and interactions that occur in urban areas such as business, restaurants, and school closure. Rural areas were less

effected by the pandemic, having more similar das of traffic than urban areas. People might travel more on the rural roads on their way home to shelter for the pandemic and remain in those areas as most people work from home.

A limitation of this thesis is that the study period did not incorporate the whole period of the pandemic. COVID-19 was clearly not over on December 31, 2020 and is still affecting every part of the world, as of writing this paper. Even reopenings and similar days of traffic are happening, as shown in our data, the world saw an increase of deaths, hospitalizations, and infections. As tourists returned to Florida in the middle of the year, traffic neared normal levels, and restaurants and stores reopened, Florida reached the highest second peak of COVID out of all states and showed that the daily deaths in mid-July were double that of the peak in April. The second waves of the pandemic continue to spread all over the world besides New York and China. COVID-19 reached record highs all over the world besides China during November and December and indications of continued increases are visible. The virus will continue to change and impact highway, rail, air, and public transit, modes throughout 2020 and into 2021 even with a vaccine being distributed throughout the world. The effects will be seen in the years that follow, and they will continue to be studied for some time. The first year of the viral onset period is critical, therefore the initial wave of the pandemic in the US, China and Sweden was the focus of this paper.

This research can be built upon and This research can be built upon by incorporating more study groups, looking at more states in the US, and more countries in Europe and other Continents. It would also provide great insight in extending the study period and seeing the effects of the COVID-19 vaccines that have been distributed throughout the world. Another interesting area that this research can be built upon is studying other modes of transportation

such as, public transit and commercial air traffic as a representation of public mobility. It would also be interesting to see how the decrease in traffic has impacted air pollution in the US, and other places in the world, and how that has been affected by the pandemic and government directives.

By providing readers a summary description of the trends and relationships between COVID spread and highway travel during the onset period of the virus during 2020 in three disparate locations of the world, this paper is meant to inform and educate decision-makers on the effects of governmental action during significant crisis events. While the focus here was on the COVID pandemic, it is thought the timing and extent to which public response can be observed relative to governmental restrictions during a major disruptive event can be used by both public authorities to evaluate and develop plans for similar future emergency and event conditions. It is also expected that the findings of this study can truly be beneficial to future researchers who continue to study various aspects of the COVID-19 pandemic and assess the public response to governmental actions.

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