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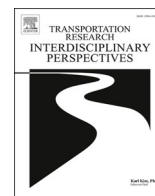
Transport impacts in Germany and State of Qatar: An assessment during the first wave of COVID-19

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ABSTRACT

Response measures to contain COVID-19 spread varied from country to country, some imposed a complete lockdown while some imposed partial restrictions. This paper compares the transport impacts of the COVID-19 pandemic for two countries having dissimilar characteristics, Germany and State of Qatar, based on the rates of infection and response measures. Secondary data, obtained from Google mobility reports, and primary data, collected from local agencies, were used for comparison purposes. The secondary data comparison from February 2020 to July 2020 indicated an overall decline in mobility for all commercial activities and an increase was noted for parks and residential locations for Saxony, Germany. For State of Qatar, the mobility was decreased to all places except residential locations. Further, the comparison for traffic volumes and the number of crashes during the first wave of the pandemic indicated that the reduction in traffic volumes, major, and minor crashes was coupled with restrictive measures rather than COVID-19 incidences for both countries. Further, the traffic volumes showed a statistically significant inverse linear relationship with the stringency index for both countries during weekdays as well as weekends. These results suggest that the policy measures are key in governing movement restrictions and containing the spread of pandemic rather than the number of COVID-19 incidences. Further, the authorities should monitor the traffic trends during the pandemic and enforce the traffic rules and regulations as soon as the movement restrictions are lifted.

Introduction

COVID-19 has affected peoples' lives all over the world since the beginning of 2020. Different countries have implemented different levels of restrictions on people's movements to contain the spread of COVID-19. These measures included the closure of schools to prohibit activities in the parks and limiting the number of people going outside (Zhang et al., 2021). These restrictions have affected the mobility greatly all over the world (Muhammad et al., 2020; Warren and Skillman, 2020). Similar to other countries, Germany and State of Qatar have implemented staged measures to reduce people's contact which has subsequently reduced the mobility. This paper compares the mobility patterns of residents of these countries by comparing traffic volumes and road safety data during the first wave of the COVID-19 pandemic with respect to the rate of infection and preventive measures imposed.

Since last year, many studies were undertaken to investigate the travel behaviour of people during COVID-19 pandemic. A study on travel behaviour before and during COVID-19 suggested that COVID-19 altered the mode preferences considerably but it constituted a small variation in the frequency of trips (Anwari et al., 2021). Abdullah et al. (2020) studied the travel behaviour of people from various countries before and during the COVID-19 pandemic to find out that people prioritized mode selection based on the pandemic related concerns such as infection concern, social distancing, cleanliness, and passengers wearing masks rather than general concerns such as travel time, cost, and comfort. Politis et al. (2021) analyzed the travel behaviour during COVID-19 restrictive measures in Greece. They found that overall trips were reduced by half, the trips by walking were increased, and public transport mode shares were considerably lowered. In another study, Eisenmann et al. (2021) assessed the mode changes in Germany during COVID-19 to find out that public transport became less popular and private cars became more important. Further, around one-third of respondents from car-free households missed having a car at home and some respondents planned to buy a bicycle. A study of traffic volumes on

Table 1
Overview of data.

Data type	Base data	Compared with	Details
Google mobility data	Mid Jan to Mid Feb 2020	15th Feb 2020–31st July 2020	Trends to six places of interest namely workplace, residential locations, transit stations, parks, retail and recreation, grocery and pharmacy for State of Qatar and Saxony
Traffic volume	last week of February 2020 (no school holidays)	March to April 2020 March to July 2020	Traffic volumes at 27 locations in Dresden Traffic volumes at 16 key intersections in Doha city, State of Qatar
Traffic crashes	Monthly average for March to July from 2017 to 2019	March to July 2020	Number of fatalities due to crashes, number of major and minor crashes for Saxony and State of Qatar

the roads of Northern Italy showed a significant reduction, more than 80%, in volumes compared to the same time in 2019. A longer period comparison, 2020 with 2015–2019 showed a reduction of more than 40% (Marinello et al., 2021). Further, an assessment of traffic volumes and safety during the initial months of COVID-19 indicated a reduction of about 30% and 37% in traffic volume and total crashes respectively in State of Qatar (Muley et al., 2021). Anke et al. (2021) conducted a survey and denoted that walking and cycling grew in importance while the overall number of trips decreased. They stated that while the effects of the pandemic are plainly visible, the effects of anti-COVID-19-measures are small and not clearly discriminable from other effects. These studies indicated that the travel behaviour of people all over the world changed due to COVID-19.

A study to assess time lag effects of the COVID-19 preventive measures on the transport system showed that the declaration of national emergency showed no policy lag, however, stay-at-home and release of restrictions had a lead effect on the mobility. Further, the magnitude of the effect was related to the sociodemographic characteristics, land use, and the type of transportation system in place (Bian et al., 2021). Additionally, the risk perception during travel for various modes of transport varied as per sociodemographic characteristics and the primary mode preference of the residents during the COVID-19 pandemic (Ozbilen et al., 2021). Earlier, it was found that the travel behaviour of people is affected by the psychological factors and cultural influences of society (von Behren et al., 2020). Further, the fear of the pandemic affected public transport usage based on the regional characteristics and life fixity levels (Kim et al., 2017). This indicates the need for assessing the differences in transport impacts of COVID-19 on the mobility and safety of two countries having dissimilar characteristics. Germany and State of Qatar are two countries located on different continents having different social, economic, and cultural characteristics and distinct transport systems in place.

The availability of a car is an important factor in mode choice selection as it affects primary mode choice and subsequently traffic volumes and safety. Habib et al. (2021) found that higher car availability increases more frequent out-of-home activities even during a complete lockdown. Further, people living in dense areas undertake more frequent trips compared to suburban areas. It should be noted that the car ownership rates were 575 per 1000 inhabitants for Germany (ACEA, 2021) and 415 per 1000 residents in 2018 for State of Qatar (CEIC, 2021). The numbers for State of Qatar should be taken with caution as it includes more than 75 % expatriate adults out of which 89 % of the total expatriate population doesn't have access to a car (Ibrahim et al., 2019).

State of Qatar and Germany also have different demographic characteristics and household structures with different lifestyles. These variables were found to affect the travel behaviour of residents

significantly (Mattson, 2012; Ha et al., 2020; Etminani-Ghasrodashti and Ardeshiri, 2015; Van Acker et al., 2016). Further, it was found that people's tendency to alter their frequency of travel and mode choice diminishes as household income increases (Vasudevan et al., 2019). The pandemic has shown a heterogeneous effect on mode shift and trip lengths based on the income of the respondents (Bhaduri et al., 2020).

In past, very few comparative studies were undertaken on transport impacts during COVID-19. Katrakazas et al. (2020) compared the driving behaviour and safety indicators for the Kingdom of Saudi Arabia and Greece using a smartphone application. It was found that the lockdown reduced traffic on the roads which lead to a slight increase in speed, mobile phone use, harsh braking and acceleration.

Germany and State of Qatar have imposed several measures to reduce the pace of pandemic spread. These countries were selected because they implemented preventive measures at early stages (although the level of restriction differs) and they targeted restricting similar activities such as education, shopping, work, and social/recreational. These measures have a direct impact on traffic flow and safety. The social differences of both countries and the differences in car usage and modal split may cause different reactions of the people to measures against COVID-19. Subsequently, the question arises, does the spread of COVID-19 and daily activities restrictions on mobility has a similar impact on traffic performance for those two regions? If differences or similarities in the impact are known, then this information can be used in future decision making to choose appropriate measures to limit mobility. In the long term, we aim at supporting society with a sound decision base for efficient control of mobility in exceptional situations and insights into traffic safety in these situations.

Research objectives

This paper answers the research question by comparing the trends in traffic volumes and the number of crashes for Germany and State of Qatar during the first wave of the COVID-19 pandemic. The specific objectives are set out as below:

● Conduct a macro-level comparison to assess mobility changes to various places of interest.
● Compare the daily traffic volumes trends and changes with that of the level before COVID-19.
● Compare the traffic volumes trends and changes with the level before COVID-19 with respect to government response measures, using stringency index.
● Determine differences in monthly traffic crashes (major and minor) compared to previous years and with respect to the stringency index.

