



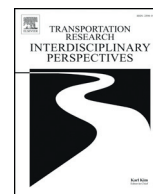
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## Transportation Research Interdisciplinary Perspectives

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# A descriptive analysis of the effect of the COVID-19 pandemic on driving behavior and road safety

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### ABSTRACT

The spread of the new coronavirus COVID-19, has led to unparalleled global measures such as lockdown and suspension of all retail, recreation and religious activities during the first months of 2020. Nevertheless, no scientific evidence has been reported so far with regards to the impact on road safety and driving behavior. This paper investigates the effect of COVID-19 on driving behavior and safety indicators captured through a specially developed smartphone application and transmitted to a back-end platform. These indicators are reflected with the spread of COVID-19 and the respective governmental countermeasures in two countries, namely Greece and Kingdom of Saudi Arabia (KSA), which had the most completed routes for users of the smartphone applications. It was shown that reduced traffic volumes due to lockdown, led to a slight increase in speeds by 6–11%, but more importantly to more frequent harsh acceleration and harsh braking events (up to 12% increase) as well mobile phone use (up to 42% increase) during March and April 2020, which were the months where COVID-19 spread was at its peak. On the bright side, accidents in Greece were reduced by 41% during the first month of COVID-19-induced measures and driving in the early morning hours (00:00–05:00) which are considered dangerous dropped by up to 81%. Policymakers should concentrate on establishing new speed limits and ensure larger spaces for cycling and pedestrians in order to enlarge distances between users in order to safeguard both an enhanced level of road safety and the prevention of COVID-19 spread.

## 1. Introduction

COVID-19, a novel coronavirus initially diagnosed in patients in Wuhan, China in December 2019 (Zhu et al., 2020), was declared a pandemic from the World Health Organization (WHO) on the beginning of March 2020 (WHO, 2020). As of May 2020, more than 3.5 million people have been infected by the virus with fatalities raising up to 247,000. In a span of nearly five months, COVID-19 has changed dramatically living conditions for the entire globe.

The most popular countermeasure to the spread of COVID-19 imposed by the majority of countries was a “lockdown” restricting everyday life activities to only the most essential and prohibiting people from leaving their residential premises. As a result, rapid changes in societal and financial patterns have been widely observed (Anderson et al., 2020; Zhang et al., 2020).

With the majority of the global population on a “lockdown” status, road traffic volumes and mobility activities in general have immensely dropped (Clarke, 2020; Google LLC, 2020). The reduction of traffic volumes moving on road infrastructure, evidently reduces their exposure to another important health problem, namely road traffic accidents. Traffic collisions kill approximately 1.35 million people and injure up to another 50 million people

each year (WHO, 2018), rates that are comparable to the current COVID-19 in perspective. However, to-date the effect of COVID-19 induced lockdowns on driving behavior has not been evaluated.

The lack of quantified evaluation of driving behavior during the outbreak of the COVID-19 pandemic forms the motivation behind the current paper. Microscopic trip data captured by the insurance telematics and driving behavioral analytics platform of OSeven Telematics ([www.oseven.io](http://www.oseven.io)), spanning from January to April 2020, are analyzed in order to assess driving behavior in two different countries (i.e. Greece and the Kingdom of Saudi Arabia; KSA) with regards to different country-wise COVID-19 measures. The collected trip data are assessed based on the performance of drivers with regards to speed, frequency of harsh braking, harsh acceleration, speeding events and mobile use, as well as trip characteristics (e.g. duration and distance) during the aforementioned data collection period.

By comparing the extent of detrimental consequences wrought by erroneous traffic behavior and COVID-19, there may be broader outputs in order to save more lives in the future. The value of reducing exposure as an effective intervention for road safety has been largely overlooked because road safety has been too narrowly focused on the road transport system itself. Furthermore, motorized private road transport reduction brings a host of several other benefits, such as less green-house gas emissions,

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**Table 1**  
Driving indicators of the analyzed data with their corresponding description (Source: OSeven, Data processing: NTUA).

Indicator	Unit	Description
Total duration	sec	Total trip duration
Total distance	km	Total trip distance
Driving duration	sec	Total duration of driving, i.e. duration of stops has been excluded
Risky hours driving	km	Distance driven in risky hours (00:00–05:00)
Harsh accelerations	–	Number of harsh accelerations
Harsh braking	–	Number of harsh braking
Speeding duration	sec	Total duration of speeding in a trip
Average speeding	km/h	Average speed over the speed limit
Average total speed	km/h	Average speed during the total duration of the trip
Average driving speed	km/h	Average speed during driving with stops been excluded from the duration of the trip
Mobile phone usage duration	sec	Total duration of mobile usage

noise or air pollution and greater opportunities for active transport. It is important to seize on the future opportunities in order to capture these benefits and re-think cities with safer road traffic and no accidents in the aftermath of the pandemic.

The aim of this study, therefore, is to quantify the effect of COVID-19 pandemic on driving behavior and road safety and identify driving behavior changes caused by COVID-19 restrictions. To achieve these objectives, eleven safety indicators (i.e. total duration, total distance driven per trip, driving duration, risky hours driving per trip, harsh accelerations per 100 km, harsh braking per 100 km, speeding duration/driving duration, average speeding, average total speed, average driving speed and mobile phone usage duration/driving duration) are captured through a specially developed smartphone application provided by OSeven Telematics and transmitted to a back-end platform. Taking into account that recently published studies (Papadimitriou et al., 2019; Stavrakaki et al., 2020; Tselentis

et al., 2019) have used the aforementioned indicators in order to estimate driving behavior, these can form a representative set of indicators to reflect the effect of COVID-19.

The paper is structured as follows: after the introduction to the problem, a brief literature review on driving behavior and road safety in relation with COVID-19 or other pandemics on transportation is taking place. That section is followed by a description of the methodological approach and a description of the data collection and then the descriptive analysis of the data is presented. Finally, conclusions on road safety effects of COVID-19 are drawn and a discussion on how policymakers and stakeholders should exploit the analysis takes place.

**2. Literature review**

To date, the impact of COVID-19 on transportation can be evaluated through reports of individual academic institutes (e.g. Molloy, 2020) or data companies such as Google (Google LLC, 2020), Apple (Apple, 2020) and TomTom (2020) which have published summary statistics of activities during the time of COVID-19. Although it is evident from these sources that traffic has been significantly reduced during the lockdown phase, the effect on driving behavior or road safety cannot be captured.

As a result the literature was searched in order to investigate if there is evidence for the relationship between driving behavior and past cases of recent pandemic outbreaks. Searching on popular scientific databases (i.e. Scopus and Google Scholar) with the Boolean terms {“COVID-19” or “Pandemic” and “driving behavior” or “driving behavior” or “road safety”}, around 170 papers have been retrieved by 29/07/2020 and were screened on titles and abstracts. Unfortunately, there was not found a large variety on titles and abstracts screening, which led to the conclusion that there are not yet enough published studies linking driving behavior or road safety with pandemics. Nevertheless, only seven studies were related to the investigating topic and are included in the current paper.

**Table 2**  
Descriptive statistics for the available parameters for the entire database in Greece and KSA.

	Greece (122,275 Trips)				KSA (325,664 Trips)			
	Mean	Standard deviation	Max	Min	Mean	Standard deviation	Max	Min
Average speeding	26.4	36.2	60	0	30.4	39.9	91.9	0
Speeding duration/driving duration	0.09	0.01	0.12	0	0.10	0.02	0.13	0
Average total speed (km/h)	43	19.3	168.4	1.97	53.7	21.8	216.11	1.92
Average driving speed (km/h)	54.2	17.9	184.7	7.01	64.8	20.4	216.11	1.92
Harsh accelerations per 100 km	8.6	29.2	550.5	0	7.3	22.2	457.3	0
Harsh braking per 100 km	13	33	819.7	0	14.8	31.6	534.6	0
Total duration (sec)	932.7	1058.3	23,880	61	1229.5	1315.5	34,781	61
Driving duration (sec)	738.3	924.3	21,213	61	1019.4	1367.2	32,971	61
Total distance driven per trip (km)	11.1	21.7	525.1	0.5	18.3	33.3	1006.7	0.5
Risky hours driving per trip (km)	0.3	3.7	353.9	0	1.3	10.5	635.9	0
Mobile phone usage duration/driving duration	0.05	0.01	0.08	0	0.14	0.03	0.20	0

