Quantifying the impact of COVID–19 preventive measures on traffic in the State of Qatar

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ABSTRACT

Ever since the beginning of 2020, the mobility of people and goods all over the world has been extremely limited as a result of movement restrictions imposed by local authorities as part of several other efforts to stop the wide spread of COVID–19 pandemic. The Supreme Committee for Crisis Management in the State of Qatar adopted the policy of incremental preventive measures that were adjusted based on the pandemic status. These actions involved several restrictions, aiming a balance between reducing the pandemic spread and the typical daily activities disturbance. This paper assesses the impact of pandemic response measures on traffic mobility by quantifying the holistic impact of the incremental measures at different stages on traffic volumes and traffic safety. Daily traffic counts from 24 intersections were collected every 15-min for several days, representing the traffic before and after implementing each preventive measure. Besides, a screenline was used to represent the traffic entering and leaving the Central Business District (CBD) in the City of Doha. The results show that the daily traffic demand distribution over the course of day was not affected by those preventive measures. However, an overall demand reduction of 30% in baseline traffic was observed for all studied intersections and the screenline when all preventive measures were active. Moreover, the analysis of traffic violations and the total crashes indicated a drop of 73% and 37% respectively. The results from this assessment will assist decision and policy makers, and planners to prioritize traffic management actions for future needs. Further, the findings can also be utilized for mega–event traffic management in the post-COVID era, such as FIFA World Cup 2022 and 2030 Asian Games.

1. Introduction

The novel Corona Virus (COVID–19) pandemic is spread over 220 countries and has infected more than 86,118,403 people all over the world which resulted in more than 1,860,834 million deaths as of January 5, 2021 (Worldometers, 2020; WHO, 2020), and imposed serious health issues for the entire humanity. To reduce the spread of infection, many countries have imposed stringent travel restrictions on people's mobility and businesses. Some countries imposed these restrictions gradually and some imposed them suddenly resulting in partial or complete lockdown (GCO, 2020a). These restrictions have changed the amount of travel and activities undertaken by individuals globally, which has a direct impact on traffic characteristics and related safety. For instance, Fig. 1 compares the reduction in mobility for

workplace-based trips for different countries, including the State of Qatar, between February 15–September 30, 2020 (Google LLC, 2020).

As there are changes in people's activities undertaken, the effects on mobility and safety will be evident during the pandemic. Before COVID–19, the world has experienced some epidemics such as MERS, SARS, Influenza (H1N1), and Ebola. Overall, these epidemics had much lesser impact compared to COVID–19 considering geographical spread, number of people infected, and severity of infection. Some studies were found on travel behavior and relationship between travel and spread of disease during the outbreak of these epidemics, however, no study was published on the assessment of traffic impacts during previous epidemics (Muley et al., 2020). Further, some studies were found on analyzing the impact of epidemics on freight transport, supply chain and logistics (Dasaklis et al., 2012; Jones et al., 2008; Queiroz et al., 2020).

Authors conducted separate extensive searches to verify this claim using various search engines and scientific databases. Some recent studies assessed the traffic impacts of the reduction in mobility due to COVID–19. The following section presents an overview of these studies dealing with traffic patterns and volumes along with traffic safety.

The effect of school closures on traffic in three university campuses was investigated in Italy (Favale et al., 2020). An abrupt change was observed in campus traffic patterns. The universities facing complete closure observed a 90% reduction in campus traffic while the university with partial closure experienced considerable incoming traffic.

A comparison of daily traffic volumes in South Korea from January to March between 2020 and 2019 showed that after the first confirmed COVID–19 case, the traffic dropped by 17.3% and in subsequent weeks the drop was around 23%–26%. Once the number of COVID–19 cases started decreasing, the traffic observed an increasing trend in March (Lee et al., 2020). The effect of restrictions imposed was assessed by comparing traffic data six weeks before and after implementation in Spain (Aloi et al., 2020). A comparison of traffic crashes data showed that the number of crashes reduced by 83.8% from 17.5 crashes per week to 2.83 crashes per week. This decrease was around 67% when compared with the average daily traffic. Further, data from traffic counters showed a 76% reduction in overall mobility due to reduced usage of private cars. Further, the trends in traffic patterns showed that the morning and midday peak traffic was dropped below usual afternoon traffic and afternoon peak did not occur.

In another study, Hudda et al. (2020) found that the closure of economic activities and statewide stay-at-home orders observed 71% and 46% drop in car and truck traffic respectively from March 27 to May 14, 2020 in Somerville. Further, the daily traffic volumes on I-93 was almost halved when compared to the same period in previous years. This reduction in traffic was also contributed to 60%–68% lower ultrafine particle number concentrations and 22%–46% lower black carbon compared to pre-pandemic conditions. Beck and Hensher (2020) studied the impact of the COVID–19 pandemic on household travel behaviors and selected mode of travel in Australia. They found that the first month of stricter social distance measures has an initial impact on travel behavior.

A comparison of 2020 highway volume data from Florida with that of the year 2019 data showed that the statewide traffic volumes were reduced by 47.5% by March 22, 2020 (Parr et al., 2020). The residents in South Florida at the epicenter of COVID–19 traveled more in initial phases while traffic inside and outside south Florida decreased considerably after school closures. Further, the traffic in urban areas of the state reduced much earlier compared to the reduction in traffic in rural areas. Also, it was observed that people first limited longer distance trips and made local trips for an additional week.

Oum and Wang (2020) used a traffic congestion economic model for urban communities to evaluate social-based optimal lockdown strictness on travel during the COVID–19 pandemic. They recommended that policy makers need to intervene to impose this type of lockdown. On the other hand, and from the traffic safety perspective, one study examined the traffic situation in California for 22 days after restrictions were imposed using a two-tailed *t*-test (Shilling and Waetjen, 2020). It was found that the daily number of crashes was significantly lower than similar period in 2019 and before imposing restrictions. The reduction in crashes accounted for savings of $40 million per day. The hospitals reported around 40% decrease in traffic crashes related cases and an almost 50% reduction in crashes related to pedestrians and cyclists. Additionally, the traffic volumes on highways reduced significantly by 20%–55%. However, this amounted to an increase in average speeds, by 1–4 mph, on some highways. Zhang et al. (2020) evaluated the impact of different travel modes on the spread of COVID–19 in China.

Oguzoglu (2020) assessed the effect of stay-at-home orders during March and April on traffic safety in Turkey using city-level and country-level reports. When the declines in both months were combined, it was found that around 200 deaths and 17,600 injuries were prevented from taking place. During stringent restrictions in April, the difference in difference estimates determined that the traffic crashes with death and injuries were reduced by 72% and 19% respectively. Furthermore, the crashes with material losses were reduced by 46%.

Brodeur et al. (2020) used country-level crash data for five states in the USA to study crash rates in a county per day using the Poisson count model. It was reported that the travel restrictions reduced the vehicular crashes by half. This contributed to a saving of $7 to $24 billion. Sarla (2020) reported that the complete lockdown in India resulted in a significant reduction in the number of traffic crashes. In one month, around 10,000 deaths due to traffic crashes were avoided compromising 200 deaths due to COVID–19. The effect of lockdown on traffic crashes in Tarragona province, Spain was assessed by collecting crash data from February to April 2020 and compared with before lockdown period in 2020 and equivalent period in 2018–2019 (Saladié et al., 2020). The results indicated that around 75% decline in the number of crashes
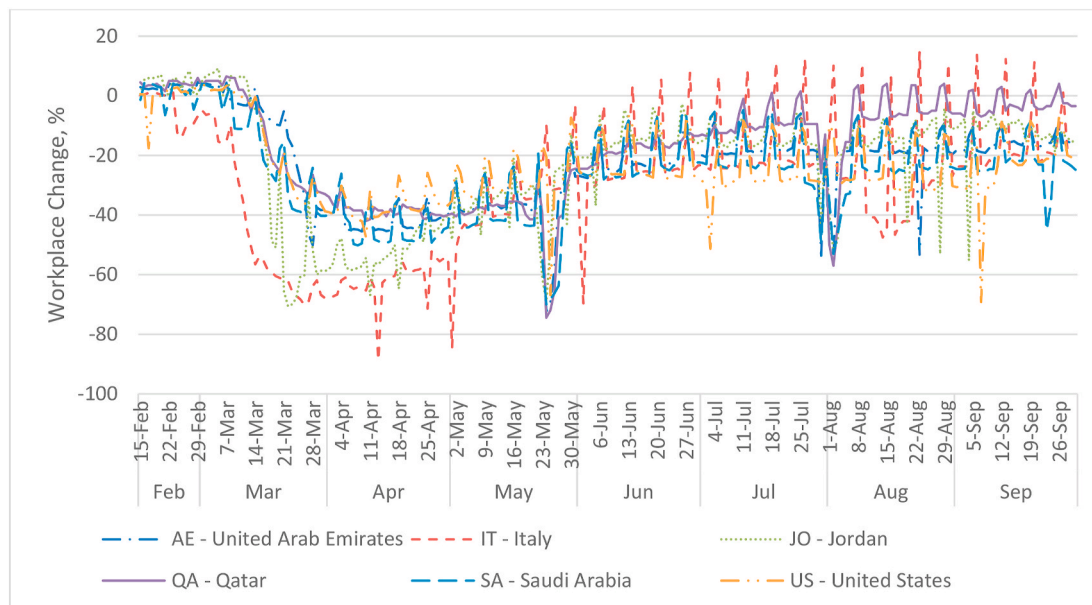

Fig. 1. The daily trend of workplace mobility changes (Feb 15 - Sep 26, 2020) (Google LLC, 2020).

during lockdown, while mobility reduced by about 63% when compared to the time before lockdown and 2018–29019.