Research approach

The comparison consisted of two steps. First, a macro-level comparison was made using Google mobility data for study areas. The size of the two countries considered in this study differs hence to make a comparison on similar ground, data for State of Qatar was compared to that of Saxony state, Germany. Further, in the second step, a detailed comparative analysis was undertaken using location-specific datasets for traffic volume and road crash datasets. Therefore, traffic count locations were chosen from Dresden in Saxony and Doha city in State of Qatar. Table 1 provides an overview of the datasets used for analysis. It should be noted that for the purpose of traffic volume analysis, the period of the first wave of COVID-19 was considered, which was from March to April 2020 for Saxony, Germany and from March to July 2020 for State of Qatar. Further, the weekday, non-workday and Saturday datasets were separated during analysis (see Table B1 and B2 for lists of holidays). It should be noted that for weekday comparison, data for Sunday to Thursday was used for Doha city while Monday to Friday was used for Saxony. Further, for the weekend comparison, data for Friday and Sunday was compared for Doha city and Saxony respectively as it will
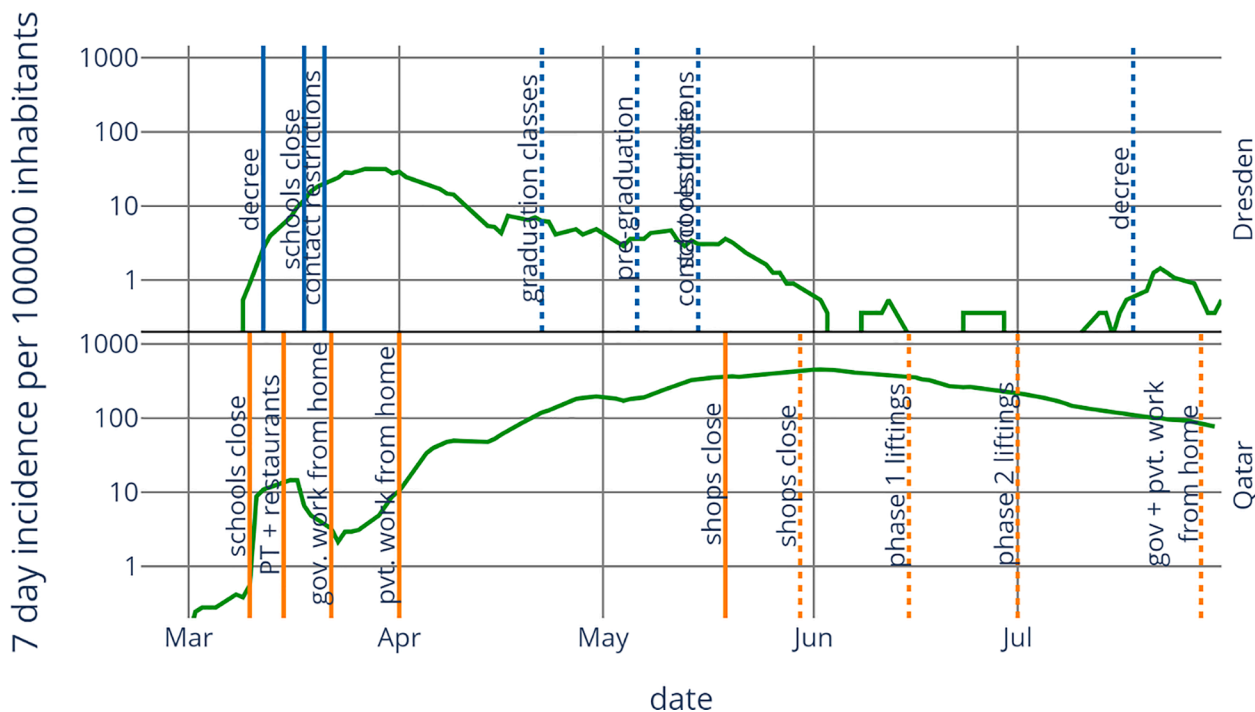
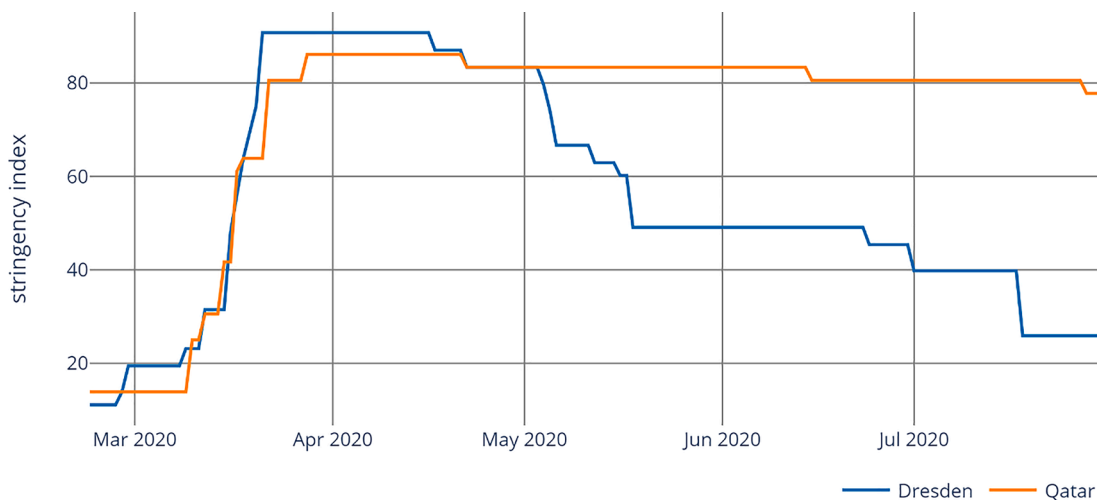**Fig. 1.** Trends for the 7-day-incidence and major response measures for Dresden and State of Qatar.

Fig. 2. Stringency index during the study period for Dresden and State of Qatar.

have similar behaviour. The traffic volumes were compared with the 7-day average of daily new COVID-19 cases and the stringency index derived from the preventive measures. For the traffic safety comparison, crash data from March to July 2020 was compared with the monthly average from three previous consecutive years (2017–2019) with respective months for both countries.

Data collection

Two types of data were used for comparison purposes; secondary data and primary data. Secondary data from 15th February 2020 to 31st July 2020 for Saxony and State of Qatar were obtained from the Google COVID-19 community Mobility report (Google, 2021). The mobility reports were generated based on the location data collected from people's mobile phones. The per cent changes were calculated with respect to late January 2020 (Newton, 2020). For Doha city, the primary traffic

data was obtained from Public Works Authority, ASHGHAL and traffic safety-related data was obtained from the website of Planning and Statistics Authority, State of Qatar (PSA, 2021). Further, the COVID-19 data was obtained from State of Qatar Open Data portal (Qatar Open Data Portal, 2021). The primary data for Dresden was obtained from Landeshauptstadt Dresden, Straßen- und Tiefbauamt and was acquired using permanent counting points as well as Traffic Eye Units. To maintain comparability with Doha city, all traffic data was collected at key intersections and main roads. Possible missing data were imputed from other data sources. Further, the traffic crash data for Federal State of Saxony was obtained from the Genesis database (STLA). COVID-19 data was downloaded from the open data platform of the city of Dresden (ODPDD). Like the traffic crash data, the COVID-19 data is recorded by hand, so that delays in reporting and registering may occur. That may cause the incidence (new COVID-19 cases per hundred thousand inhabitants) to rise in retrospect. We decided to use the incidence as given
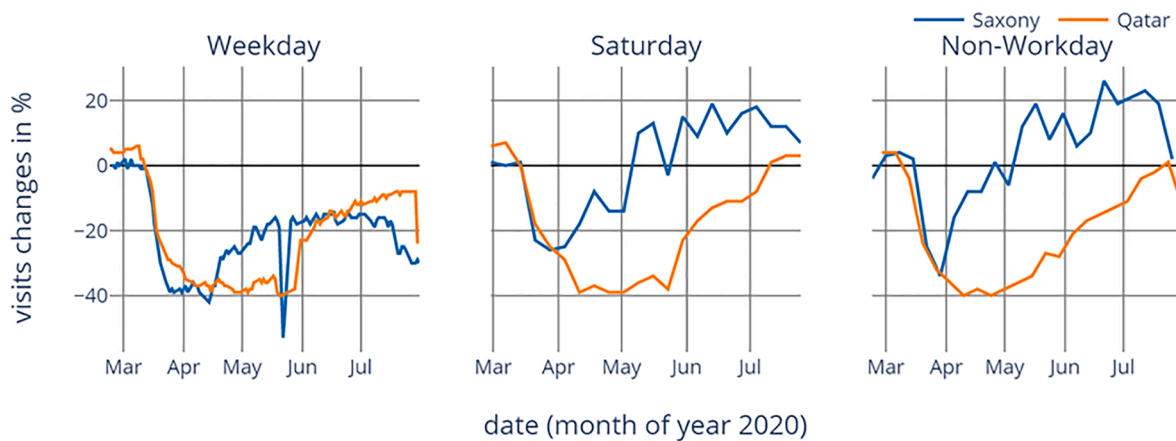
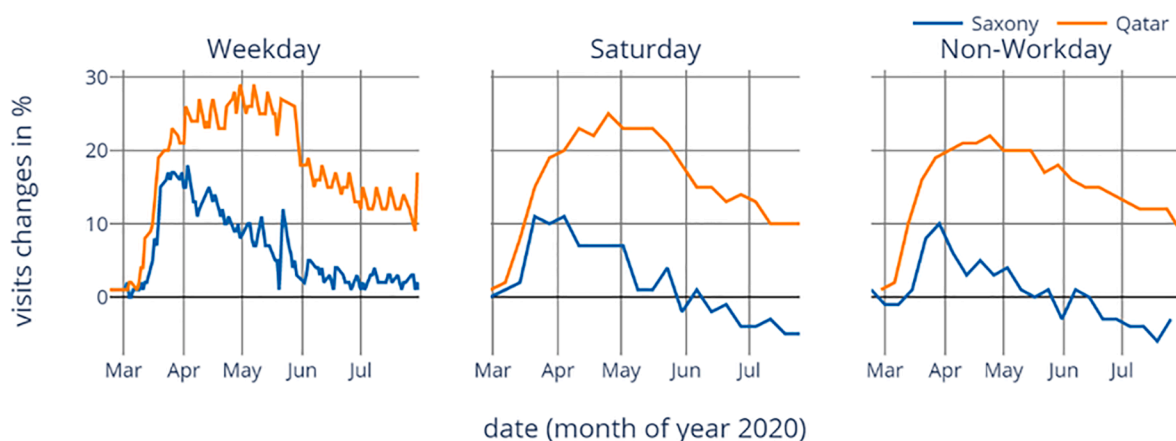**Fig. 3.** Mobility trends to workplaces for the study period.

Fig. 4. Mobility trends to residential locations for the study period.

on each day without late registrations because this has been the incidence to which people may have reacted.

Overview of COVID-19 cases and preventive measures

COVID-19 cases overview

As shown in Fig. 1 the number of cases increased greatly in mid-March and then started reducing in April and May for Dresden. Some rise in the number of cases were found in June and July showing signs of the upcoming second wave of the pandemic. For State of Qatar, the number of new cases increased steadily from March till starting of June, except for some decrease in Mid-March, during the initial days of the pandemic. The peak of the first wave started declining in June and July while still not showing values around zero.