**Table 3**  
Descriptive statistics for the available parameters for the months of COVID-19 in Greece and KSA.

	Greece (46,614 Trips)				KSA (120,852 Trips)			
	Mean	Standard deviation	Max	Min	Mean	Standard deviation	Max	Min
Average speeding	26.6	39.9	78.4	0	31.1	40.3	53.8	0
Speeding duration/driving duration	0.09	0.01	0.11	0	0.12	0.01	0.13	0
Average total speed (km/h)	44.1	19.7	183.1	3.12	54.6	22.1	186.8	3.75
Average driving speed (km/h)	54.9	18.3	156.4	7.89	65.7	20.7	189.07	8.18
Harsh accelerations per 100 km	8.5	29.3	508.5	0	7.5	22.9	457.3	0
Harsh braking per 100 km	13.1	34.3	550.1	0	15.2	32.8	415.5	0
Total duration (sec)	889.3	915.9	15,194	61	1115.3	1171.2	34,781	61
Driving duration (sec)	714.1	885.7	14,786	61	926.8	1239.6	32,971	61
Total distance driven per trip (km)	10.9	20.3	428.7	0.5	16.9	31.1	1006.7	0.5
Risky hours driving per trip (km)	0.2	3.27	142.2	0	1.2	9.2	555.9	0
Mobile phone usage duration/driving duration	0.05	0.01	0.07	0	0.16	0.02	0.19	0

**Table 4**

An example of dataset in routing requests in Greece and KSA.

Date	Greece		KSA	
	Driving	Walking	Driving	Walking
26/2/2020	105.83	107.21	86.19	82.42
27/2/2020	107.2	113.48	114.36	109.9
28/2/2020	120.29	129.68	124.63	117.13
29/2/2020	115.89	139.7	89.83	92.4
1/3/2020	113.79	118.77	82.2	84.1
2/3/2020	139.75	91.9	82.18	82.57
3/3/2020	98.77	98.65	84.53	82.65

To begin with, during the lockdown period (15 March 2020–27 May 2020), a 62% reduction in road deaths as well as a 65% decrease of traffic volume was identified on non-urban roads in Spain compared to the same period in 2019 (ETSC, 2020a, 2020b). At the same time, a sample of fixed safety cameras detected that speed violations have been increased by 39%. It is worth mentioning that while traffic volumes were reduced in several countries, the number of vehicles observed exceeding the speed limit has increased in a great extent. Specifically, during the COVID-19 pandemic, a 10% increase in the proportion of drivers speeding was found in Denmark while a 15 and 16% increase in the most serious speeding offences was identified in UK and France, respectively, compared to the same period last year (ETSC, 2020a, 2020b). In addition, a 22% increase in the drivers exceeding the speed limit on high-speed rural roads was identified in Estonia compared to 2018–2019 average. Although less speed enforcement along with less traffic, led to speeding increase in Hungary, measurements in Sweden didn't indicated any changes in the levels of speed compliance (ETSC, 2020a, 2020b).

Furthermore, early evidence of COVID-19 measurements related to driving behavior changes was identified (Stavrinos et al., 2020). In particular, results indicated that after COVID-19 restrictions, a 37% decrease of driving days per week as well as a 35% reduction in vehicle miles driven among adolescents was identified. It is important to highlight that ethnic minorities, older or employed adolescents and teens with lower prosocial tendencies appeared to be less likely to reduce their driving behavior. Recent researches have also found that especially young male drivers were more willing to exceed the speed limit and the frequency of such exceedances was higher during the COVID-19 pandemic (Vingilis et al., 2020).

Another relevant study by De Vos (2020), discussed the potential effects of COVID-19 but did not include any quantitative results or modelling. Furthermore, a new theoretical concept of “Responsible Transport” was also proposed by Budd and Ison (2020), who attempted to investigate the impact of COVID-19 pandemic on different forms of mobility and transport. They also discussed the inadequacies of existing transport policy approaches to respond to the new challenges that COVID-19 has posed. However, it should be noted that these studies were limited only to a theoretical context, and as a result, they were deemed incapable to provide significant results in terms of COVID-19 effect on driving behavior or road safety.

With regards to the previous 2009 H1N1 pandemic (Garten et al., 2009), the only evidence found with connection to the transportation domain, was the conclusion that transit stations played a significant role in spreading influenza (Cai et al., 2019) and how effective the closure of such stations along with the prevention of travelling (especially using the road infrastructure) in cases of pandemics can be (Xu et al., 2019).

Consequently, a gap in the literature exists, with regards to driver behavior characteristics in the time of a global pandemic.

### 3. Methodology

In order to quantify the effect of COVID-19 on driving behavior and road safety of different countries, different sources of information need to be overviewed:

**Table 5**

Total cases and deaths in Greece and KSA due to COVID-19.

Date	Greece		KSA	
	Total cases	Total deaths	Total cases	Total deaths
26/2/2020	1	0	–	–
27/2/2020	3	0	–	–
28/2/2020	4	0	–	–
29/2/2020	7	0	–	–
1/3/2020	7	0	–	–
2/3/2020	7	0	–	–
3/3/2020	7	0	–	–
4/3/2020	9	0	–	–
5/3/2020	31	0	5	0
6/3/2020	45	0	5	0
7/3/2020	66	0	7	0
8/3/2020	73	0	11	0
9/3/2020	84	0	15	0
10/3/2020	89	0	20	0
11/3/2020	99	0	45	0
12/3/2020	117	1	62	0
13/3/2020	190	1	86	0
14/3/2020	228	3	103	0
15/3/2020	331	4	118	0
16/3/2020	352	4	133	0
17/3/2020	387	5	171	0
18/3/2020	418	5	238	0
19/3/2020	464	6	274	0
20/3/2020	495	10	344	0
21/3/2020	530	13	392	0
22/3/2020	624	15	511	0
23/3/2020	695	17	562	1
24/3/2020	743	20	767	1
25/3/2020	821	22	900	2
26/3/2020	892	26	1012	3
27/3/2020	966	28	1104	3
28/3/2020	1061	32	1203	4
29/3/2020	1156	38	1299	8
30/3/2020	1212	43	1453	8
31/3/2020	1314	49	1563	10
1/4/2020	1415	50	1720	16
2/4/2020	1544	53	1885	21
3/4/2020	1613	59	2039	25
4/4/2020	1673	68	2179	29
5/4/2020	1735	73	2385	34
6/4/2020	1755	79	2523	38
7/4/2020	1832	81	2795	41
8/4/2020	1884	83	2932	41
9/4/2020	1955	86	3287	44
10/4/2020	2011	90	3651	47
11/4/2020	2081	93	4033	52
12/4/2020	2114	98	4462	59
13/4/2020	2145	99	4934	65
14/4/2020	2170	101	5369	73
15/4/2020	2192	102	5862	79
16/4/2020	2207	105	6380	86
17/4/2020	2224	108	7142	87
18/4/2020	2235	110	8274	92
19/4/2020	2238	113	9362	97
20/4/2020	2245	116	10,484	103
21/4/2020	2401	121	11,631	109
22/4/2020	2408	121	12,772	114
23/4/2020	2463	125	13,930	121
24/4/2020	2490	130	15,102	127
25/4/2020	2506	130	16,299	136
26/4/2020	2517	134	17,522	139
27/4/2020	2534	136	18,811	144
28/4/2020	2566	138	20,077	152
29/4/2020	2576	139	21,402	157
30/4/2020	2591	140	22,753	162
1/5/2020	2612	140	24,097	169
2/5/2020	2620	143	25,459	176
3/5/2020	2626	144	27,011	184

- i. Driving behavior data (both during COVID-19 and normal operations)
- ii. Traffic data (ideally from national or regional traffic authorities) both during the COVID-19 pandemic but also during normal operations

**Table 6**

Timeline of Covid-19 response measures in Greece.

Response measures	Date
Appearance of COVID-19	26/2/2020
Closure of educational institutions	10/3/2020
Closure of shopping centers and cafes	13/3/2020
Suspension of religious services	16/3/2020
Lockdown of non-essential movements	23/3/2020

**Table 7**

Timeline of Covid-19 response measures in KSA.

Response measures	Date
Appearance of COVID-19	5/3/2020
Closure of educational institutions	9/3/2020
Closure of shopping centers and cafes	13/3/2020
Suspension of religious services	20/3/2020
Lockdown of non-essential movements	23/3/2020

- iii. COVID-19 data with regards to cases and casualties as well as national countermeasures to prohibit dispersion of the virus
- iv. Accident data

These different data sources could depict the impact of COVID-19 on how the drivers behave as well as on the enhancement or decrease of road safety. Data from normal operations could act as the baseline of driving behavior and road safety, while the total number of cases and casualties due to COVID-19 would assist in comparing the different national strategies in prohibiting the virus.