An assessment of the short-term impacts of various policy measures implemented by the Colombian government and local authorities showed that there were changes in activity levels and travel patterns. The demand for motorized trips was reduced across the country resulting in a drop in congestion levels, transit ridership, and transport externalities (Arellana et al., 2020).

Extending the previous work done, this paper aims to quantify the traffic impacts of travel restrictions in the State of Qatar, to reduce COVID–19 spread, through assessing the impacts of COVID–19 mitigation strategies on traffic from mobility and safety perspectives. Mobility is assessed by quantifying the impact of movement restriction measures on the traffic condition on the road network, while traffic safety will be evaluated through analyzing the impacts on driving behavior traffic violations, and crash data.

2. Research objectives and approaches

The COVID–19 pandemic has a global effect on social life, economy, and public health. Its effects have extended to affect traffic mobility as well. The pandemic has reduced the demand for both private and commercial transportation systems.

Educational institutions (including schools and universities) and local businesses migrated from the classical mode into online learning and remote work environment, hence reducing traffic demand and consequently impacting traffic safety.

The main objective of this research is to determine the impact of the COVID–19 pandemic and staged preventive measures on traffic from two perspectives, traffic demand, and safety. To do so, the number of vehicles entering and leaving the City of Doha, (the capital and the largest city in Qatar) was investigated. Firstly, traffic entering and exiting the City of Doha before and after implementing a series of preventive actions are compared. Moreover, traffic before and after the start of the pandemic is compared. Further, the monthly crashes and violations were compared with those of 2019.

The outcome of this research can pave the road to identify the impact and effectiveness of each preventive measure on traffic demand and people movement, which will also provide the authorities with valuable information that reflects real-life conditions if these actions have to be implemented for the major upcoming sports events in the State of Qatar, such as FIFA World Cup 2022 or 2030 Asian Games.

3. The status of COVID–19 in Qatar

The first COVID–19 case was detected in the State of Qatar on February 29, 2020 (Qatar Open Data Portal, 2020). Then, the number of infected people has increased to exceed 100,000 positive discovered cases as of July 6, 2020. By September 30, 2020 the overall positive cases exceeded 125,000. Fig. 2 shows the trend of new daily infected cases and recovered cases as well (Qatar Open Data Portal, 2020). Since the discovery of the first case, it took 89 days to reach the point where the number of daily recovered cases has exceeded the number of newly discovered cases. Since July 15, 2020, the number of new cases is very close to the number of recovered cases (hence the two trends are almost overlapping).

Fig. 3 shows the cumulative curve of both infected and recovered cases over time (Qatar Open Data Portal, 2020). The cumulative infected cases kept a smooth accumulation but decreasing since early June 2020, while the recovered cases experienced a spike due to implementing a new protocol at end of May 2020 for the handling of COVID–19 patients by discharging the majority of patients with COVID–19 from healthcare facilities fourteen days after their first positive swab.

The figure shows that there was a jump (change of trend) started on May 29, 2020 (which is 90 days after the discovery of the first case) in recovered cases. This observation is consistent with the date when then the number of daily recovered cases exceeded the number of daily infected cases.

In terms of mortality trend, the first death case associated with COVID–19 was reported on March 28, 2020, only 28 days after detecting the first case. As of September 30, 2020, the total number of positive cases was 125,760 and 122,699 recovered cases, with 214 lost lives, and 2847 active cases that are under medical treatment.

4. Preventive mesures and implementation timeframe

The Supreme Committee for Crisis Management in the State of Qatar called the citizens and residents to commit to precautionary actions and initiated a set of preventive measures policies to reduce the spread of COVID–19 (GCO, 2020a). The first step was to temporarily ban inbound flights from countries where the virus has spread starting March 1st, 2020. Following the first step, the State of Qatar has imposed gradual restrictions over time that affected traffic mobility in general, such as closing educational and academic institutions and public parks, adopting online-based education and remote work policies, reducing the number of employees at the workplace, temporarily ban non-Qatari citizens to enter the State of Qatar through Hamad International
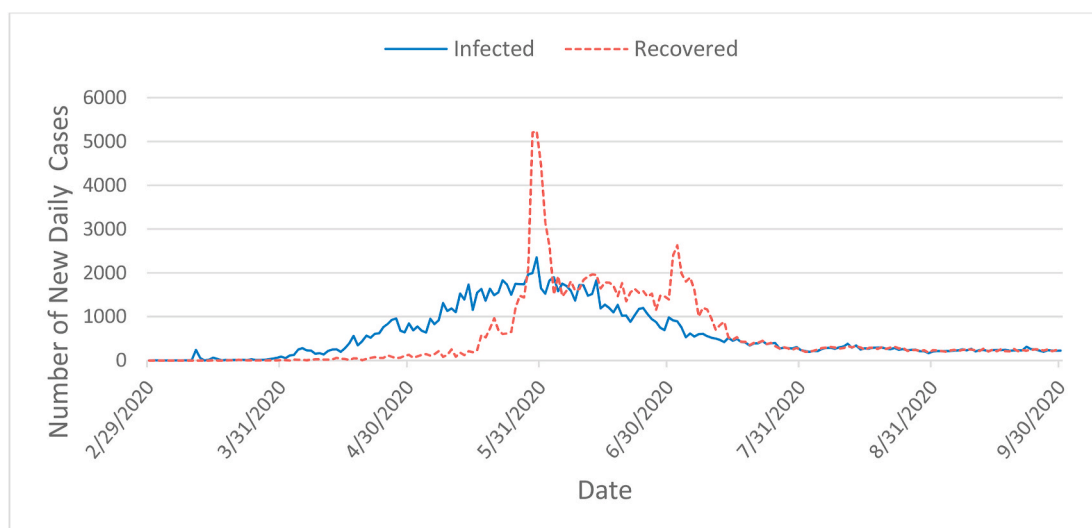

Fig. 2. The daily trend of newly infected and recovered cases in the state of Qatar (Qatar Open Data Portal, 2020).
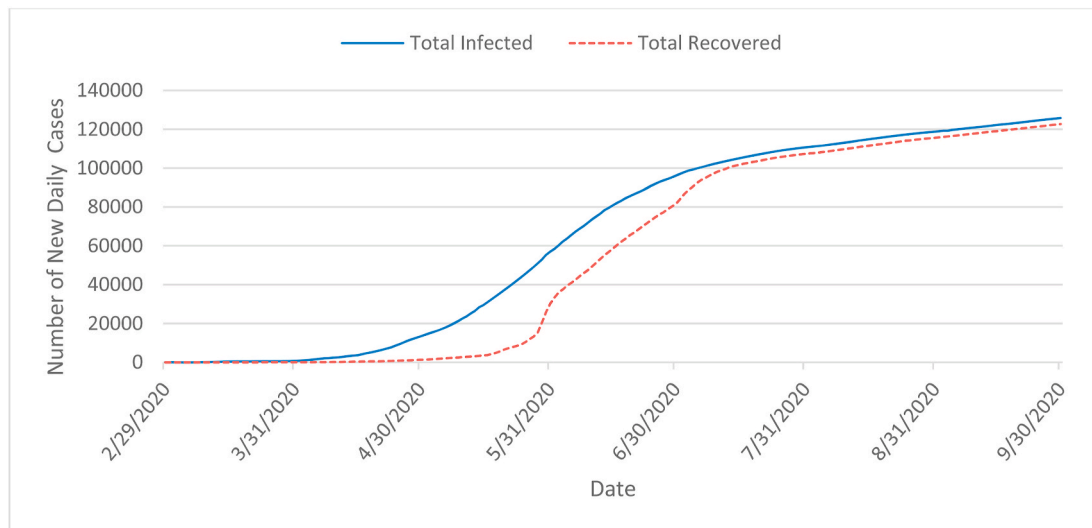
Fig. 3. The cumulative trend of infected and recovered cases in the state of Qatar (Qatar Open Data Portal, 2020).

Airport, and closing non-essential commercial activities (GCO, 2020a). To further understand the reduction of travel demand, traffic demands collected during February (Day 1, 2, and 3), which are representing the typical three days before discovering Patient Zero and before imposing any preventive actions, are averaged to represent the base-case scenario for comparison purposes.

Besides, traffic data were collected for an additional day after discovering the first COVID–19 case but before imposing any preventive measures (No preventive measure is implemented).

In other words, it reflects the personal perspective of individuals without the intervention of authorities in the State of Qatar. Lastly, measures 1, 2, and 3, described below, represent the set of three preventive measures implemented in stages, namely:

Measure 1: The closure of all educational institutions and restricting international flights from certain countries.
Measure 2: The closure of all commercial establishments (except pharmacies and food stores), taxi services, and public transport and banning international travelers from all countries. It also includes all the preventive measures adopted in Measure 1, cumulatively.
Measure 3: Limit the number of employees at the workplace to 20% and promote remote working for remaining employees for both public and private sectors. All non-essential travels are banned. It includes all the preventive measures adopted in Measure 1 and Measure 2, cumulatively.