Preventive measures (Stringency index) overview

Both countries implemented several staged measures, a summary of all the measures for both the countries is provided in with Tables A1 and A2. The preventive measures and their impacts in Dresden and State of Qatar were measured using the stringency index developed by the Oxford University COVID-19 Government Response Tracker (OxCGRT) project (Hale et al., 2020). The stringency index is a number between 0 and 100 and is based on the containment and closure policies, classified into eight categories (C1 to C8) and one health system policy (H1). These categories were ranked on ordinal scales considering their level of impact. The details of the indicator coding and stringency

index calculation are available in OxCGRT (2021). The Stringency indices were calculated considering State-specific response measures for Dresden as the responses varied from state to state in Germany based on the level of contamination. For State of Qatar, the available indices from the source database were cross-checked for accuracy and found appropriate; hence they were used as it is. Fig. 2 shows that both countries initiated anti-COVID-19 measures before March 2020 and intensified them in March 2020. From mid-April 2020, Dresden started to loosen the measures stepwise reaching a plateau of stringency index 50 in the middle of May ending with a value of 25 by end of July. This variation is in contrast to State of Qatar where the stringency index reached a value of 80 by mid-March 2020 and remained steady until the end of July.

Mobility trends

The Google mobility data was used to compare the trends to various places of interest during the COVID-19. It should be noted that data for special days / public holidays were excluded from this analysis. A list of public holidays used for this study can be found in Appendix B. Overall, the trends showed significant changes in mobility to all places of interest during the COVID-19 pandemic. However, as the number of COVID-19 cases reduced or restrictive measures were released the changes to the mobility reduced.

The mobility trends to workplaces (Fig. 3) showed a reduction on weekdays throughout the study period for both countries. On Saturdays and non-workdays, State of Qatar followed a similar trend to the weekdays with lesser trips compared to baseline. However, the trips started matching the baseline values in July 2020 after the first wave
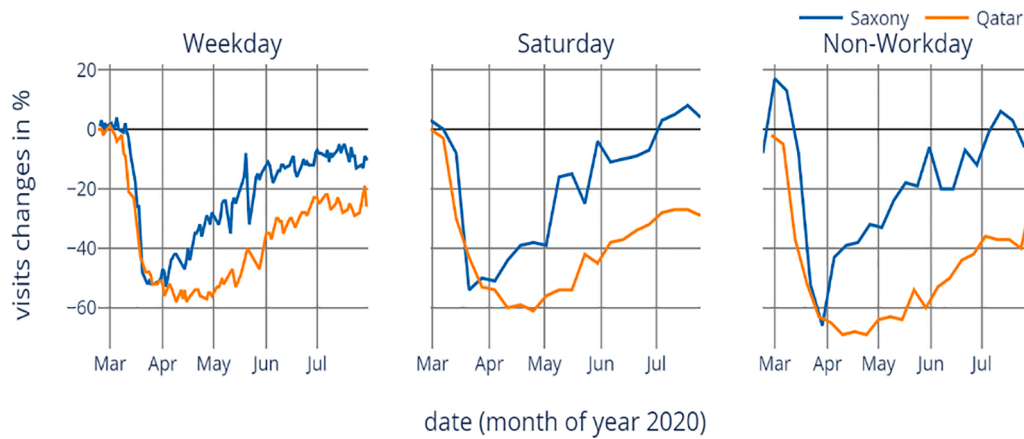
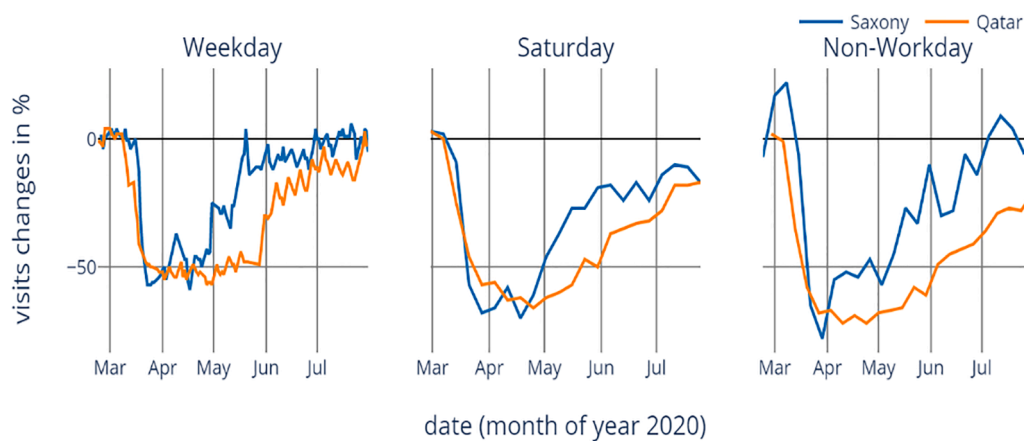**Fig. 5.** Mobility trends to transit stations for the study period.

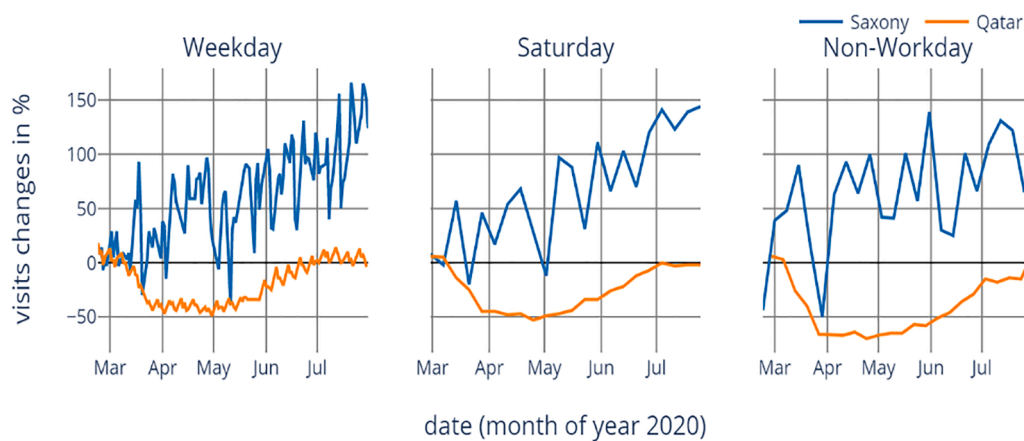**Fig. 6.** Mobility trends to places of retail and recreation for the study period.

Fig. 7. Mobility trends to parks for the study period.

subsided. For Saxony, the workplaces trips exceeded the baseline values after May 2020 and showed an increase of up to 20–25% in the non-weekdays. This increase can be explained by an increase in staggering work involving the weekend.

On the contrary, mobility to residential locations, increased by 20% to 25% on weekends and up to 30% on weekdays for State of Qatar (Fig. 4). The increase was higher during April-June 2020 when COVID-19 was in peak stage and all restrictive measures were in place. No drop-in mobility was observed with respect to baseline. Similarly, for Saxony,

the highest increase was more than 15% on weekdays, and on weekends, the maximum increase of 10% was observed during March-April 2020. Further, a reduction in mobility of up to 5% was observed on weekends during June-July 2020. It is interesting to note that for Saxony the baseline residential mobility was reached during the beginning of June while for State of Qatar a decrease of about 12 per cent was observed until July. This is remarkable because the workplace mobility was similar in both countries for weekdays until the beginning of the summer holidays in Saxony on July, 20th.
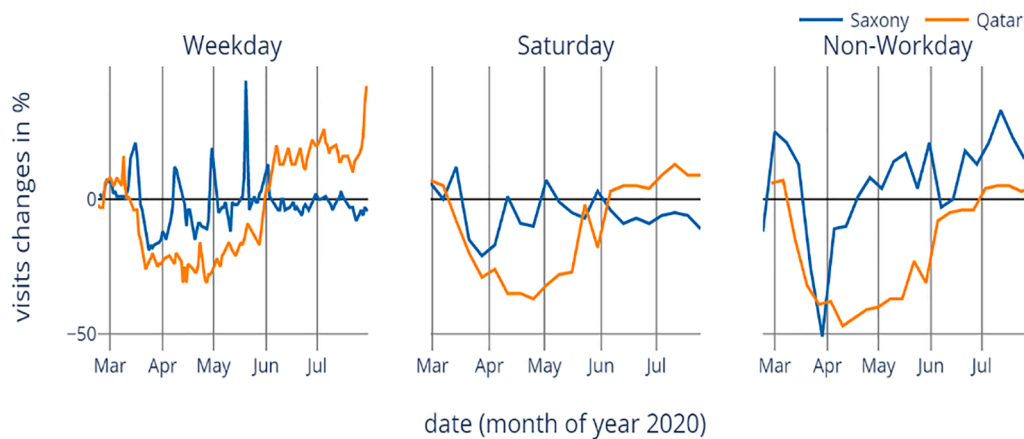
Fig. 8. Mobility trends to grocery and pharmacy for the study period.

Fig. 9. Daily mean traffic volumes for the study period for Dresden.

The trips to transit stations have shown similar trends for both countries (Fig. 5) observing lower trips throughout the study period on weekdays with a maximum reduction of 50–60% compared to the baseline. On Saturdays, the trend for State of Qatar was similar to that of weekdays but for Saxony, the trend was similar to weekdays initially, but some increase in trips was observed in July 2020. On non-workdays, a sudden drop was observed in March 2020 for Saxony, but the trend later matched with that of Saturdays. For State of Qatar, the non-workday trends were similar to other days with some lesser reduction in July showing signs of increased transit usage.

The trends for the retail and recreation trips (Fig. 6) were very similar to that of the trends for transit stations for both countries and all days. However, the amount of reduction was higher than the reduction for transit station trips. For State of Qatar, the trips were below baseline values for the entire study period, however for the case of Saxony, the trips were slightly higher than baseline values in July 2020.

The trends to the parks showed a lot of fluctuations on weekdays trips for both countries with Saxony having higher spikes and State of Qatar having smaller variations (Fig. 7). For Saxony, the trips to the parks were higher than the baseline values of up to 150% for almost the entire study period except for a reduction below the baseline for a few days in April and May 2020. On the contrary for State of Qatar, the trips to parks were below baseline values for all days with a maximum reduction of 50% on weekdays and Saturdays and more than 50% on non-workdays.