**4. Data collection**

**4.1. Driving behavior**

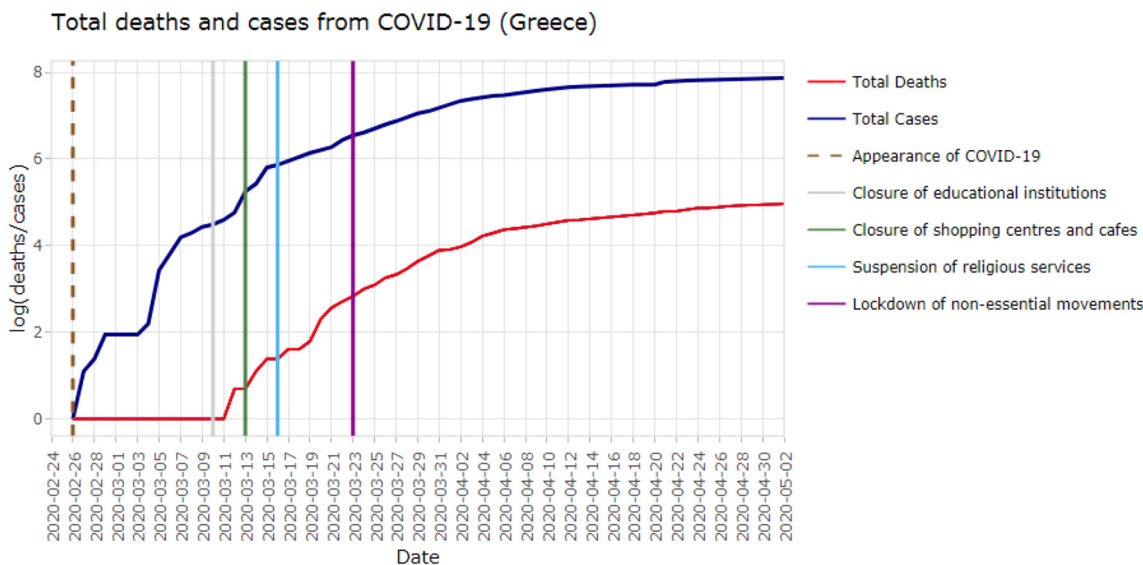
For the purpose of the analysis, OSeven has provided a representative subset of trips from its database for Greece and the KSA for a 4-month timeframe from 29/12/2019 to 03/05/2020, so that a sufficient period both prior and after the COVID-19 crisis and the lockdown measures is included. Greece and the KSA were chosen as the studied areas, since the two countries had the largest number of trips available in the available dataset and therefore would provide better support for the results.

Geographical differences between the two countries was not taken into account, as detailed location data were not provided and spatial analysis did not take place. The subset corresponds to the same set of random users (although user specific data has not been provided, as all data was provided in an anonymized format) so that the data before and after the COVID-19 crisis are fully comparable. The raw driving behavior data from the smartphone sensors (e.g. GPS, accelerometer data, and gyroscope data) is collected using the smartphone applications technology that has been developed by OSeven. This data is sent to the OSeven backend infrastructure where it is evaluated using filtering, signal processing, machine learning algorithms and safety/eco scoring models.

The final outcome of the analysis is risk related driving events such as speeding, mobile use, harsh accelerations and harsh brakes as well as safety/and eco scores. OSeven platform follows strict information security procedures and privacy policies in full compliance with the General Data Protection Regulation and the related EU directives. Therefore, all data has been provided by OSeven in an anonymized format and without geolocation information for the trips. As the data have been provided at a country-level, no specific road type is considered for the analysis have been included in the dataset. The subset of trips that was provided by OSeven for the aforesaid period included roughly 448,000 trips database, along with several driving performance indicators for each trip, which are described in Table 1.

Table 2 presents descriptive statistics (i.e. average, standard deviation, max, min,) with regards to the available parameters for the complete subset of trips in Greece and KSA provided by OSeven (both before and after the appearance of COVID-19 in these countries). It is evident that the majority of driving exposure indicators (i.e. average speeding, average total/driving speed, harsh events per 100 km, etc.) for KSA appeared to have higher than the corresponding indicators for Greece. Hence, on a country level, KSA drivers appeared to be more aggressive, than Greek drivers.

Table 3 illustrates descriptive statistics for the parameters only for the months after the appearance of COVID-19 in Greece and KSA. It was revealed that during the COVID-19 period, values for all available indicators for two countries (i.e. Greece and KSA) were higher compared to period both before and after the appearance of COVID-19 in these countries. This indicates that drivers observing empty roads chose to undertake more risks and appeared to have a worse driving behavior in comparison to their normal driving habits. The restrictions resulted in an overall increase in average speeding, average total/driving speed, harsh events per 100 km, while a reduction in total/driving duration and total distance per trip was identified compared to the overall examined period (before and after COVID-19 pandemic). It should be noted that changes between risky



**Fig. 1.** Evolution of total deaths and cases in Greece.

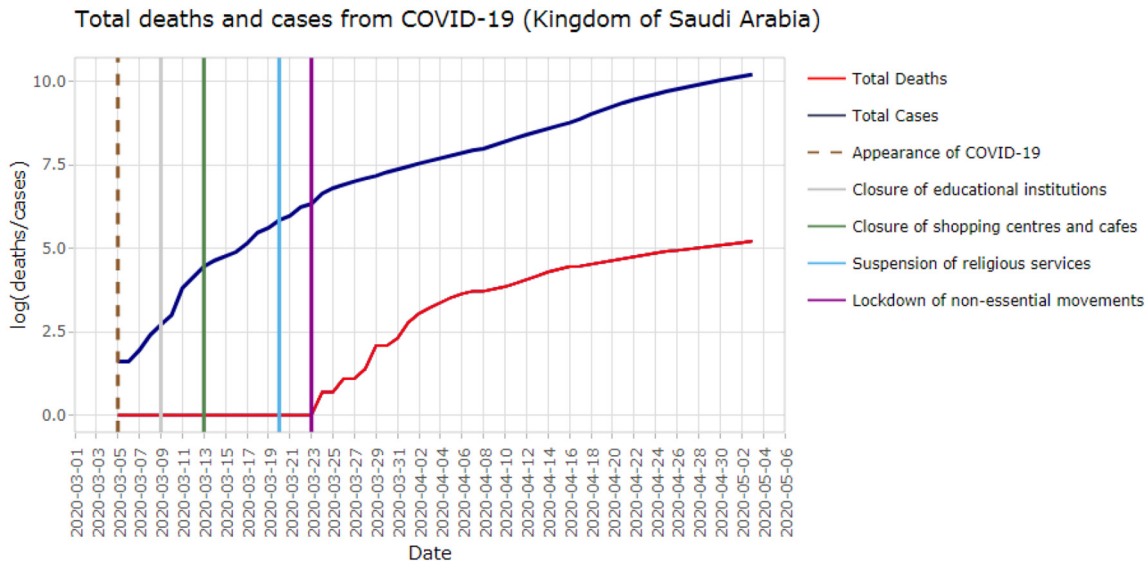


Fig. 2. Evolution of total deaths and cases in KSA.

hours driving per trip and mobile phone usage duration/driving duration were negligible.

4.2. Traffic data

As getting data from traffic authorities usually requires time for data authorization and approval, it was decided to use the mobility data reports from Apple (Apple, 2020) as a proxy of the driving activities in the two aforementioned countries (i.e. Greece and KSA).

The aggregated data collected from Apple show the mobility trends for major cities and several countries or regions. The information is generated by counting the number of requests made to Apple for directions. The data sets are then compared to reflect a change in volume of people driving, walking or taking public transit around the world. Data availability in a particular city, country, or region is subject to a number of factors, including minimum thresholds for direction requests made per day. Table 4 depicts an example of dataset in routing requests both in Greece and KSA.

4.3. COVID-19 cases, casualties and countermeasures

4.3.1. Cases and casualties

With regards to COVID-19 data, information was retrieved from the national ministries of health and were cross-checked with governmental press releases and popular webpages counting the spread of COVID-19 (e.g. Worldometer, 2020).

Table 8  
Change in traffic volume in Greece (Source: Apple).

	Change compared to February	
	March	April
Driving	-41.85%	-73.96%
Walking	-41.39%	-72.31%

Table 9  
Change in traffic volume in KSA (Source: Apple).