The preventive measures discussed earlier are summarized in Table 1 corresponding to the dates used for analysis (GCO, 2020a).

5. Research Methodology

Two different datasets were obtained for this study; traffic demand data and traffic safety data. The traffic demand data were obtained from the Public Works Authority (ASHGHAL) and they are based on traffic detectors data at 24 signalized intersections. Fig. 4 shows the location of these key intersections. Besides, the figure shows an imaginary screen-line that is surrounding the main Central Business District (CBD) area within the City of Doha that is characterized for being an attraction area for businesses and residence. Therefore, it contains a dense and wide-spectrum of land uses, including residential units, towers and compounds, universities and colleges, institutional and governmental headquarters, private businesses, and commercial activities. The screenline selection takes into account the public transport services coverage, the metro, and buses. Concerning the traffic safety data, the monthly statistics about traffic safety data across Qatar were collected from the Planning and Statistics Authority, State of Qatar (Planning and Statistics Authority, 2020). The variation in the number of crashes and

Table 1
Details of the selected dates for traffic impact analysis (GCO, 2020a).

Day Code	Day Description	Survey Date	Day of Week
Day 1	• Typical day before discovering COVID–19 first case • Three weeks before the school closure	February 17, 2020	Monday
Day 2	• Typical day before discovering COVID–19 first case • Three weeks before the closure of non-essential commercial activities	February 25, 2020	Tuesday
Day 3	• Typical day before discovering COVID–19 first case • Three weeks before 80% of government employees to work from home, public transport closure	February 26, 2020	Wednesday
Baseline	• The average of the three typical days (Day 1, 2, and 3)	*Average*	*Average*
No Measure	• Working day during COVID–19 • No imposed preventive measures	March 4, 2020	Wednesday
Measure 1	• Working day during COVID–19 • Closure of schools, colleges, and universities • Closure of public parks • Restrictions on international travels from a few countries	March 11, 2020	Wednesday
Measure 2	• Closure of all commercial establishments (except pharmacies and food stores) • Closure of public transport and taxi services • Ban on international travels from all countries	March 18, 2020	Wednesday
Measure 3	• Two weeks after reducing the workforce at the workplace by 80% for public and private sectors • All non-essential travel banned	April 14, 2020	Tuesday

Fig. 4. The study intersections and the screenline surrounding the study area.

violations was determined from January 2020 to May 2020. These parameters were compared with respective values for the same month in the previous year that is 2019.

6. Data analysis

6.1. Observed overall traffic demand trends

Traffic demand trends for the 24 studied intersections and for selected days reported in Table 1 are summarized in Fig. 5 (for the daily traffic demand) and in Fig. 8 (for the AM and PM peak periods). The figures show clearly that the total traffic demand is decreasing after

implementing each of the three preventive measures.

For the hourly distribution of traffic, Fig. 6 shows that in general, the hourly distribution remains the same, with low traffic volume between 12:00–6:00 a.m. After which traffic demand starts to increase between 6:00–10:00 a.m. Traffic demand seems to remain steady throughout the rest of the day before it starts dropping from 5:00 p.m. till midnight. However, the four days before any preventive measures were taken have experienced a very similar hourly trend and demand volume. Fig. 6 also indicates that the morning peak period (AM Peak) is between 7:00–8:00, and the evening peak period (PM Peak) is between 13:00–14:00.

Since the traffic demand is expected to be reduced after implementing the measures, the ratios between hourly and daily demand for
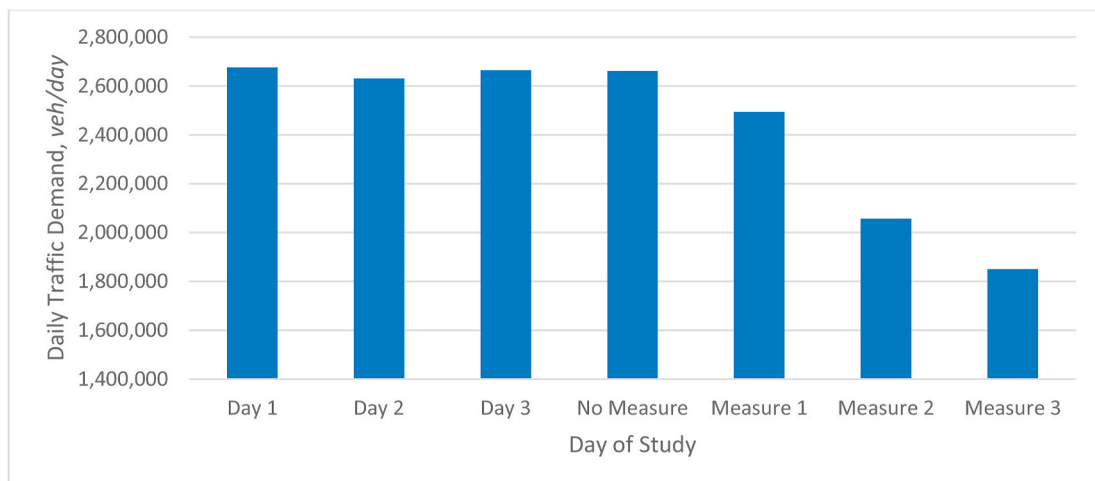

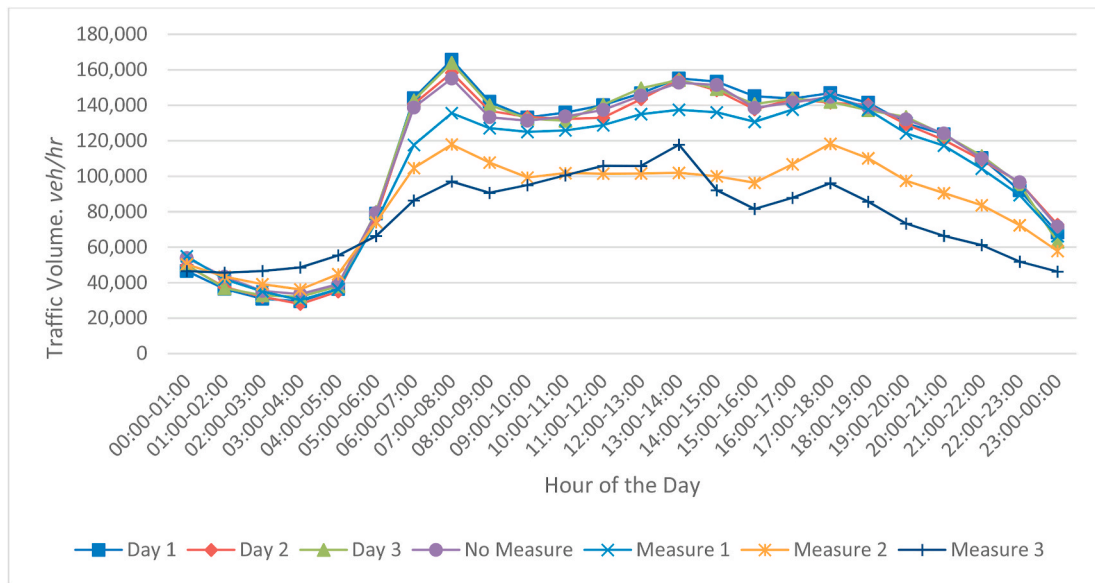**Fig. 5.** Total daily traffic demand for all intersections.

Fig. 6. Hourly variation in traffic demand (all intersections).

each day are plotted in Fig. 7 which indicates that the hourly relative distributions are very similar regardless of the demand changes, except for April 14, 2020 (after implementing the three preventive policies). This observation means that the traffic reduction rates for most of the hours of the days are similar. However, when all the three preventive measures were implemented, those reduction rates vary.

Fig. 8 shows the changes in peak hour traffic demand trend during the two peak hour periods. The figure shows that there is a continuous drop in AM peak demand after implementing the measures. However, the PM peak has experienced an increase in demand after implementing Measure 3. This increase coincides with two underlying events. The first one is the approach of the Holy Month of Ramadan, where a significant increase in shopping trips is often experienced. The second one is the recreational trips that are made by individuals and families where they tend to simply drive around without leaving the vehicles as this approach of leisure has become popular during the COVID–19 pandemic. These two underlying events can explain the difference in PM peak trips while comparing Measure 2 and Measure 3.

6.2. CBD screenline traffic demand analysis

While the results demonstrated earlier considered all the study junctions, this section highlights the change in traffic demand across the screenline shown previously in Fig. 4. The screenline is selected to identify any potential changes in the traffic demand entering and leaving the Central Business District (CBD) area of Doha City. Therefore, the traffic entering (Inbound) and leaving (Outbound) the CBD area through the screenline needs to be estimated. For this reason, only the movements entering and leaving the CBD at the nine intersections are considered in the screenline analysis. Fig. 9 shows the inbound and outbound traffic for the entire day for all selected days at the screenline. It can be seen that the inbound, as well as outbound traffic to the CBD, decreased continuously after the implementation of Measures 1, 2, and 3.