For the trips to grocery and pharmacy centres (Fig. 8), weekdays observed a lot of variations with Saxony showing some reductions in

April-May 2020 followed by higher increases (spikes). Further, a small reduction was observed during June-July 2020. For State of Qatar, a reduction of up to 30% was observed during April-May 2020 and an increase in trips by up to 20% was seen in June-July 2020. On Saturdays, Saxony witnessed a reduction in trips throughout the study period with a maximum reduction of 20% in April 2020, while State of Qatar, followed a similar trend to the weekdays with a similar reduction in trips. On non-work days, Saxony showed a sudden drop in trips at the end of April 2020, during other times the trips were 20–30% higher than the baseline values. For State of Qatar, the trend was similar to other days with a decrease of more than 40% in April 2020.

In general, it can be stated that there was a steep decline in Saxony mobility during March 2020 that concerned all commercial activities (less steep for daily goods) but an increase in mobility to residential places and parks. Whilst for State of Qatar, a decrease in mobility in all areas was noted except residential places. The decrease in mobility lasted longer for State of Qatar (until the end of July 2020) whilst in Saxony, there was an almost immediate increase in mobility leading back to baseline values for most of the areas after the collapse in March 2020.

Results

trends

Trends for weekdays

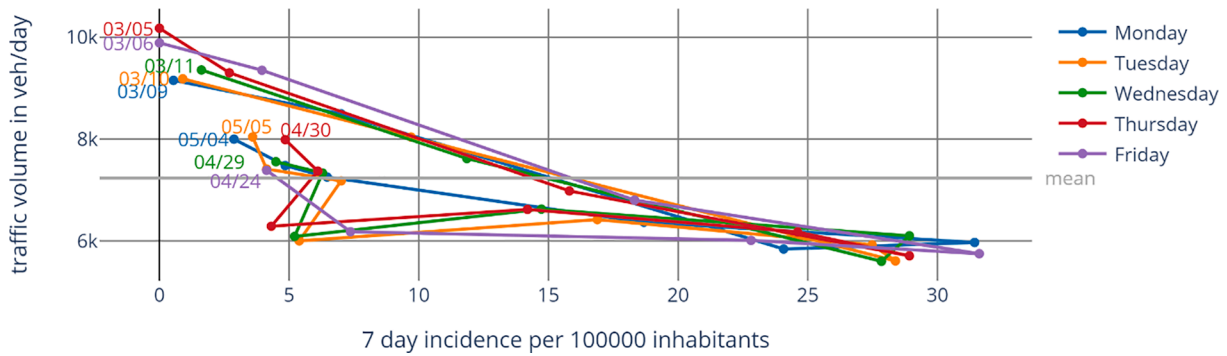This section presents the traffic volume trends for Dresden and Doha

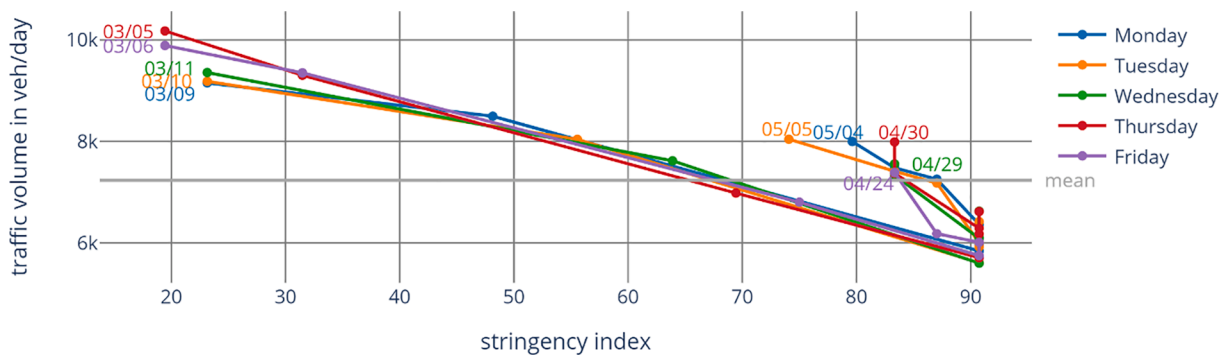**Fig. 10.** Traffic volume trends for Dresden on weekdays (March – April 2020).

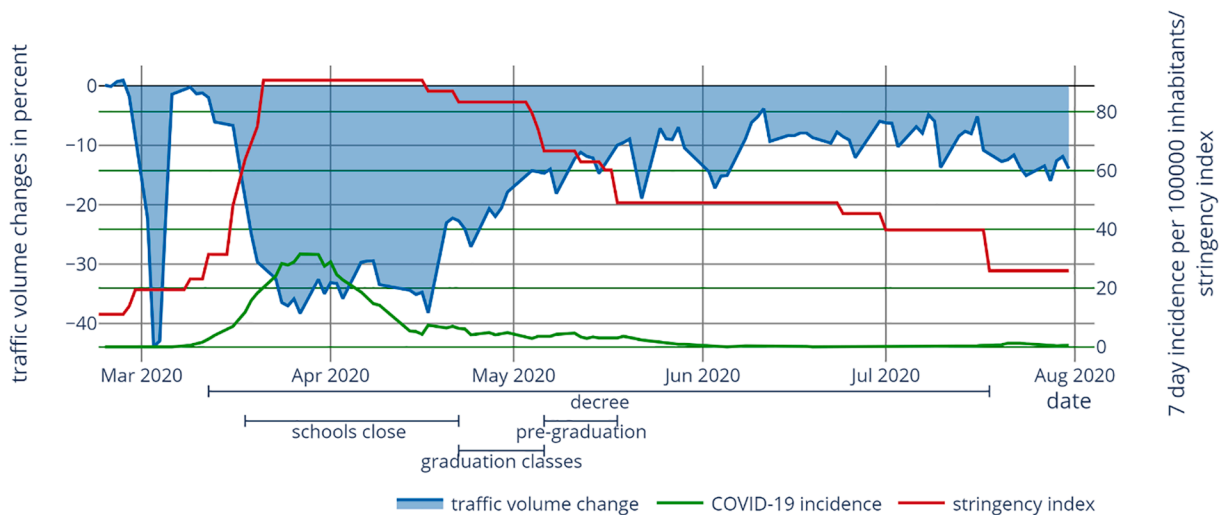**Fig. 11.** Traffic volumes w r to stringency index on weekdays for Dresden.

Fig. 12. Traffic volume changes w r to baseline for Dresden on weekdays.

during the first wave of COVID-19. According to Fig. 9, the daily traffic volumes of Dresden decreased in March and increased again in April 2020 to reach a steady volume by mid-May before a small drop in July 2020. All days of the week showed similar behaviour. During the initial days, at low COVID-19 incidences, higher traffic volumes were observed (Fig. 10). The traffic volumes started decreasing during the second week of March 2020. Later, as the peak approached the traffic volumes reduced sharply/significantly and were associated with the movement restrictions. As the number of incidences reduced, the traffic volumes stayed at a lower level and increased later again. Overall, the trend was similar to a right side/hand curve. It should be noted that the traffic volume increase after the reduction of the incidence was higher for

Mondays compared to other weekdays.

For all weekdays, as the stringency index increased the traffic volumes decreased linearly during initial preventive measures (Fig. 11). At the highest restriction level, the traffic volume increased steadily. Later, as the release of preventive measures was announced, the traffic volumes started increasing with the reduction in stringency index. Overall, an inverse linear relationship was observed between traffic volumes and stringency index. The bivariate correlation analysis showed that the traffic volumes on weekdays were strongly correlated with stringency index (*spearman's* $\rho = -0.676$, $p < 0.001$) and 7-day-incidences (*spearman's* $\rho = -0.649$, $p < 0.001$).

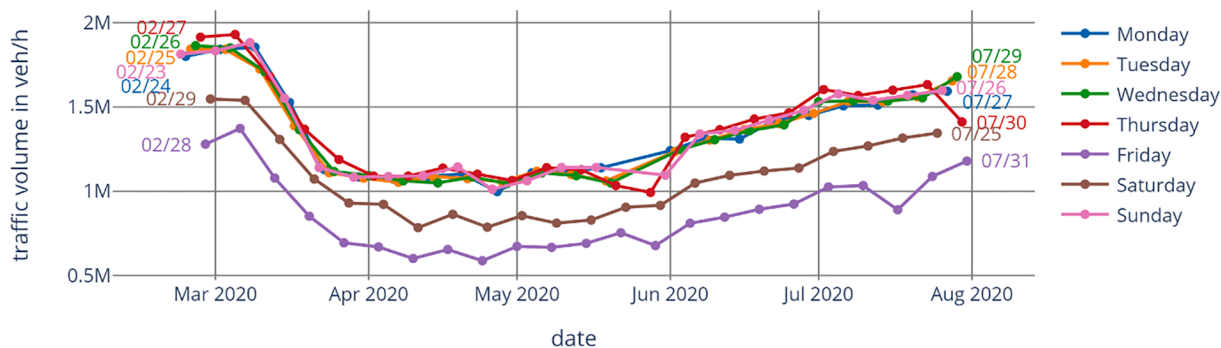It is interesting to note the steep drop in the traffic volumes of 43% at

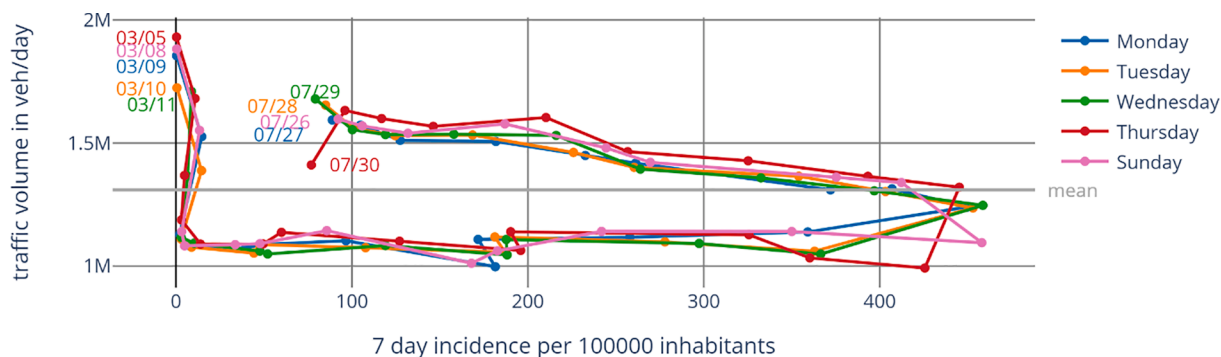**Fig. 13.** Daily mean traffic volumes for the study period for Doha city.