	Change compared to February	
	March	April
Driving	-25.86%	-54.78%
Walking	-21.74%	-44.22%

The first case of COVID-19 was diagnosed in Greece on the 26th of February 2020 and in KSA on the 5th of March. Table 5 illustrates the evolution of total cases and casualties in both countries.

4.3.2. Response measures

4.3.2.1. Greece. Table 6 summarizes the timeline of Covid-19 response measures that have been announced by the Greek Government.

4.3.2.2. KSA. Table 7 summarizes the timeline of Covid-19 response measures that have been announced by the KSA Government.

Table 10  
Changes in driving behavior and trip characteristics during the months of COVID-19 compared to January and February 2020.

Measurement	Change compared to January			Change compared to February	
	February	March	April	March	April
Average speeding	2%	4%	9%	2%	7%
Greece					
Speeding duration/driving duration	17%	25%	37%	7%	18%
Average total speed	2%	9%	13%	6%	11%
Average driving speed	2%	6%	8%	4%	6%
Harsh accelerations/100 km	-5%	-10%	0.25%	-6%	5%
Harsh braking/100 km	-1%	-4%	10%	-3%	12%
Total duration	2%	-32%	-68%	-33%	-68%
Driving duration	2%	-30%	-66%	-31%	-74%
Total distance	4%	-26%	-64%	-29%	-65%
Risky hours driving	-8%	-50%	-76%	-45%	-74%
Mobile phone usage duration/driving duration	8%	6%	31%	-1%	21%
Saudi Arabia					
Average speeding	1%	5%	6%	4%	5%
Speeding duration/driving duration	7%	22%	45%	14%	36%
Average total speed	-4%	1%	4%	5%	8%
Average driving speed	-3%	0.35%	3%	4%	7%
Harsh accelerations/100 km	1%	4%	12%	3%	11%
Harsh braking/100 km	3%	4%	14%	0.31%	10%
Total duration	-2%	-34%	-76%	-33%	-75%
Driving duration	-2%	-34%	-76%	-32%	-75%
Total distance	-5%	-33%	-75%	-30%	-73%
Risky hours driving	-17%	-44%	-84%	-33%	-81%
Mobile phone usage duration/driving duration	9%	21%	54%	11%	42%

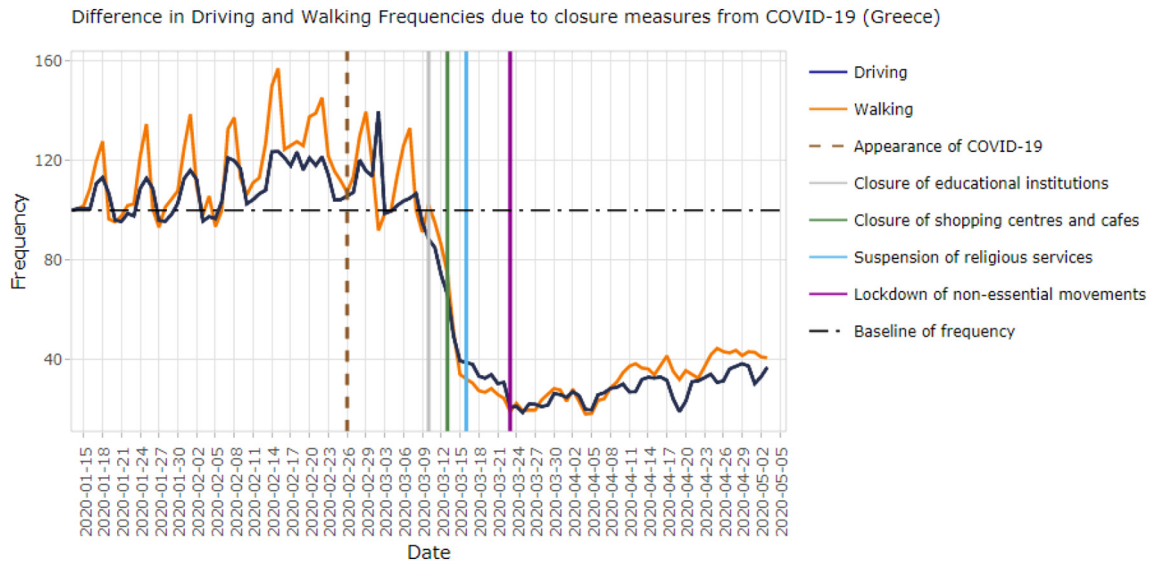


Fig. 3. Change in routing requests since 13 January 2020 in Greece. (Source: Apple).

4.3.3. Overview of the evolution of cases and casualties

Figs. 1 and 2 show the evolution of cases and casualties from COVID-19 along with the respective countermeasures from the local governments in Greece and KSA.

4.4. Road accidents data

With regards to road accidents, only Greek data on deaths, severe and slight injuries accidents were available until the end of July 2020. Therefore, a comparison between countries cannot be drawn but for completion the data are displayed in Section 5 to draw conclusions along the driving behavior data of Greek drivers.

5. Cross-country exploratory analysis of driving behavior and road safety

As mentioned before, the purpose of this paper is to overview and assess driving behavior in two countries (i.e. Greece and KSA) with regards to traffic as well as driving behavior and trip characteristics in the time of COVID-

19 induced lockdown. This section will present the results of the exploratory analysis.

For a better comprehension by the reader, each of the following subsection presents:

- Figures depicting the evolution of each indicator with regards to time and the COVID-19 countermeasures in Greece and the KSA
- Summary tables (i.e. Tables 8, 9 and 10) describing the monthly change of traffic volume and driving behavior indicator values in March and April, compared to the baseline normal operations during January and February 2020 in Greece and the KSA.

All the aforementioned figures and tables are accompanied by commentary on traffic and road safety considerations.

5.1. Driving and walking volumes

5.1.1. Greece

Fig. 3 depicts the volume of driving and walking sessions of Apple users in Greece from January 2020 and until early May 2020.

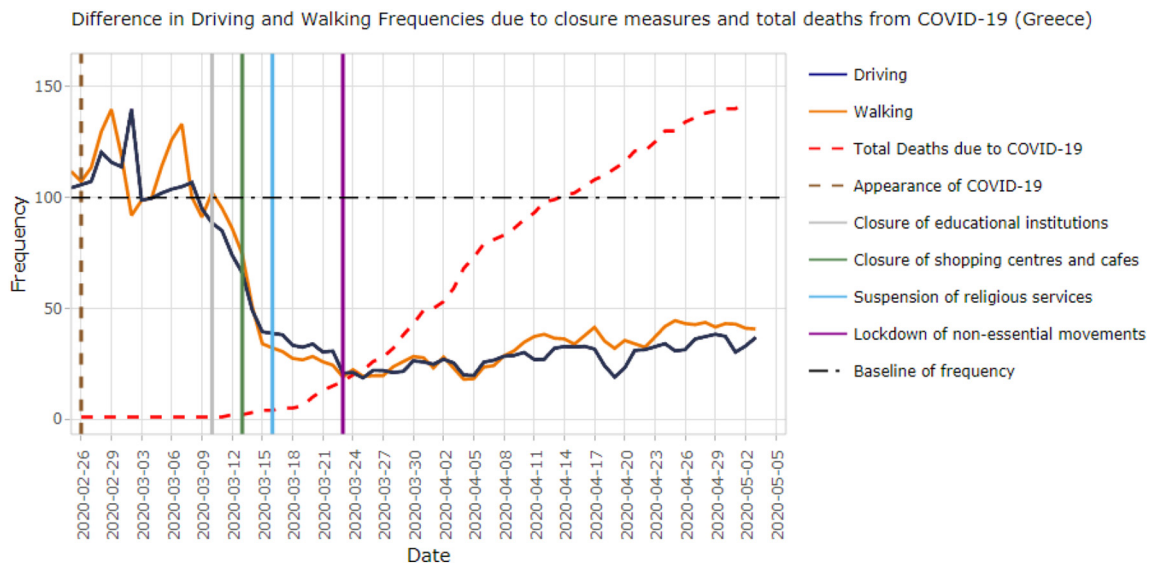


Fig. 4. Change in routing requests with corresponding deaths since 26 February 2020 in Greece.