Fig. 10 shows the hourly distribution of the traffic volume entering the CBD screenline (inbound). The distribution was similar for all days except for the day after Measure 3 where higher volumes were observed
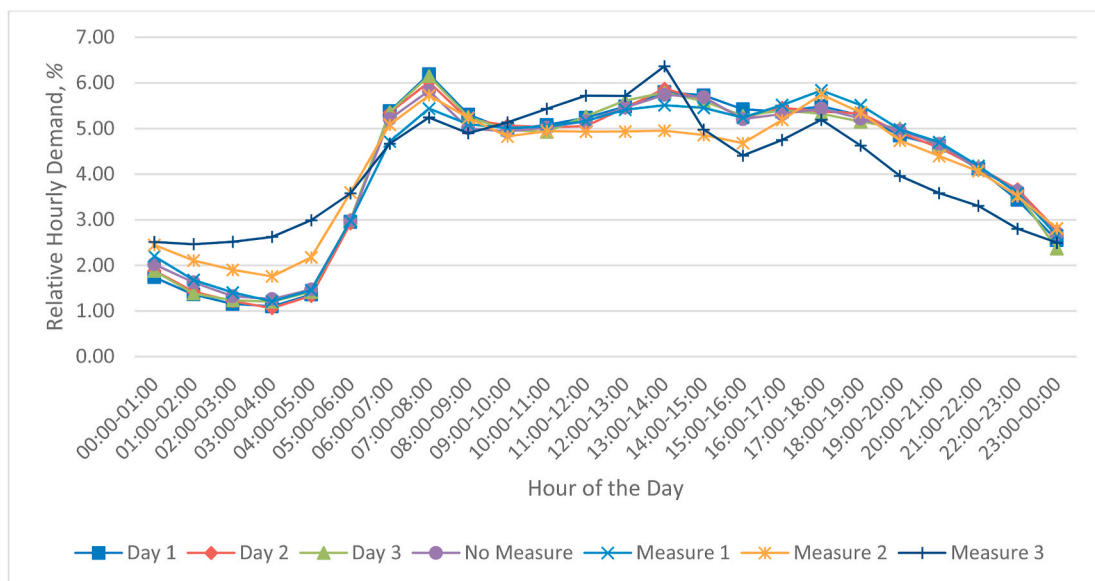

Fig. 7. Relative hourly to daily traffic demand distributions for all intersections.
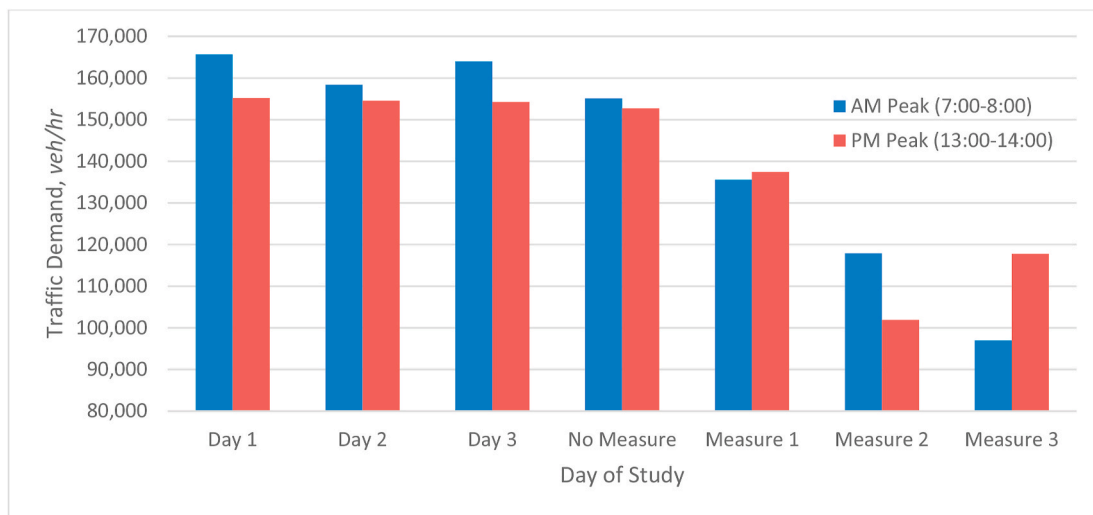
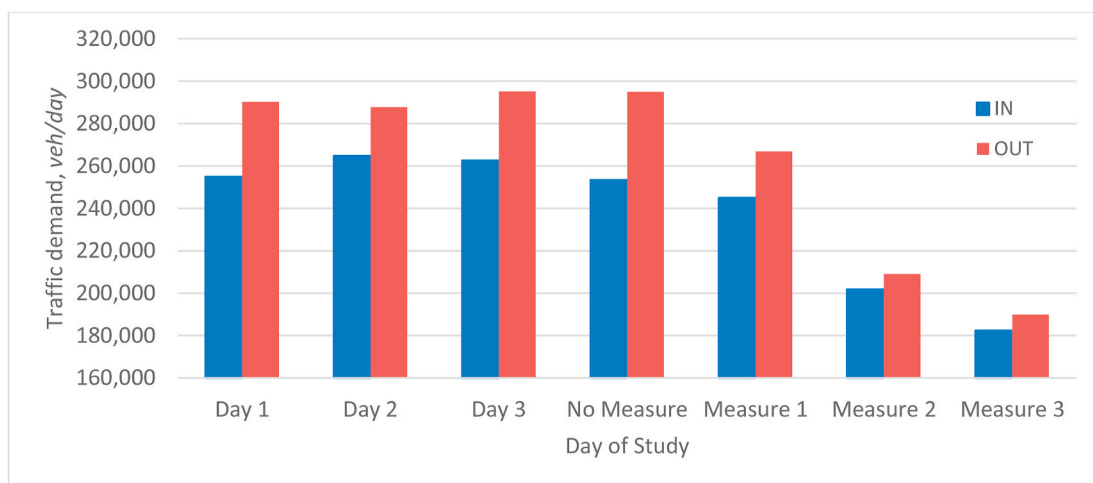**Fig. 8.** Peak hour traffic demand for all studied intersections.

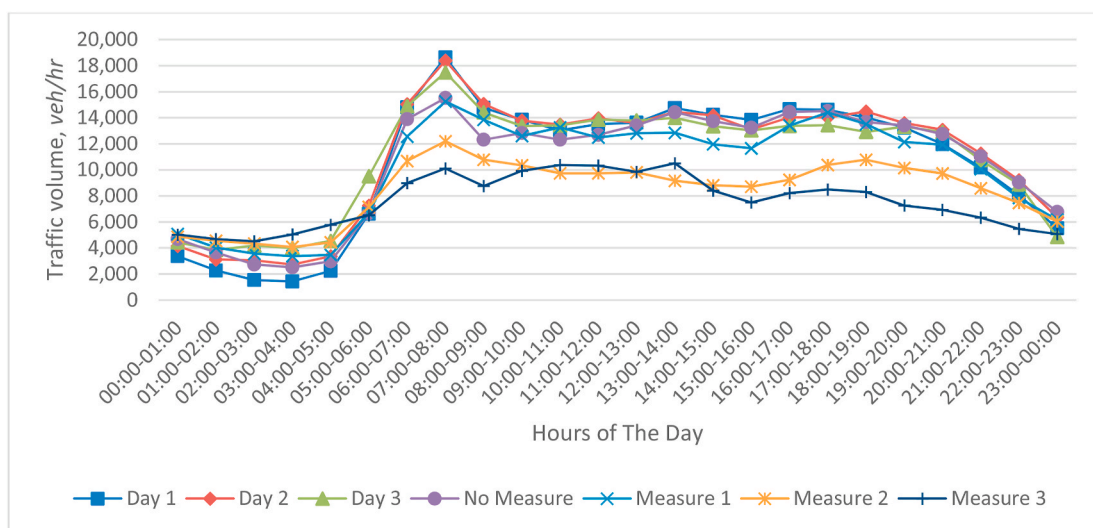**Fig. 9.** Total screenline daily traffic demand.

Fig. 10. Hourly traffic demand distribution entering CBD screenline (inbound).

in the morning between 4:00 to 7:00. For all other days, similar trends were observed with the morning peak from 7:00 to 8:00 and afternoon peak from 13:00 to 14:00.

The hourly distribution of the traffic volumes exiting the CBD screenline (outbound) is shown in Fig. 11. It can be seen that all the days observed similar distribution with morning peak from 7:00–8:00 and PM peak from 13:00–14:00. Further, the trends in peak hourly volumes for traffic entering and exiting the CBD screenline are shown in Fig. 12.

A continuous reduction in inbound and outbound traffic at the CBD screenline was observed for AM and PM peak after implementations of Measures 1, 2, and 3 except for a slight increase in inbound and outbound traffic for PM peak after implementation of Measure 3. This change can be attributed to similar reasons mentioned earlier for all studied intersections for an increase in PM traffic after Measure 3 implementation.