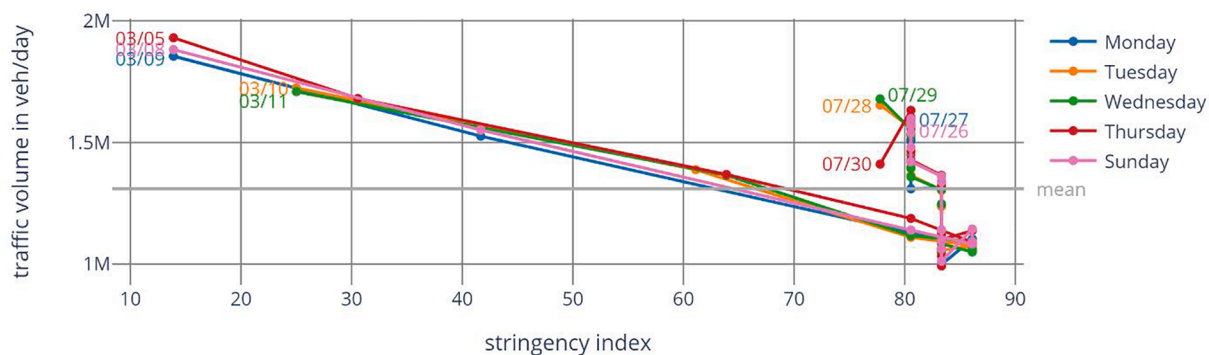**Fig. 14.** Traffic volume trends for Doha city on weekdays (March – July 2020).

Fig. 15. Traffic volumes w r to stringency index on weekdays for Doha city.

the beginning of March 2020 when the first/initial cases were published in Saxony (Fig. 12). Additionally, the second large decrease started after another general decree came into action in mid-March 2020. The phase of almost standard traffic volumes between the both descends is marked by the absence of most measures. The general decree in mid-March led only to a slight decrease in the first days of its effectiveness. When people anticipated the school closure the descent got steeper. With the school closure, the mobility in Dresden declined further to a maximal decrease of 35% and rose again with the first release even though many children were still homeschooling or only had emergency care. While the least reduction was observed from June onwards when only a general decree including slight contact restrictions was in place without specific movement restrictions. This duration was also associated with the lowest COVID-19 incidences and a lower stringency index. This behaviour suggested that the first decrease was coupled with the detection of the COVID-19 incidences while later on the regulations or stringency index became decisive. Overall, the shapes of the curves for COVID-19 incidences and stringency index were similar and traffic

volume reductions exhibited an opposite curve.

The daily traffic volume trends for Doha are shown in Fig. 13. The traffic volumes decreased by about 40% in the second half of March 2020. Later, the volumes were stable until the end of May where some further reduction was observed. Further, the traffic volumes increased at a low rate till the end of July. Fig. 14 shows the traffic volumes on weekdays with respect to the 7-day-incidence. The curve first saw a left side shape which is contrary to the curve for Dresden. Consequently, the traffic volumes in State of Qatar decreased steeply in the beginning and showed a slow increase later. The traffic volumes dropped significantly during the initial stages of the COVID-19, this might be due to sudden closures of educational institutions and commercial establishments announced by the government authorities. The traffic volumes remained constant as the number of new cases increased. Once the cases were reduced the traffic volume started to show a slow increase. However, the increase did not reach the initial stages when minimum COVID-19 cases were detected and no movement restrictions were imposed. It should be noted that all weekdays followed a similar trend, unlike Dresden. From
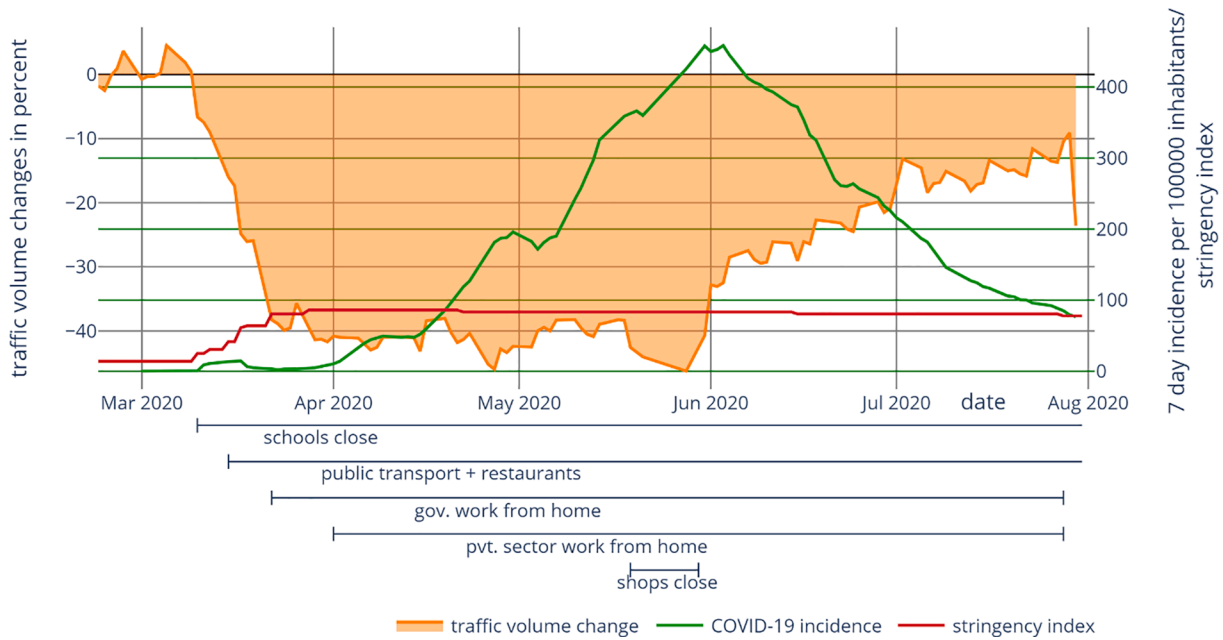
Fig. 16. Traffic volume changes w r to baseline for Doha city on weekdays.

Fig. 17. Traffic volumes trends for Dresden on weekends (March – April 2020).
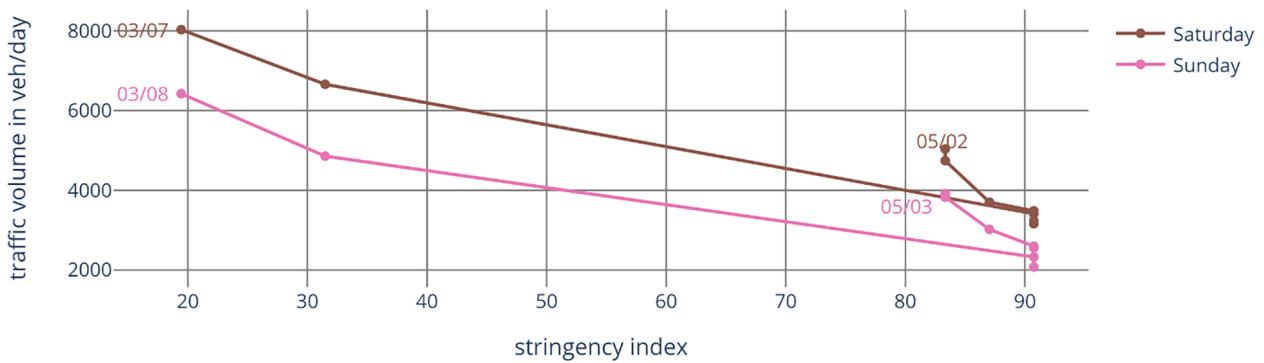
Fig. 18. Traffic volumes w r to stringency index for weekends for Dresden.

Fig. 15 it can be seen that the traffic volumes decreased as the stringency index increased until it reached its maximum value. Further, an increase in traffic volume was observed for a given stringency index, this was due to the partial relaxation of preventive measures coupled with a decrease in new COVID-19 cases. This trend/curve is similar for all weekdays which also matched with the trend observed for Dresden.

The bivariate correlation analysis indicated that similar to Dresden, the traffic volumes were strongly correlated with the stringency index

($spearman's$ $\rho = -0.847, p < 0.001$) and 7–day-incidence ($spearman's$ $\rho = -0.380, p < 0.001$).

Fig. 16 shows the percentage changes in traffic volumes over time along with the major movement restrictions and stringency index. The traffic volumes reduced significantly throughout the study period except for a minor increase during the initial days when the number of incidences was lowest. The initial reduction in traffic volume was associated with a higher stringency index.
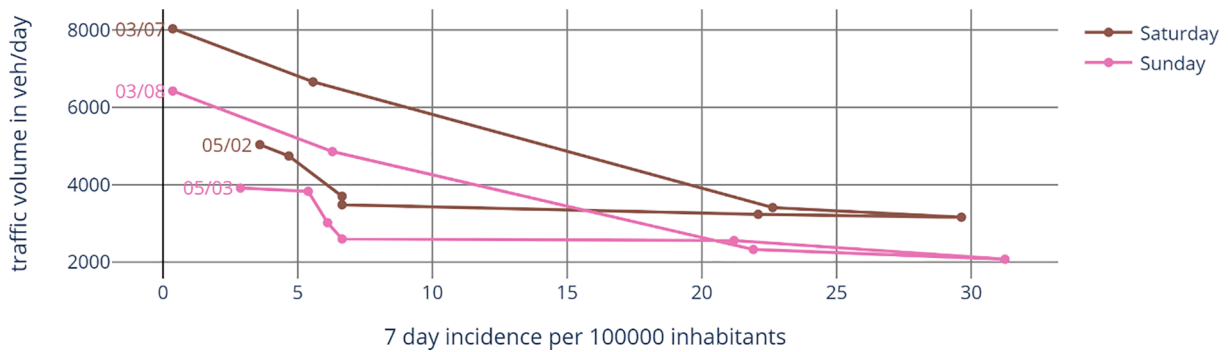
Fig. 19. Traffic volumes trends for Doha city on weekends (March – July 2020).