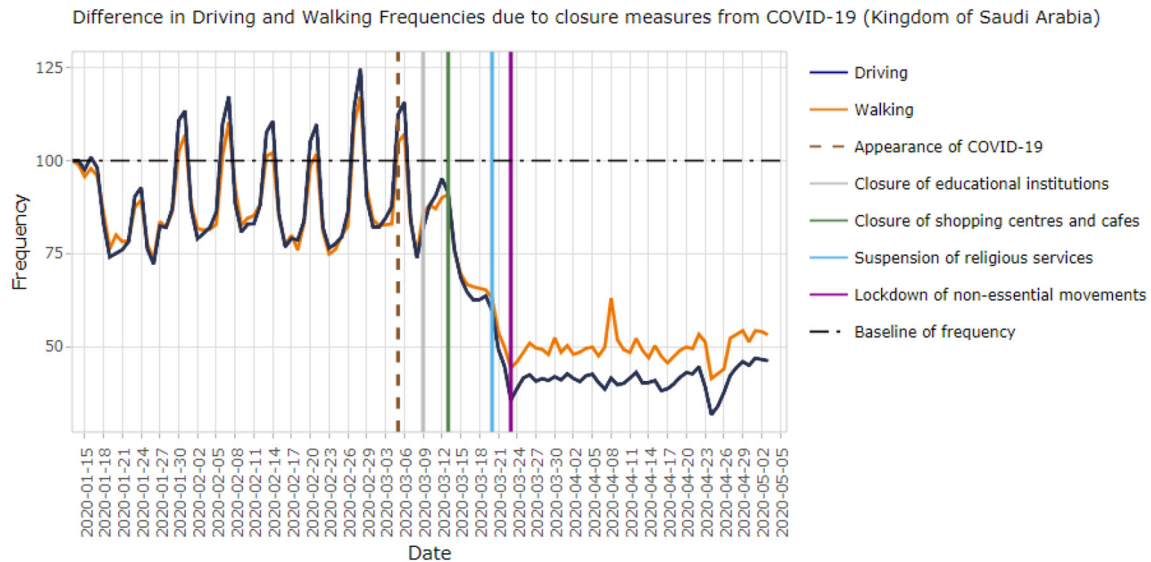


Fig. 5. Change in routing requests since 13 January 2020 in KSA (Source: Apple).

It is evident that there is a significant reduction in the volume of people driving and walking during the COVID-19 spreading in Greece. From the beginning of March and especially after the initiation of the lockdown in the middle of the month, a 62% reduction of people driving and a 58% reduction of people walking is observed. Traffic volumes have dropped roughly 10% since the first week of March and up to 75% since the first week of April compared to the baseline (i.e. the average figures for the months before the COVID-19 pandemic).

Furthermore, Table 8 depicts the change that occurred in traffic volume in Greece between March and April compared to February. Specifically, a 41.85% reduction of people driving and a 41.39% reduction of people walking was identified in March compared to February. At the same time, a significant 73.96% reduction of people driving and a remarkable 72.31% reduction of people walking was identified in April compared to February.

To further clarify the impact of COVID-19 countermeasures on driving and walking patterns, Fig. 4 depicts driving and walking patterns in comparison with the number of COVID-19 casualties and the countermeasures taken from the Greek government. It can be observed that a crucial drop in walking and driving began with the shutdown of schools and all

educational institutes and continued until the decision for lockdown on the 23rd of March.

5.1.2. KSA

With regards to KSA, similarly with Greece, both driving and walking were significantly less frequent in the time of COVID-19. Nevertheless, as depicted in Fig. 5, the reduction was smaller than in Greece with a 56% and 47% reduction for driving and walking respectively. Traffic volumes have dropped up to 20% since the first week of March and up to 50% since the first week of April.

Table 9 depicts the change that occurred in traffic volume in KSA between March and April compared to February. Specifically, a 25.86% reduction of people driving and a 21.74% reduction of people walking was identified in March compared to February. At the same time, a 54.78% reduction of people driving and a remarkable 44.22% reduction of people walking was identified in April compared to February.

Fig. 6 illustrates driving and walking patterns in comparison with the number of COVID-19 casualties and the countermeasures taken from the KSA government. It can be observed that a crucial drop in walking and driving began with the shutdown of schools and all educational

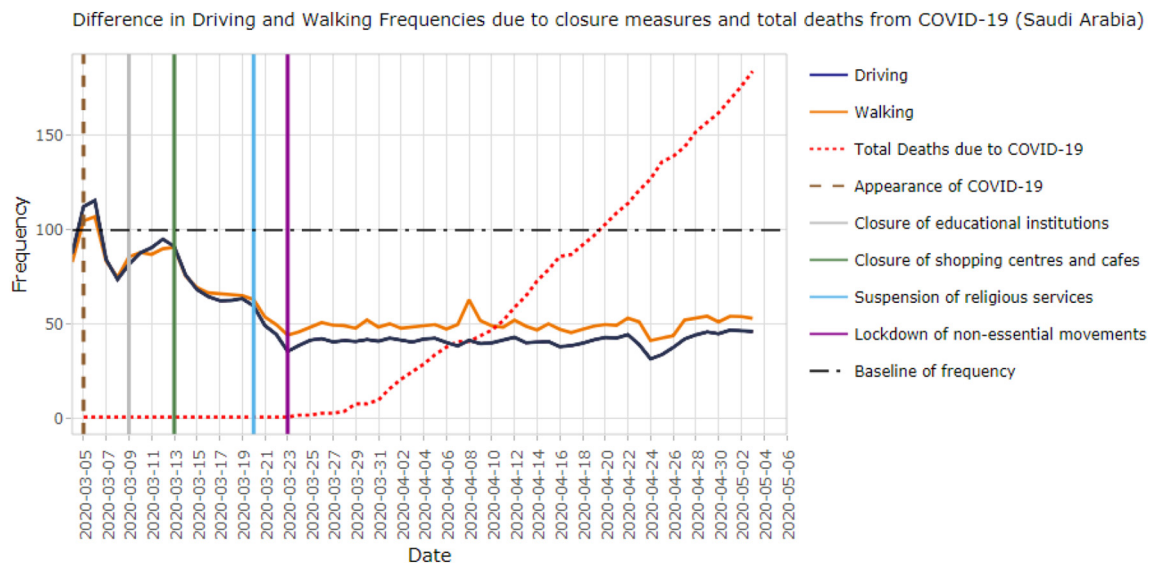


Fig. 6. Change in routing requests with corresponding deaths since 5 March 2020 in KSA (Source: Apple).



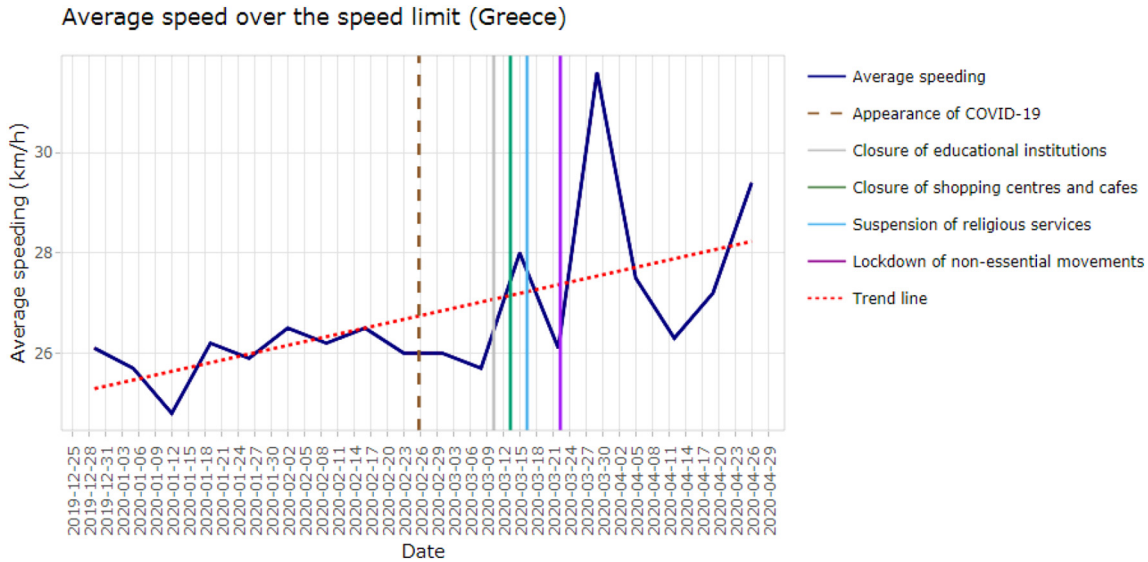


Fig. 7. Average speed over the speed limit per week in Greece.

institutes and continued until the decision for lockdown on the 23th of March.