6.3. Quantifying the impact of preventive measures on traffic demand

Table 2 summarizes the traffic demand on the 24 studied intersections for each case and compares the reduction of each measure relative to the base scenario, and relative to the previously implemented measures. The results show that the traffic demand has no significant change when no preventive measures are implemented. However, the daily traffic demand has dropped constantly after implementing three measures. Once Measure 1 was implemented, the traffic demand has dropped by 6.2% at all studied intersections. As for Measure 2, it has further dropped the demand by an additional 17.5% compared to the demand after implementing Measure 1. The two measures combined (Measure 1 and Measure 2) has reduced the baseline traffic by 22.6%. Finally, once Measure 3 was implemented, it has dropped the already reduced traffic (due to Measures 1 and 2) by an additional 10.1%. The three measures together have contributed toward reducing the background traffic by 30.4%, which is almost one-third of the baseline demand.

While the previously mentioned statements were applicable to the daily traffic demand, a similar analysis was performed for the morning and evening peak periods, between 7:00–8:00 for the AM Peak and between 13:00–14:00 for the PM Peak. The results show that the implementation of three preventive measures was able to reduce approximately 40.4% of the morning peak traffic demand and 23.8% of the evening peak period demand. In other words, the impacts of preventive measures are more noticeable in reducing the traffic demand for the morning peak period. This finding is explained by the fact that restricting employment rates and closing educational institutions have more influence on the morning traffic. For the evening traffic, it can be concluded that the three measures have less influence on reducing traffic demand due to other activities.

Table 3 shows the change in traffic demand at the CBD screenline along with the traffic demand changes for inbound and outbound traffic during the AM and PM peak hours. The results for total inbound and outbound traffic demand at the screenline are similar to that of the total demand for all studied intersections mentioned in the earlier section. Implementation of three measures has reduced the baseline inbound and outbound traffic to the CBD by about 30% and 35% respectively. Further, the AM and PM inbound peak traffic demand had shown similar trends of reduction after the implementation of each measure. The AM peak has observed a reduction of 44% and the PM peak recorded a decrease of 27% compared to baseline traffic demand after the implementation of three measures. The reduction of inbound trips is attributed to the closure of workplaces, educational institutions, and limited commercial activities. The increase in PM inbound traffic demand after the implementation of Measure 3 could be due to the special conditions mentioned earlier.

Additionally, the AM peak outbound traffic demand also decreased by 29%, 32%, and 24% respectively after implementation of Measures 1, 2, and 3 in addition to the decrease by previous measures. On the contrary to the results of traffic volume reductions mentioned earlier, PM peak outbound traffic volume observed an increase of about 21% compared to baseline traffic volume after implementation of Measure 1. Furthermore, a slight (0.6%) increase is observed after Measure 2 implementation with respect to traffic volume for Measure 1. The restrictions for Measure 3 increased the traffic demand by about 62% with respect to Measure 2. However, a marginal (about 3%) increase was seen in PM peak outbound traffic demand compared to baseline conditions after the implementation of all measures.

6.4. Traffic demand trends beyond implemented measures

Since the preventive measures were implemented as part of the Supreme Committee for Crisis Management policies, all of the measures
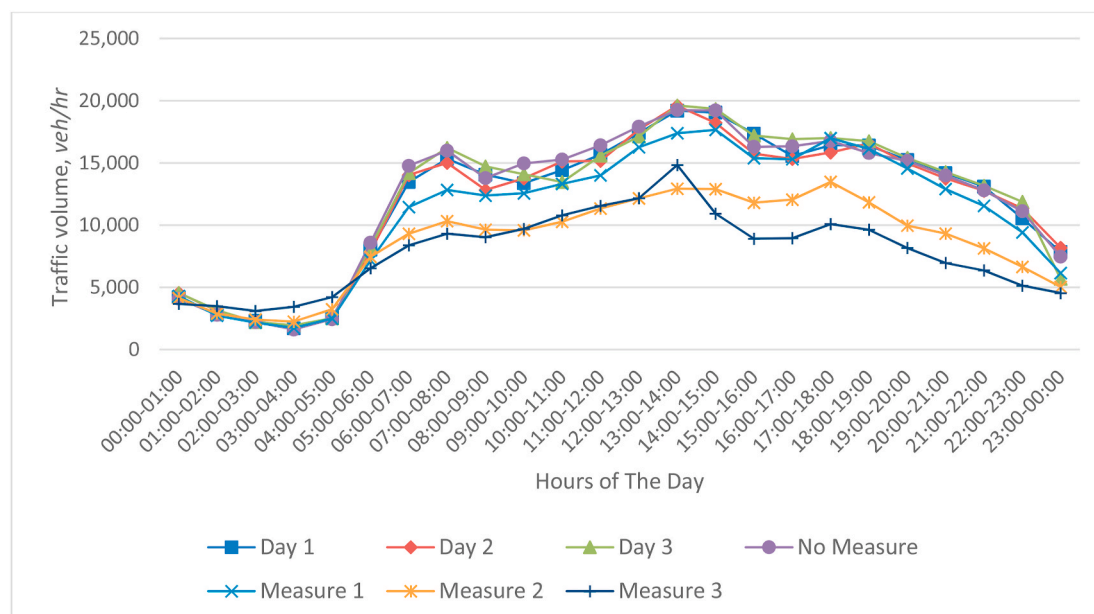
Fig. 11. Hourly traffic demand distribution exiting CBD screenline (outbound).
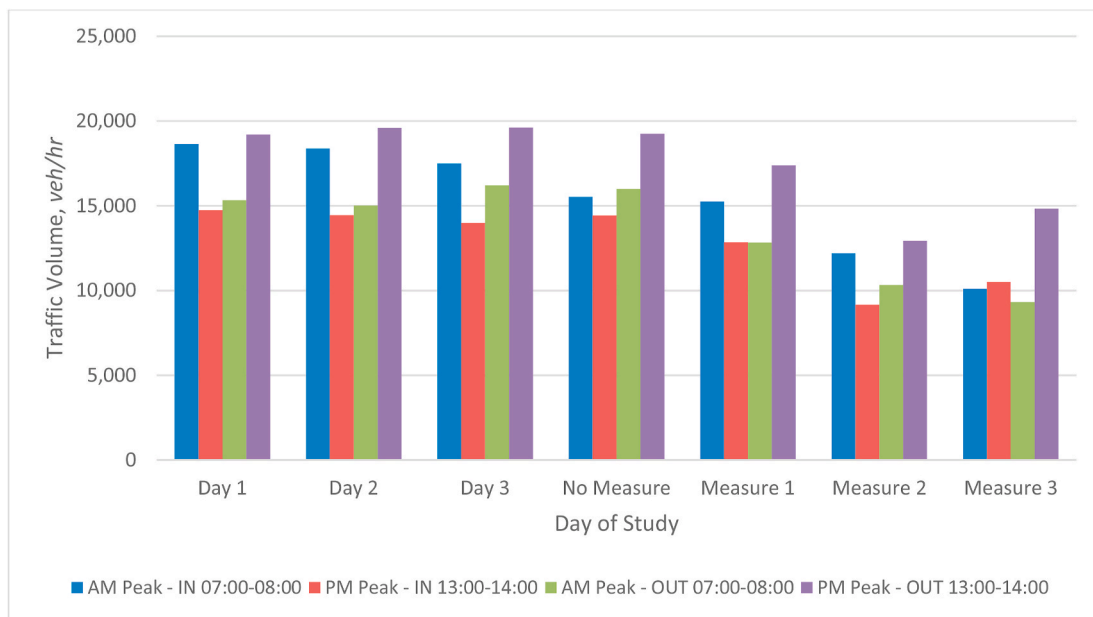
Fig. 12. Peak hour traffic demand for the screenline (both inbound and outbound).

Table 2
Changes in Daily Traffic Demand at all intersections due to Preventive Measures.

	Baseline	No Measure	Measure 1	Measure 2	Measure 3
	Daily Traffic (24-hr)				
Daily Traffic Demand	2,657,517	2,661,664	2,493,902	2,057,422	1,850,344
Reduction Relative to Baseline, %	------	-0.2	6.2 *	22.6 *	30.4 *
Reduction Relative to Measure 1, %	------	------	------	17.5 *	25.8 *
Reduction Relative to Measure 2, %	------	------	------	------	10.1 *
	AM Peak (7:00 – 8:00)				
AM Peak Hour Demand, *veh/hr*	162,687	155,114	135,591	117,890	97,025
Reduction Relative to Baseline, %	------	4.7	16.7 *	27.5 *	40.4 *
Reduction Relative to Measure 1, %	------	------	------	13.1 *	28.4 *
Reduction Relative to Measure 2, %	------	------	------	------	17.7 *
	PM Peak (13:00 – 14:00)				
PM Peak Hour Demand, *veh/hr*	154,683	152,742	137,459	101,917	117,793
Reduction Relative to Baseline, %	------	1.3	11.1 *	34.1 *	23.8 *
Reduction Relative to Measure 1, %	------	------	------	25.9 *	14.3 *
Reduction Relative to Measure 2, %	------	------	------	------	-15.6 *

Note: Highlighted Cells indicate the demand reduction percentage for each action independently
* The difference is statistically significant with 95% confidence level based on baseline traffic variance

remained active until the middle of June 2020. starting June 15, 2020, the committee announced a four-phase plan to gradually lift the restrictions (GCO, 2020b). Therefore, the impact of those preventive measures is expected to continue influencing the daily traffic demand (although this influence is getting less over time) for the rest of the year of 2020. A separate study is being performed to evaluate the recovery patterns and their impact on traffic mobility and traffic safety. Figs. 13–16 demonstrates the traffic demand trends covering the time period before discovering the first positive case of COVID–19 and the Middle of June 2020.