Fig. 20. Traffic volumes w r to stringency index for weekends for Doha city.
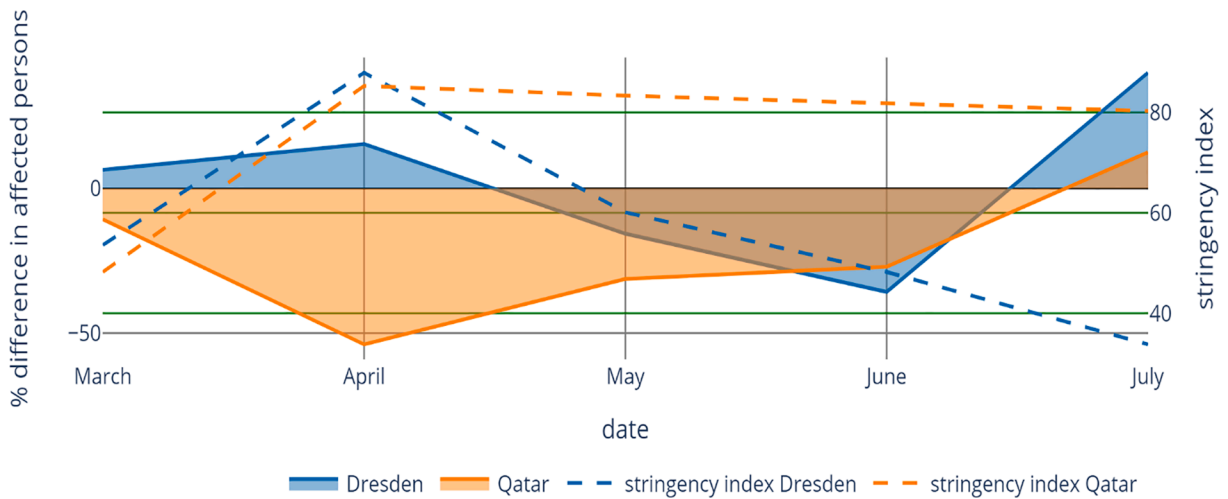
Fig. 21. Variation in fatalities due to crashes for Dresden and State of Qatar during 2020.

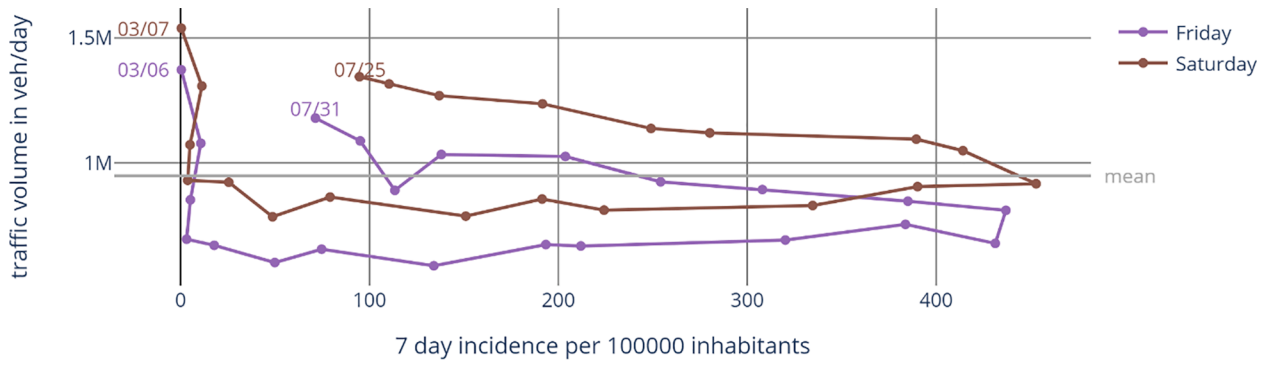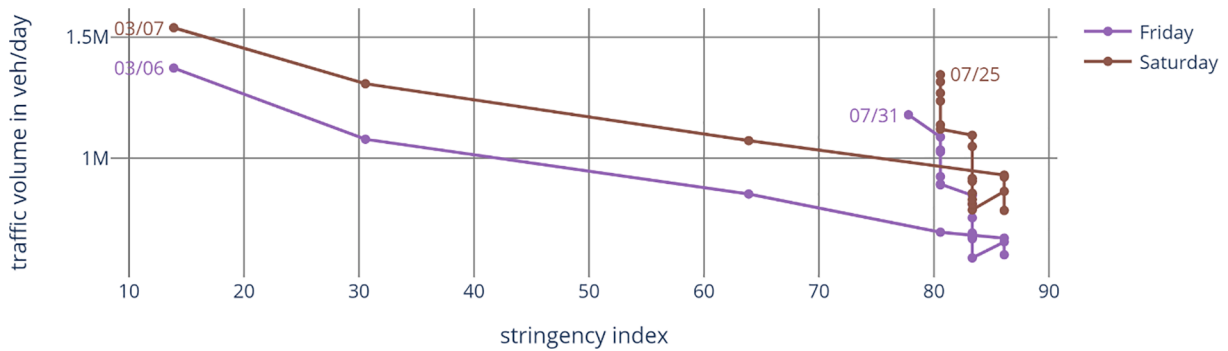Later, the stringency index was constant hence it was not related to any volume changes. The maximum reduction of up to 45% was observed during May and June 2020 when COVID-19 was in the peak stage with the highest number of incidences and all restrictions in place. As the restrictions were relaxed the traffic volume reductions were lesser. This suggested that the decrease in traffic volumes was mostly coupled with movement restrictions rather than the new COVID-19 cases, similar to Dresden.

Trends for weekends

Although for the weekends the magnitude of traffic volumes in Dresden was less, the trend was similar to that of weekdays having a right side curve. Both days showed the same qualitative behaviour

having about 25% lower volumes (Fig. 17).

The volume changes on weekends followed a similar trend to that of the weekdays showing a reduction in volumes with an increase in stringency index and an increase in volumes with the release of preventive measures that is a reduction in stringency index (Fig. 18). The bivariate correlation analysis indicated that similar to weekdays, the traffic volumes are statistically correlated with stringency index (*spearman's* $\rho = -0.776$, $p < 0.001$) and 7-day-incidences per 100,000 inhabitants (*spearman's* $\rho = -0.717$, $p < 0.001$) for Dresden.

For Doha, the weekend trend was similar to that of weekdays showing a left side curve (Fig. 19). The traffic volumes were lesser compared to weekdays and traffic on Saturdays were about 25% higher than on Fridays which is very similar to the Dresden trend. This might be

Fig. 22. Variation in major crashes during COVID-19 for Dresden and State of Qatar.

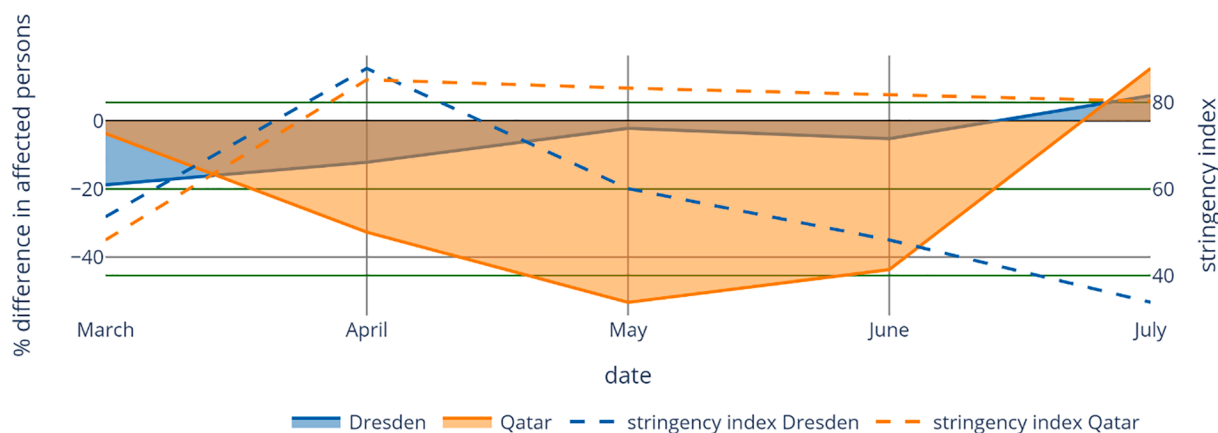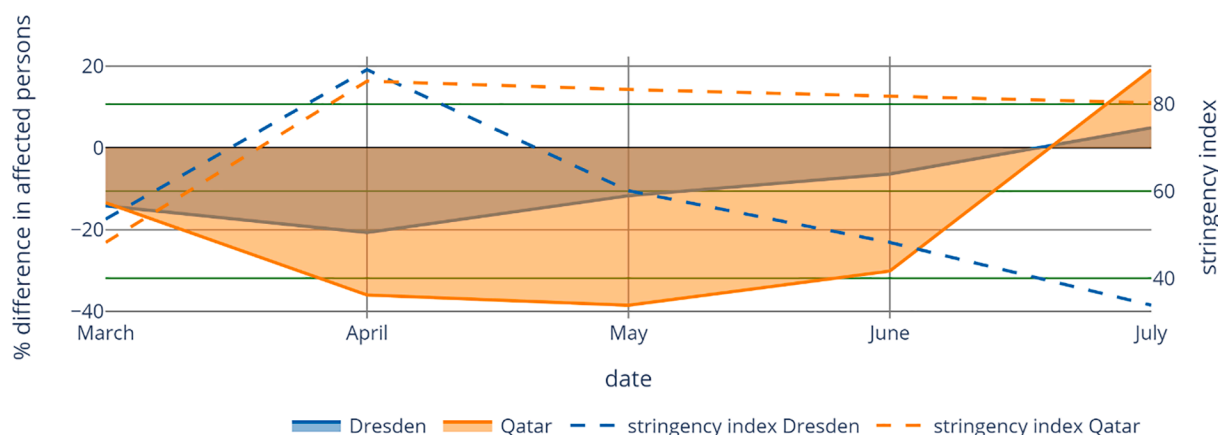**Fig. 23.** Variation in minor crashes during COVID-19 for Dresden and State of Qatar.

because State of Qatar observes a holiday for all sectors on Fridays and Saturdays most of the private sector offices observe a working day. It is interesting to note that for both countries, these differences between working Saturday and non-working Sunday/Friday is stable also during the phases with closed commercial establishments.