5.2. Speed and speeding

Before beginning to illustrate the results on driving behavior and trips characteristics, it should be mentioned that all the figures in Sections 5.2, 5.3 and 5.4, illustrate the mean metrics of the indicators mentioned in Table 1 per week. Therefore, the horizontal axis in these figures denote the beginning of each week, i.e. the measurement on the 26th of April denotes the mean indicator for all trip data during the week between the 26th of April and the 4th of May.

5.2.1. Average speeding

Fig. 7 indicates that with fewer vehicles on city streets, slightly more drivers are blowing the speed limit. Although with less traffic, drivers are

getting to their destinations faster, there was also a slight increase in the average speed over the speed limit. First reported in March a 2% spike in average speeding compared to a normal period in February. Moreover, a 7% increase in average speeding was found in April compared to February. It is worth mentioning that an increase in average speeding was pointed out, before the lockdown had been announced.

Similarly, in KSA as depicted in Fig. 8, a 4% increase in average speeding was found in March compared to February, while a 5% increase in average speeding was found in April compared to a normal period in February.

5.2.2. Ratio of speeding duration/driving duration

Fig. 9 depicts an upward trend in the ratio of speeding duration per driving duration in March compared to February. More specifically, a 7% increase was observed in March and an 18% increase in the ratio of speeding duration per driving duration was found in April. With regards

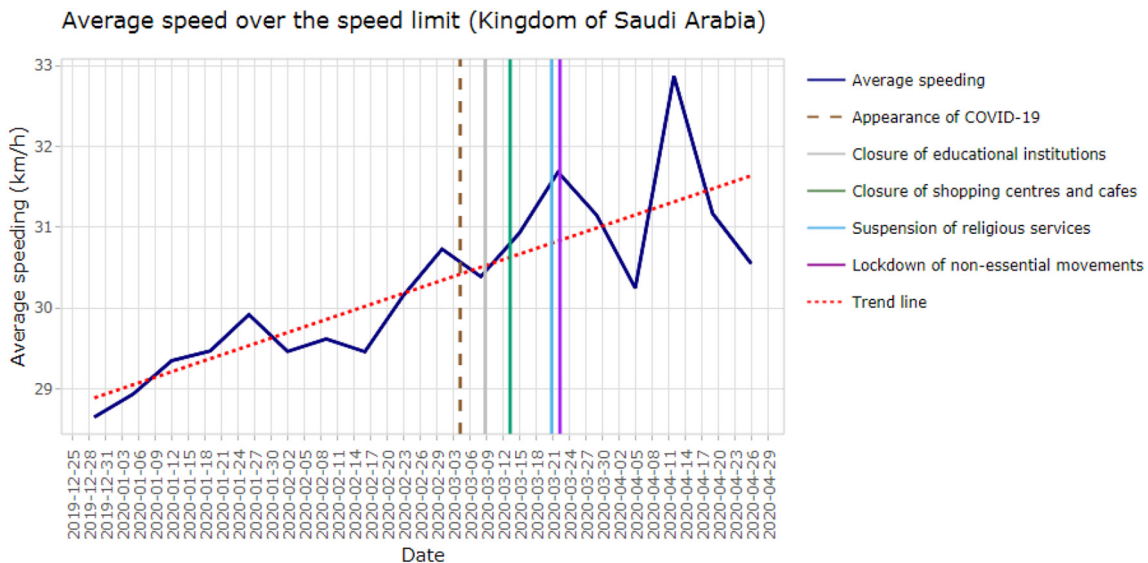


Fig. 8. Average speed over the speed limit per week in KSA.

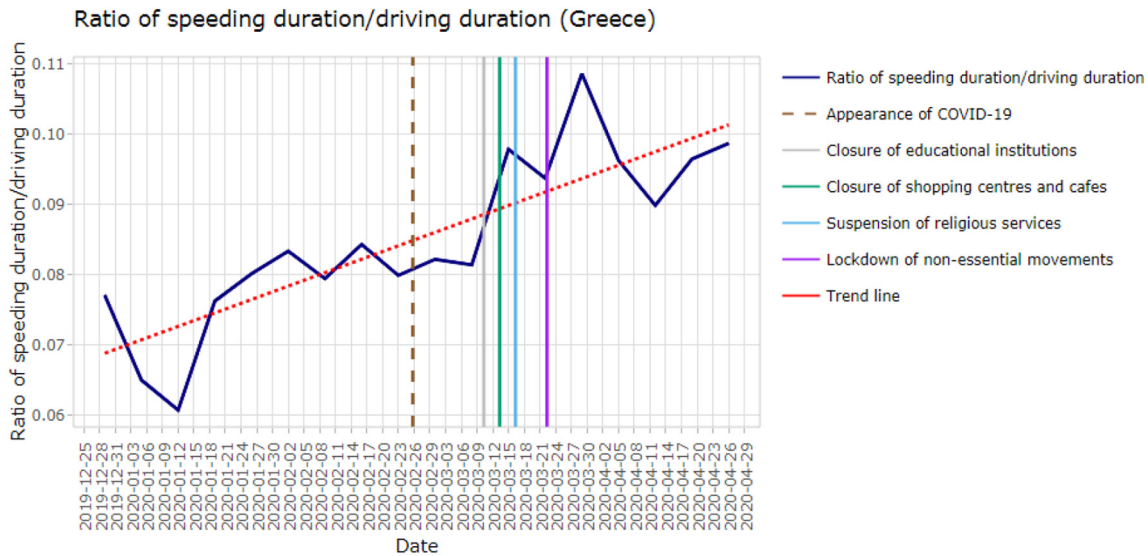


Fig. 9. Ratio of speeding duration/driving duration per week in Greece.

to the KSA, as depicted in Fig. 10, a 14% increase in the ratio of speeding duration per driving duration in March compared to February, while a 36% increase in the ratio of speeding duration per driving duration was found in April compared to February.

It is worth noticing that during the first days of January, a period of public holidays for Greece, a reduction in the ratio of speeding duration/driving duration was found, which is probably due to the fact that with lower driving traffic volumes (due to the holidays), drivers were more willing to exceed the speed limit. Afterwards, a gradual increase in this ratio was identified, culminating after the appearance of COVID-19 pandemic. With regards to the ratio of speeding/driving duration in the KSA, a slight increase is generally observed until the appearance of COVID-19, while during the time period of the pandemic, this increase became more rapid.

5.2.3. Average total speed

With regards to the total average speed, a 6% increase was found in March compared to February, while an 11% increase in average speed was observed in April compared to the normal period of February, as shown in Fig. 11. With regards to the average speed in KSA, a 5%

increase in average speed was found in March and an 8% increase was determined in April compared to a normal period in February, as shown in Fig. 12.

It should be mentioned that a reduction in average total speed before COVID-19 pandemic was identified, which seems reasonable as the first days of January include public holidays (i.e. New Year's Eve) for both countries. In particular, within the first days of January, when a reduction in traffic volume was observed, drivers tended to increase their average speed and speeding, while during the following days, they returned to their normal driving performance, under normal conditions, which led to slightly increased speeds. Then, the appearance of COVID-19, resulted in significantly reduced traffic volumes and drivers started to increase their average total speed.

5.2.4. Average driving speed

Fig. 13 shows evidence of driving average speed, especially, after the first appearance of COVID-19. A 4% increase in driving average speed was determined in March as well as a 6% increase in driving average speed was found in April compared to February. Although, in absolute

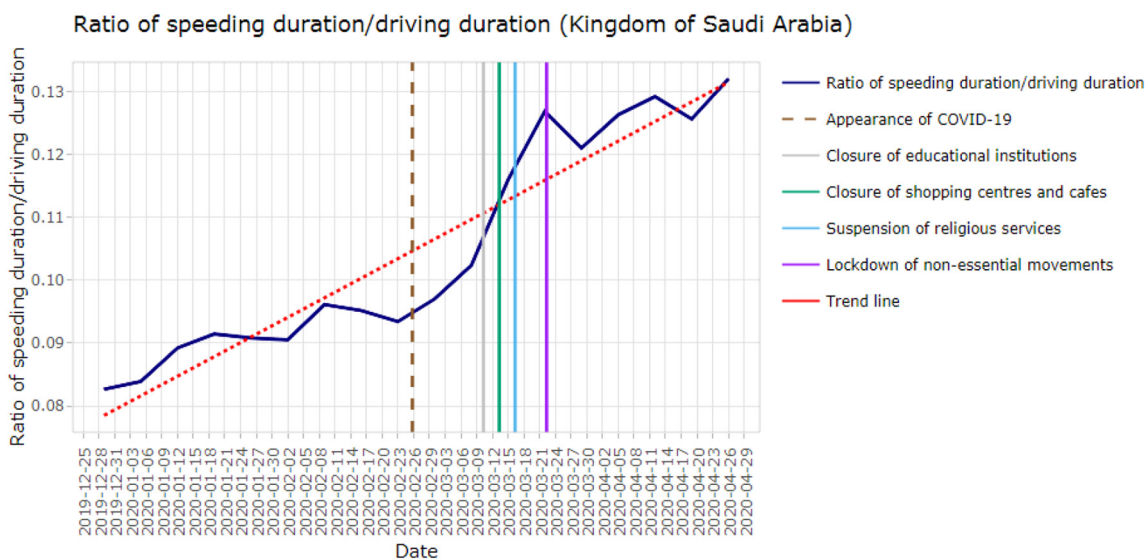


Fig. 10. Ratio of speeding duration/driving duration per week in KSA.