The daily trends and peak hour trends are shown for all the sites and for the screenline as well. The figures are only showing the traffic demand for typical weekdays (i.e., for all the Mondays, Tuesdays, and Wednesdays) between February 24 - June 15, 2020. The weekends (Fridays and Saturdays) were excluded because these days tend to have their own trend even before the start of the COVID–19 pandemic, Sundays and Thursdays did not follow the same trend as for the rest of the weekdays being adjacent to weekends.

It is worth mentioning that the majority of the Qatari population celebrate the Holy Month of Ramadan, where Muslims fast from sunrise to sunset which happened during 24 April – May 24, 2020. This month is followed by days of celebration (called Eid Al-Fitr), where an extended national holiday is granted to all employees (both governmental and private sectors). Therefore, the period between April 20 - May 31, 2020, has its own traffic trend, in addition to the impact of COVID–19 preventive measures.

However, if the effect of special occasions on travel behavior and traffic demand is ignored, it can be noticed that traffic demand after mid-April starts to increase slightly, although there has been no change in the preventive measures policy. This can be attributed to travel related to preparations for the Holy month of Ramadan. Traffic demand remained steady until mid – May. There was a significant drop in demand by the end of May to approximately 50% of the baseline case. This drop in demand started to gain increasing momentum with the beginning of June, where a steady demand increase is noticed, reaching approximately 80% of baseline demand. This can be because of the

Table 3

Changes in the CBD Screenline Traffic Demand due to Preventive Measures Policies.

	Baseline	No Measure	Measure 1	Measure 2	Measure 3
			Screenline Inbound Daily Traffic (24-hr)		
Daily Traffic Demand	260,707	253,345	244,957	201,737	182,319
Reduction Relative to Baseline, %	------	2.8	6	22.6 *	30.1 *
Reduction Relative to Measure 1, %	------	------	------	17.6 *	25.6 *
Reduction Relative to Measure 2, %	------	------	------	------	9.6 *
			Screenline Outbound Daily Traffic (24-hr)		
Daily Traffic Demand	291,063	295,062	266,871	209,102	189,867
Reduction Relative to Baseline, %	------	-1.4	8.3 *	28.2 *	34.8 *
Reduction Relative to Measure 1, %	------	------	------	21.6 *	28.9 *
Reduction Relative to Measure 2, %	------	------	------	------	9.2 *
			Screenline Inbound AM Peak (7:00 – 8:00)		
Peak Hour Demand, *veh/hr*	18,174	15,525	15,252	12,198	10,107
Reduction Relative to Baseline, %	------	14.6 *	16.1 *	32.9 *	44.4 *
Reduction Relative to Measure 1, %	------	------	------	20 *	33.7 *
Reduction Relative to Measure 2, %	------	------	------	------	17.1 *
			Screenline Outbound AM Peak (7:00 – 8:00)		
Peak Hour Demand, *veh/hr*	15,517	15,991	12,829	10,321	9,315
Reduction Relative to Baseline, %	------	-3.1	17.3 *	33.5 *	40 *
Reduction Relative to Measure 1, %	------	------	------	19.5 *	27.4 *
Reduction Relative to Measure 2, %	------	------	------	------	9.7
			Screenline Inbound PM Peak (13:00 – 14:00)		
Peak Hour Demand, *veh/hr*	14,397	14,429	12,847	9,164	10,501
Reduction Relative to Baseline, %	------	-0.2	10.8	36.3 *	27.1 *
Reduction Relative to Measure 1, %	------	------	------	28.7 *	18.3 *
Reduction Relative to Measure 2, %	------	------	------	------	-14.6 *
			Screenline Outbound PM Peak (13:00 – 14:00)		
Peak Hour Demand, *veh/hr*	19,473	19,254	17,387	12,928	14,836
Reduction Relative to Baseline, %	------	1.1	10.7 *	33.6 *	23.8 *
Reduction Relative to Measure 1, %	------	------	------	25.6 *	14.7 *
Reduction Relative to Measure 2, %	------	------	------	------	-14.8 *

Note: Highlighted Cells indicate the demand reduction percentage for each policy independently
* The difference is statistically significant with a 95% confidence level based on baseline traffic variance
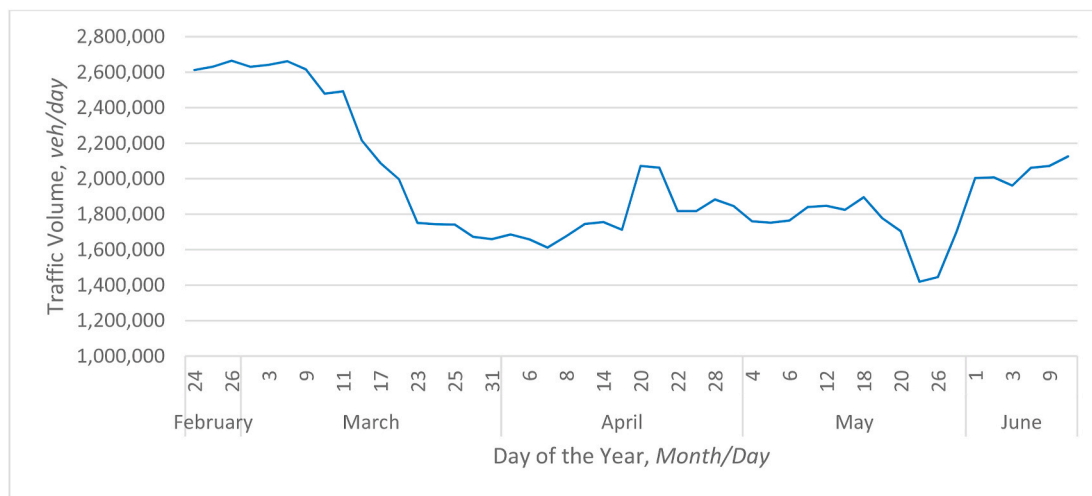

Fig. 13. All sites daily traffic demand for typical weekdays (February 23 – June 14, 2020).

announcement of lifting of restrictions due to preventive measures gradually.

6.5. Traffic safety

Another aspect of assessing the impact of COVID–19 on traffic is traffic investigating different traffic safety aspects within the context of traffic crashes and traffic violation. The traffic crashes are recorded in the State of Qatar by the General Directorate of Traffic at the Ministry of Interior and are classified into three categories; deaths, major, and minor crashes. While on the other hand, traffic violations are monitored

to control the driving behavior. The state of Qatar records ten types of traffic violations and applies various penalties for the same.

It should be noted that the intention of this section is only to compare the recorded traffic crashes and violations during the COVID–19 pandemic in 2020 against the corresponding months in 2019, regardless of the changes in traffic demand.

6.5.1. Traffic crashes

Fig. 17 shows a comparison of traffic crashes involving fatalities per month for 2019 and 2020, respectively. While there was no unified trend for January, February, and March of both years, fatalities tend to
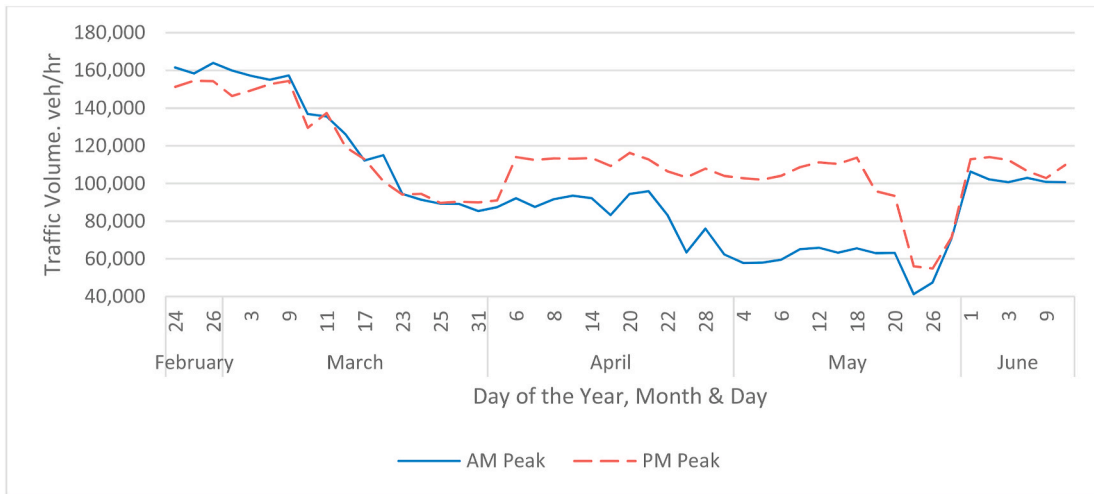
Fig. 14. All sites peak hour demand for typical weekdays (February 23 – June 14, 2020).
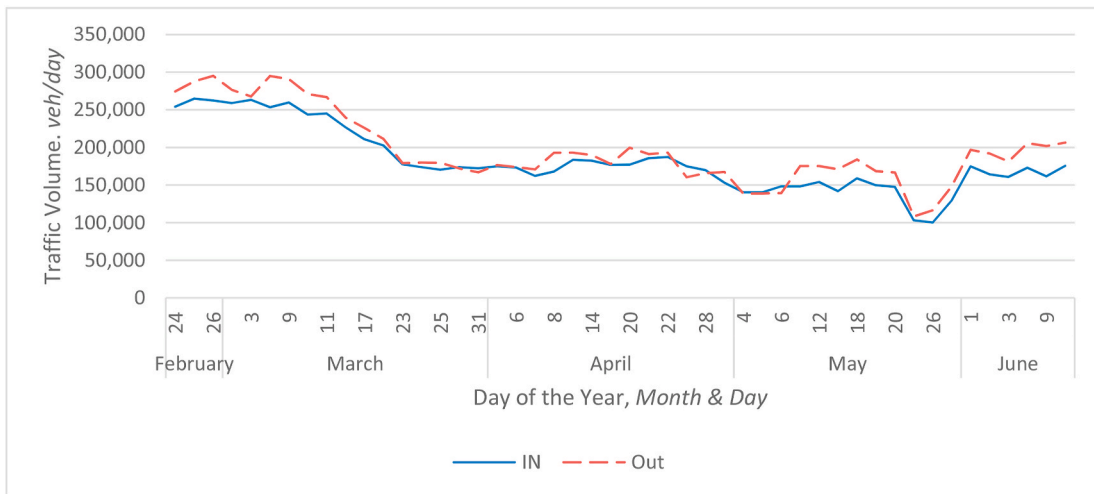