Fig. 20 shows the relation between the stringency index and traffic volumes for both weekend days for Doha city. The curve/relationship was similar to that of the weekdays for both countries and weekends for Dresden. However, the increase in traffic volume after the phased opening announcement was much higher compared to that of the weekdays. Unlike the weekdays and Dresden trend for weekends, the traffic volumes for State of Qatar on weekends were not correlated with the stringency index. However, a strong correlation was observed between traffic volume and 7-day-incidences on weekends (*spearman's* ρ = -0.720, $p < 0.001$).

Overall, the trends for both cities showed similar trends for weekdays and weekends with weekends having about 25% lesser traffic volumes. The Dresden curves followed a left-hand curve during the study period. On the contrary, Doha city showed a right side curve. This difference in shape might be due to the differences in the duration of the first COVID-19 wave. However, both cities exhibited similar trends of a drastic reduction in traffic volumes after initial announcements of COVID-19 incidences. Later, the reductions or gain in traffic volumes were coupled/associated with movement restrictions rather than the number of COVID-19 incidences.

Crashes trends

Regarding the variation in fatalities, both regions showed a diverse

behaviour (Fig. 21). Dresden observed higher crashes compared to previous years in April and July 2020. This can be caused because of changed mode choices due to COVID-19 when inexperienced bicycle riders may involve in crashes more often than others. Also, the reduction in traffic volumes on the roads contributed to some aggressive/unsafe driving behaviour (Newton, 2020). For Dresden, the highest reduction of about 35% in fatalities was observed during June 2020 compared to previous years. The months during the peak of the first wave (+15% in April) and during the summer (+40% in July) experienced higher fatalities compared to the mean of the fatalities during previous years.

For *State of Qatar*, a reduction in fatalities was observed till June 2020 and an increase of about 10% was recorded during July 2020 compared to previous years. A maximum reduction of more than 50% was observed in April 2020 when all preventive measures were in place. The sudden increase in stringency index was coupled with the highest reduction and increase in fatalities for State of Qatar and Dresden respectively for April 2020. For all other months, as the changes in stringency index stabilized the reduction in fatalities due to crashes reduced for State of Qatar, while for Dresden, surprisingly, as the stringency index reduced the number of fatalities reduced except for July 2020.

The correlation analysis of the number of fatalities and stringency index did not show any statistical significance for both countries. Further, the number of fatalities were not statistically significantly different for both countries when compared to previous years. Crashes with severe injuries were reduced for both countries during this period except for July 2020 where an increase of about 7% and 15% was recorded for Saxony and State of Qatar respectively (Fig. 22). The proportion of reduction was considerably higher (more than half) for State

Table A1

Anti-COVID-19 measures in Dresden, Germany; first case in Dresden on March 9th, 2020.

Date effective	Date stopped	Action details
31.01.2020		Obligation to report corona cases for medical professionals
12.03.2020	18.07.2020	City of dresden issues general decree main measure: events with more than 1000 persons prohibited-100–1000 participants must be reported
13.03.2020		Czech Republic, Poland and Denmark close their borders.
13.03.2020	15.05.2020	Discontinuation of play operations at cultural institutions in the city of Dresden
16.03.2020	13.05.2020	At the borders with France, Austria, Luxembourg, Denmark and Switzerland, the German government is enforcing comprehensive controls and entry bans
18.03.2020	4.22.2020, 5.6.2020, 5.18.2020, 6.29.2020	Schools and daycare centres close (stepwise opening)
17.03.2020	13.05.2020	Entry ban for third-country nationals,
17.03.2020	–	Worldwide travel warning,
17.03.2020	13.05.2020	Restriction of non-essential travel to the EU
17.03.2020	20.04.2020	Closure of numerous businesses
17.03.2020	04.05.2020	Ministries begin to close
18.03.2020	13.06.2020	EU entry ban
20.03.2020	04.05.2020	DVB operate only according to a special timetable
20.03.2020	15.05.2020	Restaurants, hair salons and hardware stores also have to close
21.03.2020	15.05.2020	New general decree, contact resctrictions, exit bans, closing of further facilities
25.03.2020	03.04.2020	Closure of the weekly markets
01.04.2020	30.06.2020	Extension of contact restrictions until 19.4.
03.04.2020	–	Opening of weekly markets
08.04.2020	–	Begin switching the pedestrian demand lights (automatic instead of request triggered)
20.04.2020	–	Elimination of exit restrictions, opening of smaller stores
20.04.2020	–	Dresden provides 200,000 masks (to fetch at city halls)
20.04.2020	–	Mandatory masks in public transport and stores
22.04.2020	–	Opening of schools for graduating classes
04.05.2020	–	Federal and state governments agree on further relaxation of Corona measures. The focus is on opening playgrounds, museums, zoos and places of worship
04.05.2020	–	Opening of public offices
04.05.2020	–	Relaxations of contact restrictions in Saxony-Anhalt and other BLs.
06.05.2020	–	Opening schools to all pre-graduation classes and 4th graders
13.05.2020	–	Federal government decides to phase out systematic controls at Germany's external borders
15.05.2020	–	Wide openings in almost all areas
18.05.2020	–	Daycare centres in SN, elementary schools in SN start opening, gatherings of up to 50 people allowed
18.05.2020	–	Daycare centres mostly open
13.06.2020	–	Federal interior minister announces the extensive lifting of controls at German borders for citizens of almost all EU countries as of June 13
10.06.2020	–	Travel warnings extended (for countries outside Europe)
29.06.2020	–	Dresden's kindergartens and daycare centres resume regular operations
29.06.2020	–	Dresden's/Saxony's kindergartens and daycare centres resume regular operations.
30.06.2020	–	

Table A1 (*continued*)

Date effective	Date stopped	Action details
30.06.2020	–	Family celebrations with up to 100 participants and opening of music clubs allowed
		Ministry of health adopts phased approach for action in Corona hotspots
18.07.2020	31.8.2020	Many events with >1000 people allowed
24.07.2020	–	Federal and state health ministers agree on free tests for returning air travellers

of Qatar. This can be attributed to the longer prevalence of the first wave of COVID-19 and related restrictive measures for State of Qatar compared to Dresden. The variation in stringency index with the number of major crashes was mostly similar to the number of fatalities except for Dresden, which showed a higher reduction in April 2020 similar to State of Qatar. The bivariate correlation coefficient was not statistically significant for both countries between the number of major crashes and the stringency index. The major crashes in State of Qatar in May 2020 were statistically significantly different from previous years ($t = 11.371, p = 0.008$). For Dresden, no significant difference was observed for all months considered.

Similar to the major crashes, minor crashes were also reduced from March to June 2020 and an increase was observed in July 2020 for both countries (Fig. 23). The reasons are similar to those mentioned earlier. The amount of reduction was similar (about 14%) for both countries in March 2020 and it increased further. The amount of reduction increased in April 2020 to 20% and then gradually decreased for Dresden. For State of Qatar, the reduction increased to 35–38% in April and May 2020 and later decreased in June 2020 as the preventive measures were lifted. The variation of stringency index with the number of minor crashes was similar to the trends observed for major crashes for both countries. The minor crashes were correlated with the stringency index for State of Qatar (*Spearman's* $\rho = 0.964, p < 0.001$), while no significant correlation was obtained for Saxony. Further, for Saxony, the difference between minor crashes from June 2020 was significantly different from their previous year's values of the same month ($t = 7.544, p = 0.017$). For State of Qatar, the minor crashes were significantly different from the corresponding months of previous years for April ($t = 7.979, p = 0.015$), May ($t = 14.658, p = 0.005$), and July ($t = -6.351, p = 0.024$) for 2020.

In an earlier study, Katrakazas et al. (2020) found that the crashes in Greece were reduced by 41% during the first month of lockdown, showing a similar trend. For Dresden, the reduction was lower but State of Qatar reached a similar value. In general, both countries exhibited similar behaviour here, but the decrease in fatalities and major crashes for Dresden was quite unstable or low. Significance can only be assumed for March.

In general, Dresden observed an increase in fatalities during the peak COVID-19 stage that may be influenced by a higher number of (inexperienced) bicycle users, a higher amount of pedestrians, and higher speeds of vehicles during the first phase of the pandemic. This indicates that traffic safety needs to be monitored and enforced strictly after preventive measures are lifted to ensure minimal crashes. On the contrary, State of Qatar observed a reduction in fatalities during the peak COVID-19 stage. Further, the number of major and minor crashes were reduced for both countries until the traffic started coming back to normal conditions, with State of Qatar experiencing higher reductions compared to Dresden. This may be because of comparatively lower mode shifts and higher speed limits in the case of State of Qatar.