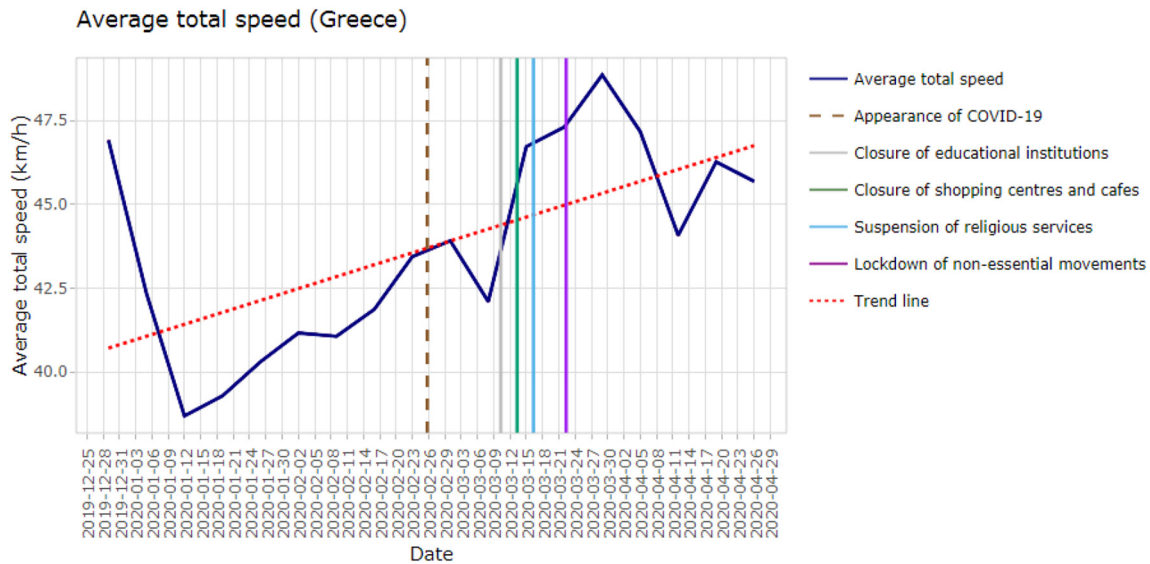


Fig. 11. Average total speed per week in Greece.

values the increase of driving speed is roughly the same before and during the pandemic, in Fig. 13 it is observed that the increase of average speed before the appearance of COVID-19 in Greece had an upward trend with very few fluctuations, while during the pandemic two sudden decreases of average driving speed occurred and average driving speed reached its maximum value of nearly 60 km/h on the 29th of March.

In Saudi Arabia the corresponding increase in driving speed ranged from 4% in March to 7% in April compared to February. Nevertheless, it can be observed that speeds were higher in Kingdom of Saudi Arabia than Greece during the lockdown phases, as shown in Fig. 14.

With regards to average driving speed, and similarly with average total speed, during the first days of January, increased speeds were observed. However, since the increase of traffic volume in mid-January and the sudden drop of average driving speed, drivers demonstrated incrementally faster speeds, until the sudden peak after the appearance of the pandemic in the country.

### 5.3. Harsh events

#### 5.3.1. Harsh acceleration events

With regards to harsh accelerations, although in March and during the first phase of the lockdown a 6% reduction was observed, in April harsh accelerations were increased by 5% compared to February, as shown in Fig. 15. Drivers were found to accelerate harshly in KSA during the months of COVID-19. Specifically, in March 3% more harsh accelerations per km were observed, while in April this percentage has risen to 11%, as depicted in Fig. 16.

It is important to notice that harsh acceleration events appeared to have neutral trend in Greece, while an increase in harsh accelerations per distance was identified during the first days of January. This is probably due to the fact that during holiday's period, less traffic volume on empty roads led to smoother traffic behavior, and afterwards, drivers returned to their previous usual driving habits and as a result drivers accelerated more

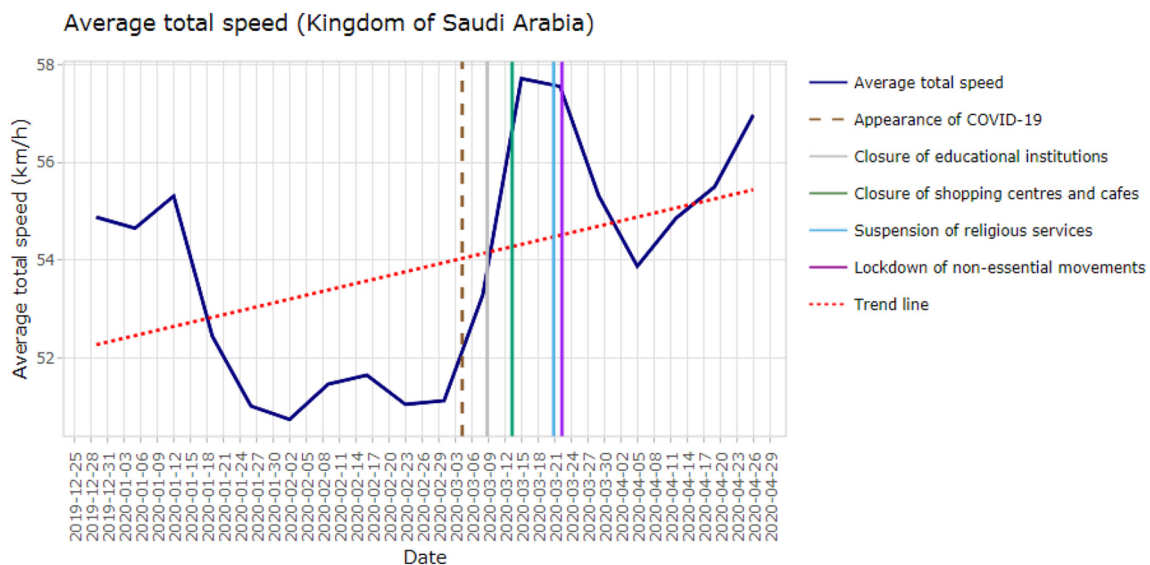


Fig. 12. Average total speed per week in KSA.

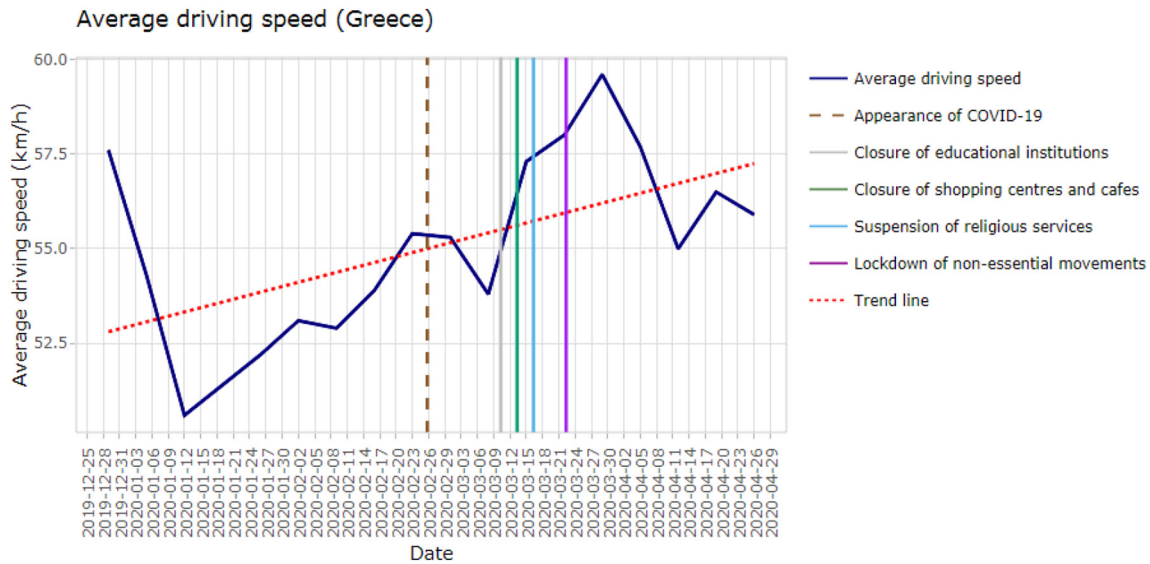


Fig. 13. Average driving speed per week in Greece.

harshly. The increase in harsh acceleration events is evident after the lockdown initiation, as streets were emptier in a similar fashion as with the holiday period. Similar observations were made for the KSA as well.