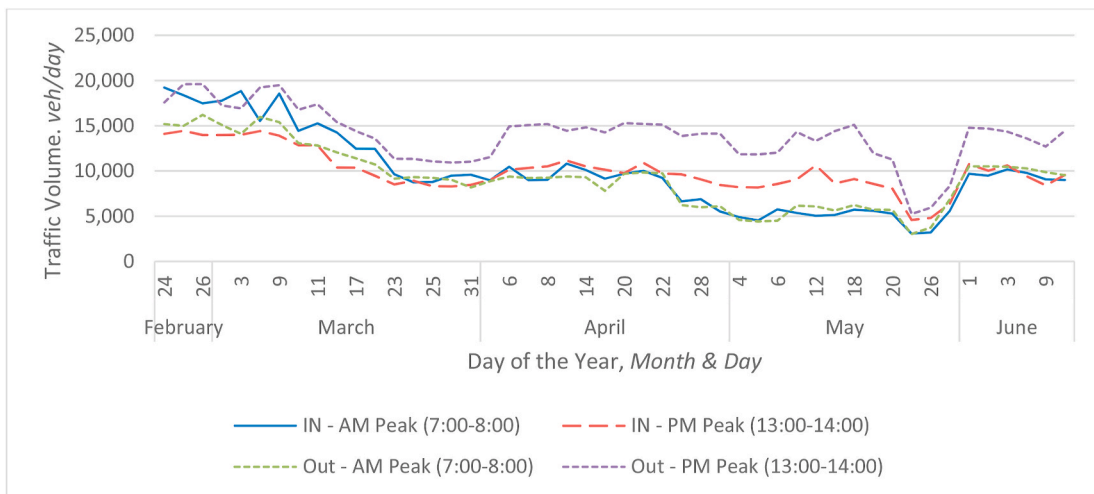**Fig. 15.** Screenline daily traffic demand for typical weekdays (February 23 – June 14, 2020).

Fig. 16. Screenline peak hour demand for typical weekdays (February 29 – June 14, 2020).
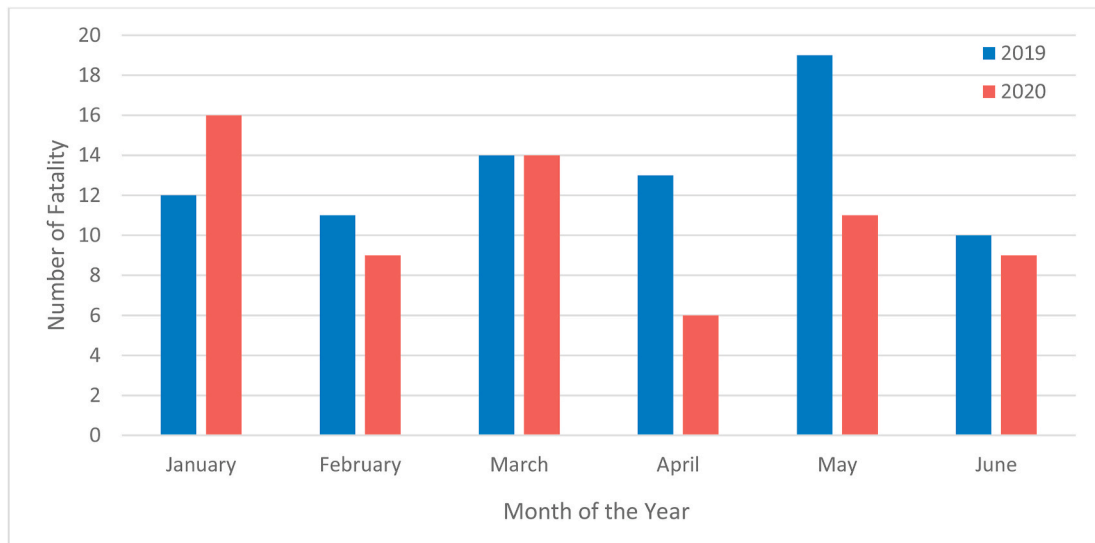
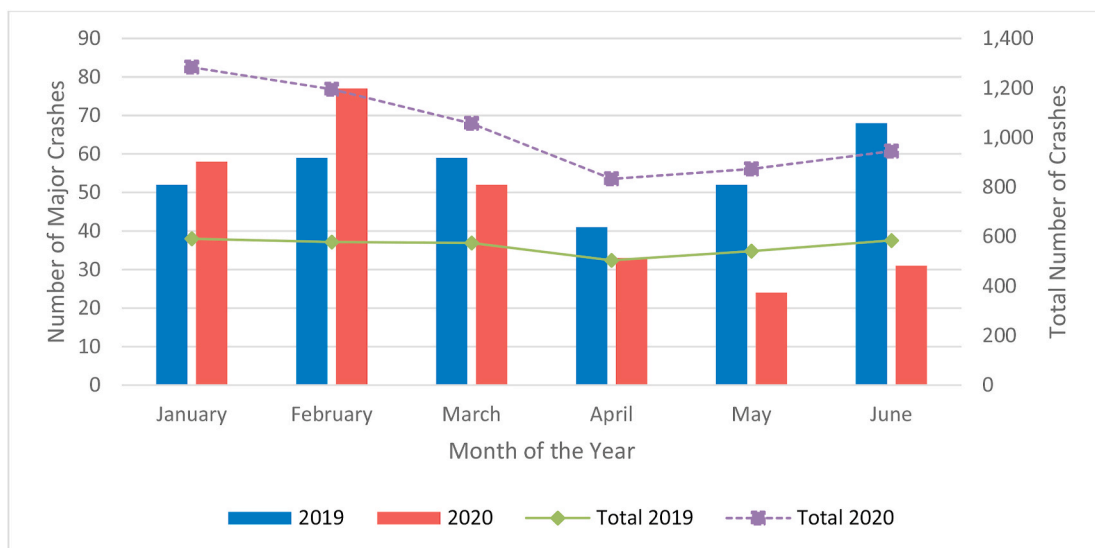**Fig. 17.** Number of traffic fatalities (January to June 2019–2020).

Fig. 18. Total number of major and total traffic crashes (January to June 2019–2020).
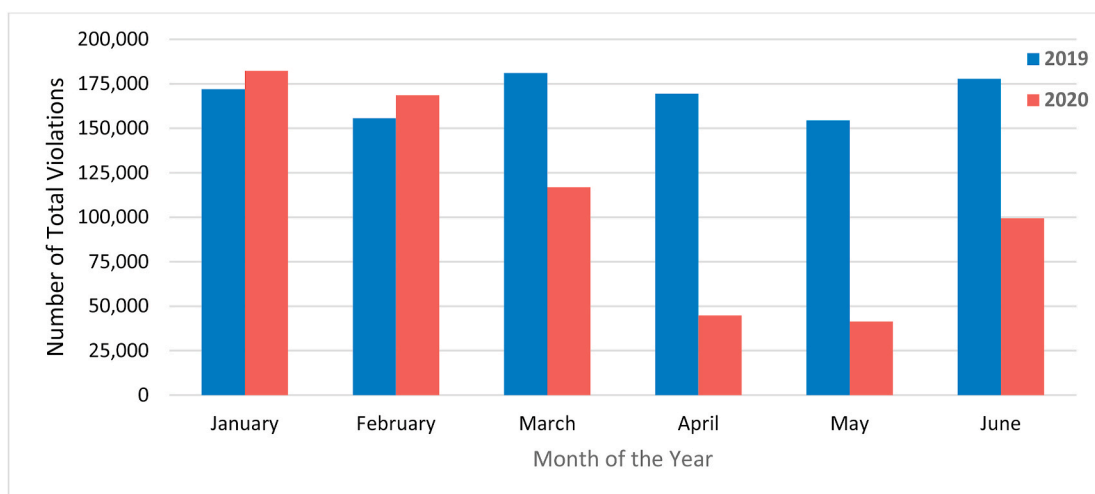

Fig. 19. Total number of violations (January to June 2019–2020).

decrease after March (for April and May) by almost 54% and 42% respectively when restrictions for all three measures were imposed. The decrease in fatalities was only 10% after the COVID–19 peak was passed and four-phase plan for lifting restrictions was announced. It should be noted that the Phase 1 of lifting restrictions started on June 15, 2020. Fig. 18 shows the number of major and total crashes for the study period. A reduction in major traffic crashes of 12%, during March, 20% during April, and 54% during May and June were reported when compared to the corresponding months in 2019.