Conclusions

This study assessed how the transport sector demand and performance varied due to the COVID-19 pandemic for two regions namely, Saxony and State of Qatar, having different demographic,

Table A2
Anti-COVID-19 measures for State of Qatar; first case on February 29th, 2020.

Date effective	Date stopped	Action details
01.03.2020		People travelling from Egypt temporarily restricted
06.03.2020	31.12.2020	All State of Qatari citizens and citizens of the Gulf Cooperation Council countries entering the State of Qatar or travelling to other Gulf countries should use their passports and not their ID cards as of 6 March 2020.
10.03.2020	01.09.2020	closure of all schools and universities until further notice, all residents to avoid gatherings in public places, and avoid travel except if absolutely necessary, Ministry of Public Health bans hookah/ shisha in State of Qatar until further notice.
13.03.2020	01.09.2020	closure of cinemas, theatres, children's play areas, gyms and wedding venues, elderly avoid going out, State of Qatar Museums (QM) has closed all its museums and heritage sites to visitors until further notice, Doha metro temporary suspension
16.03.2020	01.09.2020	all public transport, taxi stopped, entry suspended to European countries and 14 days quarantine in effect, dinning in bars clubs stopped, football, health clubs, gyms closed
18.03.2020	15.06.2020	closure of shops, parks, mosques, residents advised staying home unless necessary
22.03.2020	28.07.2020	80% govt employees to WFH, driving schools closed, ban on all forms of gatherings
23.03.2020	01.07.2020	temporarily closing all restaurants, cafes, food outlets and food carts
26.03.2020	12.05.2020	closure of in-person money exchange and transfer service offices
27.03.2020	15.06.2020	completely shut down the non-essential businesses
29.03.2020	15.06.2020	(MoPH) has launched remote healthcare services, shut down all the following outlets: outlets serving hot and cold beverages, coffee shops and cafeterias, companies and commercial shops to operate from 6 am to 7 pm, suspension of the hearings of the court matters
30.03.2020	15.06.2020	Suspend some non-emergency health services
01.04.2020	28.07.2020	80% private sector employees to work from home, rest work fewer hours, Stopping the temporary home services system provided by cleaning, catering, and other hospitality companies, Reducing the number of workers who are transported by buses to half the capacity of the bus
03.04.2020	15.06.2020	Banned the movement of all types of scooters and 'Jet Ski' boats until further notice
09.04.2020	09.07.2020	Close the shops and suspend all commercial activities on weekends
22.04.2020	13.05.2020	No more takeaways: Cafes and restaurants can only home deliver orders
06.05.2020	15.06.2020	Reopening of industrial area with restricted entry
11.05.2020	15.06.2020	New entry and exit procedures to the remaining parts of the Industrial Area, from Street 34 to Street 54
12.05.2020	31.12.2020	Money exchanges in State of Qatar to reopen
13.05.2020	31.12.2020	Restaurants and cafes in State of Qatar can resume takeaway services
17.05.2020	31.12.2020	Wearing a face mask is compulsory when outside of the house
19.05.2020	30.05.2020	Halting most commercial activities until May 30
19.05.2020	14.08.2020	No more than two people are now allowed to be in the same vehicle. Exceptions for three people are made for private vehicles driven by the family driver, or transportation in taxis, group exercising will not be allowed
22.05.2020	31.12.2020	Mandatory to install and activate the EHTERAZ app when leaving the house for all citizens and residents
15.06.2020	31.12.2020	Removing the requirement for entry and exit permits to and from the Industrial Area, Phase 1 lifting of restrictions
01.07.2020	31.12.2020	Phase 2 lifting of restrictions, cancellation of entry and exit points to and from the Industrial Area
09.07.2020	31.12.2020	Cabinet revokes decision to close shops and commercial activities on weekends
28.07.2020	31.12.2020	Phase 3 lifting of restrictions

Table B1
Holidays in Germany in the investigation period.

date	Holiday
2020/04/10	Good Friday
2020/04/13	Easter Monday
2020/05/01	Labour Day
2020/05/21	Ascension Thursday
2020/06/01	Whit Monday

Table B2
Holidays in State of Qatar in the investigation period.

date	Holiday
2020/04/24	Start of Ramadan
2020/05/24	Eid al-Fitr
2020/05/25	Eid al-Fitr
2020/05/26	Eid al-Fitr
2020/05/27	Eid al-Fitr
2020/07/31	Eid al-Adha

socioeconomic characteristics along with distinct transport systems available. The evaluation was undertaken by comparing the traffic volumes and road safety statistics during the first wave of COVID-19 which affected these countries predominantly from March to July 2020. It should be noted that the first wave was mainly existent for two months for Saxony state and a prolonged duration of about five months for State of Qatar. The macro-level comparison for Saxony state and State of Qatar for Google Mobility data from March 2020 to July 2020 showed that overall the mobility decreased to various places of interest for both countries except to residential locations and parks for Saxony state and residential locations for State of Qatar. The maximum reductions of up to 60% were observed for trips to transit stations, retail and recreation on weekdays for both countries. This reduction to retail and recreation was up to 70–80% on non-work days for both countries.

The micro-level traffic volume comparison with respect to 7-day-incidences was undertaken for the period of the first wave of COVID-19. For Dresden, traffic data from 27 locations were used for March to April 2020. The maximum reduction of around 45% and 35% was recorded in the traffic volume during the initial days and when the schools were closed. The traffic volume comparison for State of Qatar was undertaken considering data from March to July 2020. With a sudden decrease in the initial time, the volume became quite stable. The maximum reduction of 45% was noticed when COVID-19 was at the peak stage and all restrictions were in place. Overall, the comparison showed that although the shapes of the curves were different for both the countries and the maximum reduction was around 45%. This amount exceeds the numbers described in the literature for Germany and State of Qatar but is lower than denoted for Italy or Greece against the background that State of Qatar has had a much higher stringency index than Dresden. The fact that both countries show the same reduction in traffic volumes can be explained by the differences in modal split and car availability in both countries. Consequently, the volume reductions were coupled with movement restrictions imposed by government authorities rather than the number of COVID-19 incidences. Further, the comparison of traffic volume variation with the stringency index showed that the traffic volumes were having an inverse linear relationship with the stringency index for both countries for weekdays as well as weekends. However, as the opening/release of restrictions was announced an increase in the traffic volume was observed for the given stringency index. The traffic volumes were statistically correlated with 7–day-incidences for both countries during all days. Further, a strong correlation was observed with the stringency index for all days for Dresden and for weekdays for Doha city.

The monthly crash data from March 2020 to July 2020 was compared with the monthly averages for respective months from 2017

to 2019. The comparison of fatalities resulting from crashes showed that the fatalities increased in March and April and later reduced during May and June before observing an increase in July 2020. This indicates that fatalities increased when COVID-19 was at peak and traffic volumes were lowest. The authorities need to understand the reasons behind this and formulate strategies to minimize these losses of lives. For State of Qatar, the fatalities were reduced for all months except July 2020. The maximum reduction noted was more than 50% in April 2020 when all restrictions were in place.

Further, the comparison of major crashes indicated that the number of crashes was lesser during the COVID-19 pandemic for both countries. However, the reduction was much higher for State of Qatar (maximum of more than 50% in May 2020) compared to Saxony state (maximum reduction of around 20%). The comparison of minor crashes also indicated a similar trend to major crashes for both countries showing reductions for all months except July 2020. The maximum reduction for Saxony was around 20% in April 2020 while for State of Qatar it was around 40% in May 2020.

Both the countries observed an increase in fatalities, major and minor crashes in July 2020 when the number of COVID-19 incidences was lower and the restrictions placed were being relaxed and as a result traffic flows were on a recovery path. This implies that after relaxing the movement restriction, authorities in all countries should prepare a plan to ensure that the system is ready with proper resource allocations to ensure the safe and efficient handling of anticipated traffic volumes. Statistical analysis showed that the stringency index was correlated with minor crashes only for State of Qatar, all other correlations of the stringency index with types of crashes were not statistically significant for Saxony and State of Qatar. Further, the number of major crashes for State of Qatar in 2020 in May, minor crashes for the months April, May, and July, and minor crashes for June for Saxony were significantly different from previous years' crashes for corresponding months. All the other types of crashes in 2020 were not statistically significantly different from previous years during the respective months for both countries. According to the literature, drivers show riskier driving styles which is a plausible explanation for the fatal crash numbers described in this paper (Katrakazas et al., 2020).

The results from this study suggested that although the two countries possess dissimilar characteristics, the transport impacts are similar. The traffic volumes were correlated with the number of incidences and stringency index. Further, the reductions in traffic volumes were associated with response/restriction measures rather than the number of COVID-19 incidences. School closure was the most effective restriction driving the traffic volume reduction.

These results will help transport planners in devising policies to manage traffic operations and measures to improve safety based on the magnitude of effects. The policies can be devised based on the measures implemented and their effect can be estimated in advance. One outcome is the need to further investigate the reasons for the higher number of fatalities in Dresden and the development of possible countermeasures. Researchers can use these results to propose new strategies to better manage traffic in future during emergencies or while suggesting temporary traffic management measures. Showing, that traffic volumes react significantly on measures both policy-makers as well as transport planners can act more quickly and with more certainty.

The reduction in fatalities, major and minor crashes also needs to be investigated for State of Qatar to assist authorities in planning to achieve similar results in future. The analysis presented in this study is limited to vehicular traffic only. To further quantify transport impacts the usage of other motorized and non-motorized modes need to be monitored to get a complete picture to assist in planning and strategy making.

Disclaimer

All views and results presented in the paper are solely those of the authors and do not necessarily reflect the official policy or position of any agency in State of Qatar or Germany. Assumptions made within the analysis are not reflective of the position of any State of Qatari or German government entity.

CRediT authorship contribution statement

Birgit Jaekel: Conceptualization, Methodology, Validation, Software, Data curation, Writing – original draft, Writing – review & editing. **Deepti Muley:** Conceptualization, Methodology, Validation, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

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

Appendix A

Appendix B

Appendix C. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2022.100540.

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