As the imposed restrictions increased, the number of major crashes decreased. Further, a drop of 17% and around 36% was reported minor traffic crashes during March, and April to June respectively. Overall, the statistics for total crashes showed a reduction of 16%, 35%, 39% and 38% during March, April, May, and June respectively. It should be noted that although the reduction in traffic fatalities was lesser for June 2020, after movements were partially allowed, the trend for major, minor, and total crashes was similar to April and May 2020 when complete movement restriction were put in place.

6.5.2. Traffic violations

Fig. 19 shows the variation of total traffic violations for the study area between January–June 2020 against registered violations for the same months of 2019.

It can be seen that January and February observed a minor increase in violations compared to last year when no COVID–19 restrictions were imposed. A sudden drop of 35% violations was observed in March 2020 when partial restrictions were imposed. Further, a steady drop of approximately 73% was seen for April and May when all three measures were implemented. June 2020 observed a 44% reduction in violations, the drop in amount of violations was lesser compared to earlier months as the four-phase plan for removing restrictions was announced and people started to travel, and subsequently, traffic volumes increased. The highest increase in violations was noticed for "Passing traffic signal" violation for all months and the highest decrease rate was seen for "Metallic plates" in January and February, "Passing traffic signal land lines" in March, and "Registration and Form Non-Renewal Violations" in April, May, and June compared to the same month in the previous year.

The results show that the imposed measures to prevent the spread of COVID–19 are associated with an overall reduction in traffic crashes and traffic violations. While the free-flow conditions tend to encourage drivers to adopt aggressive behaviors and the tendency to violate traffic (by violating speed limits and reckless driving), the data suggested that these free-flow conditions did not promote such driving attitudes during the pandemic.

The comparison of traffic crashes and violations in 2020 against 2019 data indicates that further statistical analysis based on more disaggregated and detailed data can be performed to quantify the effect of preventive measures and demand reduction on traffic safety.

7. Policy implications

The Qatar National Vision 2030 is a roadmap that is meant to advance the society and improve the living standards for all citizens by 2030. The vision has mainly four pillars, human development, social development, economic development, and environmental development (GSDP, 2008). Therefore, several national policies were adopted or implemented to achieve this vision. Ultimately, sustainable transport is one of the major areas that was targeted with these developments. Sustainable transport, though indirectly, has crossed paths with the COVID–19 preventive measures.

The assessment of staged preventive measures indicated a decline in the traffic volumes, violations, and crashes for the analyzed period during the pandemic. The findings from this analysis will guide the policy makers during the post–COVID–19 era to better manage traffic mobility in short-term, long-term as well as during special/mega–events or emergency situations. Although there are many strategies to manage

traffic demand and supply, such as promoting public transport, encouraging non-motorized mobility, and adopting more sustainable modes of travel, the preventive measures have led to demand reduction and lower traffic crashes and violations (Shaaban et al., 2018a, 2018b; Shaaban and Ghanim, 2018; Ferwati et al., 2018; Muley et al., 2019a, 2019b). The main objective of these preventive measures was to limit the pandemic spread. However, it is expected that fewer efforts will be needed to monitor, manage, and operate traffic. Hence, for the short term, the utilized resources for incident response services or patrolling services can be reduced or reallocated as needed. Furthermore, the demand reduction will contribute toward reducing emissions and pollution, targeting sustainable environment. This short-term benefits are expected to promote permanent modal shift and utilization or travel behavior changes for residents.

Policy makers and relevant authorities can benefit from the preventive measures in adopting and promoting certain interventions as part of the long-term policy lessons, such as promoting distance learning, online shopping, and remote working environment. These lessons can be further extended to adopt policy strategies to support online marketing and governmental services by enhancing their digital infrastructure. Moreover, the transport sector can investigate better ways of managing logistics services by subsidizing environmentally friendly initiatives and sustainable modes.

It is expected that such policies will reduce traffic, energy demands, and emissions in the long run. Generally, mobility and safety trends also aid policy makers and planners in developing targeted modal shift policies and enforcement to improve traffic safety. The policy makers can also utilize this opportunity to develop strategies for promoting new transport modes that are more resilient than other modes and not severely affected by such pandemics such as car sharing and Mobility as a Service (MaaS).

8. Conclusions

This study quantifies the traffic impacts of staged and sequential preventive measures implemented by the government of the State of Qatar to control the spread of the COVID–19 pandemic. The various measures included the closure of educational institutions and switching to online education, restrictions on non–essential commercial activities, and a significant reduction in the number of employees working from offices at government as well as private offices. The implemented actions were divided into three preventive measures based on their schedule of implementation.

Traffic demand at a set of 24 key signalized intersections that were strategically selected to cover a wide area within the City of Doha and CBD screenline were observed for different days corresponding to the different preventive measures and after implemented measures. A comparison of the traffic volumes with baseline conditions indicated that the traffic patterns were similar before and after the implementation of the measures, although the volumes were significantly reduced to more than 30%. In general, the AM and PM peak traffic volumes were reduced after the execution of each measure. However, the reduction of PM peak after implementing Measure 3 did not follow the anticipated trend due to other factors such as the approach of the Holy Month of Ramadan, where residents often change their travel behavior while preparing for this month.

The total inbound and outbound traffic volumes at the CBD screenline were also reduced after the implementation of each measure. A similar trend was observed for the CBD screenline traffic when compared to the whole study area. The screenline traffic demand witnessed a reduction of 30% in total inbound traffic volumes and 35% in total outbound traffic volumes compared to baseline conditions. It should be noted that there is no significant change in traffic demand before detecting the first COVID–19 case or implementing any preventive measure.

With respect to safety, the monthly traffic crashes and violations

were compared with the values of the year 2019, for January–June. The total crashes showed a reduction of 16%, 35%, 39% and 38% during March, April, May, and June respectively. In March, the partial restrictions (Measures 1 and 2) showed no change in traffic crashes with fatalities, while in April and May the application of three measures (i.e., complete restrictions) reduced fatal crashes drastically by 54% and 42% respectively. After COVID–19 peak was over and movement were allowed the reduction in fatalities was only 10% for June 2020. Further, reductions between 12% and 54% were reported in major traffic crashes during March and June 2020. The data for traffic violations showed that a drop of 35% in March 2020 when partial restrictions (Measures 1 and 2) were imposed, 73% in April and May when all the restrictions were in place, and 44% when Phase 1 of lifting of movement restrictions was implemented. These reductions indicated that the movement restrictions implemented to curb COVID–19 lowered the traffic volumes by one third and improved the traffic safety significantly in the State of Qatar. Further, the lower volumes did not contribute to increased aggressive driving and traffic violations.

Moreover, the results indicate that the highest reduction in peak traffic demand was associated with implementing Measure 3 and Measure 2 respectively. This finding can assist authorities to choose the most appropriate measure for achieving targeted reduction with minimal disturbance to the public, which can be found beneficial in planning Temporary Traffic Management (TTM) measures during special/mega-–events. Especially when such background traffic demand reduction can be utilized to accommodate the temporarily traffic demand increase. Most importantly, the effect of closures/implemented measures on traffic on certain roads can be adequately quantified from the findings of this study, since the effect is based on real-life data. Subsequently, the abovementioned strategies can be extensively adopted during major events in the State of Qatar (such as FIFA Arab cup 2021, FIFA World cup 2022, and Asian Games, 2030) as soft measures to reduce background traffic.

To gain more insights in transport situation, it is recommended to evaluate the attitude of residents toward trip making under the pandemic and its relationship with existing traffic demand. It is also recommended to assess the changes in traffic safety performance in terms of traffic demand reduction due to the implemented preventive measures. In the future, the traffic recovery profiles need to be investigated to determine the traffic recovery period.

Author contributions

Deepti Muley: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Visualization; Roles/Writing - original draft; Writing - review & editing. Mohammad Shareef Ghanim: Data curation; Formal analysis; Investigation; Methodology; Visualization; Roles/Writing - original draft; Writing - review & editing. Anas Mohammad: Raw Data Collection, Methodology, Resources; Writing - review & editing. Mohamed Kharbeche: Raw Data Collection, Methodology, Resources; Writing - review & editing.

Disclaimer

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