5.3.2. Harsh braking events

With regards to harsh braking as illustrated in Fig. 17, data showed a minor decrease of 3% during March but a 12% increase in April. This is probably due to the fact that with emptier roads drivers tend to increase their speed more and braked suddenly when an obstacle or pedestrian was observed. Nevertheless, from Fig. 17 it is evident that although on absolute average values, a similar change on harsh braking frequency in Greece was observed, a “mirrored” fluctuation exists. More specifically, until the appearance of COVID-19, harsh braking frequency was steadily decreasing but during the pandemic period, harsh braking became more frequent on average with two significant drops occurring after the initiation of the lockdown.

The increase in harsh braking events is more obvious in Fig. 18 and the data for KSA. It can be observed that harsh braking is having an upward trend especially after the closure of religious services and the initiation of the lockdown. Specifically, only a 0.31% increase in harsh braking per

distance was found in March compared to February, while a 10% increase in average harsh braking per distance was found in April.

Similarly to harsh acceleration patterns, harsh braking frequency per 100 km was increased during the first days of January, while in the following days, a reduction was identified.

5.4. Trip characteristics

5.4.1. Total duration

As shown in Figs. 19 and 20, both in Greece and KSA driving trips were significantly reduced due to the lockdown. A 29% reduction in total duration was observed for Greece in March and a 65% reduction in April. Similarly, in KSA 30% shorter trips were made in March and 73% shorter trips were observed during April.

5.4.2. Driving duration

In accordance with the driving lengths, Figs. 21 and 22 illustrate a reduction also with regards to driving duration especially, after the first appearance of the pandemic.

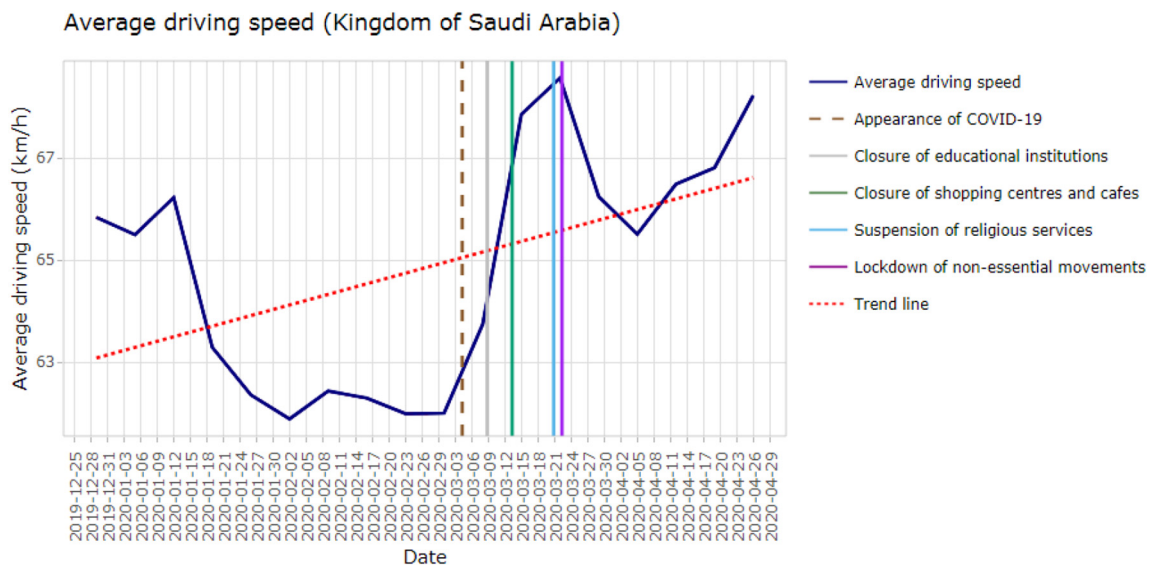


Fig. 14. Average driving speed per week in KSA.

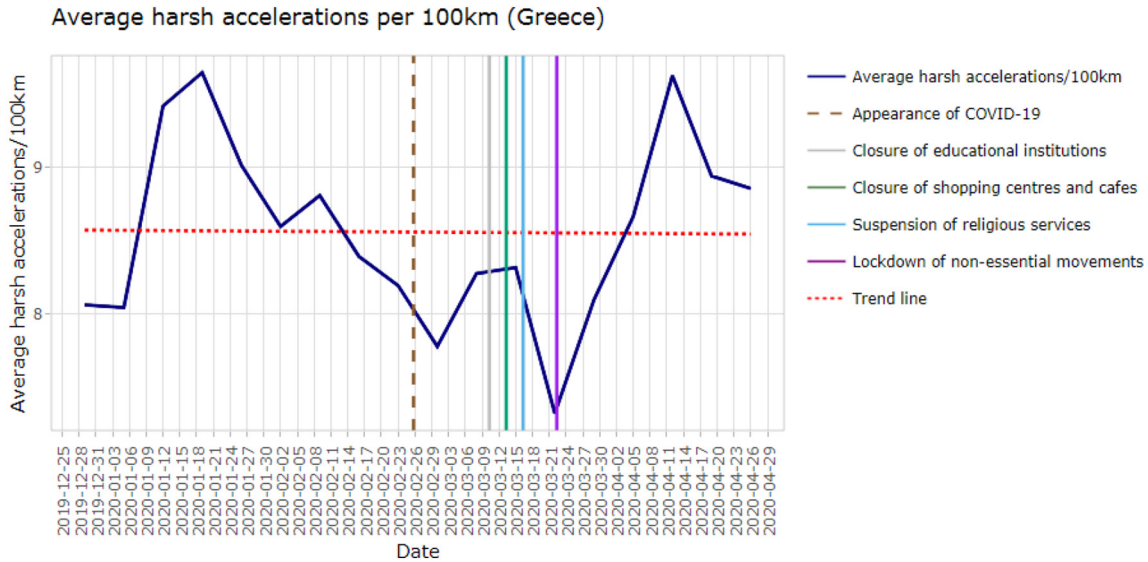


Fig. 15. Harsh accelerations per distance per week in Greece.

In Greece a 31% decrease in driving duration was found during March and a significant 74% was illustrated during April. The reduction was greater in KSA, with 32% in March and 75% shorter trips during April.

5.4.3. Total distance

Work and travel restrictions mean that overall, it is likely that less journeys are being made. For road safety, this may be an upside: less journeys should theoretically mean less crashes. There is evidence that since the COVID-19 pandemic, there has been a reduction in distance driven, as shown in Fig. 23. Greece started to increase weekly mileage, reaching a 29% decrease in total distance monitored in March, compared to February. Interestingly, total driving distance per week had already dropped by around 65% in April after the lockdown had even been announced.

With regards to distance driven in KSA, a 30% decrease in total driving distance was determined in March, as well as a 73% reduction in total driving distance was determined in April compared to a normal period in February, as shown in Fig. 24.

5.4.4. Risky hours

Fig. 25 shows a reduction in distance driven in risky hours, from 00:00 am to 05:00 am, especially after the total lockdown throughout Greece. In particular, a 45% reduction in risky hours driving was found in March compared to February, while a 74% decrease in risky hours driving was determined in April compared to a normal period in February.

A reduction in distance driven in risky hours, was observed in KSA. In particular, a 33% reduction in risky hours driving was found in March compared to February, and an extreme 81% decrease in risky hours driving was determined in April compared to a normal period in February, as shown in Fig. 26.

5.4.5. Ratio of mobile phone usage duration/driving duration

With regards to mobile phone use, Figs. 27 and 28 illustrate a general increase in the ratio of mobile phone usage duration per driving duration when comparing data from March and April (i.e. COVID-19 months) with data from February (i.e. normal operations). In more detail, a 1% decrease

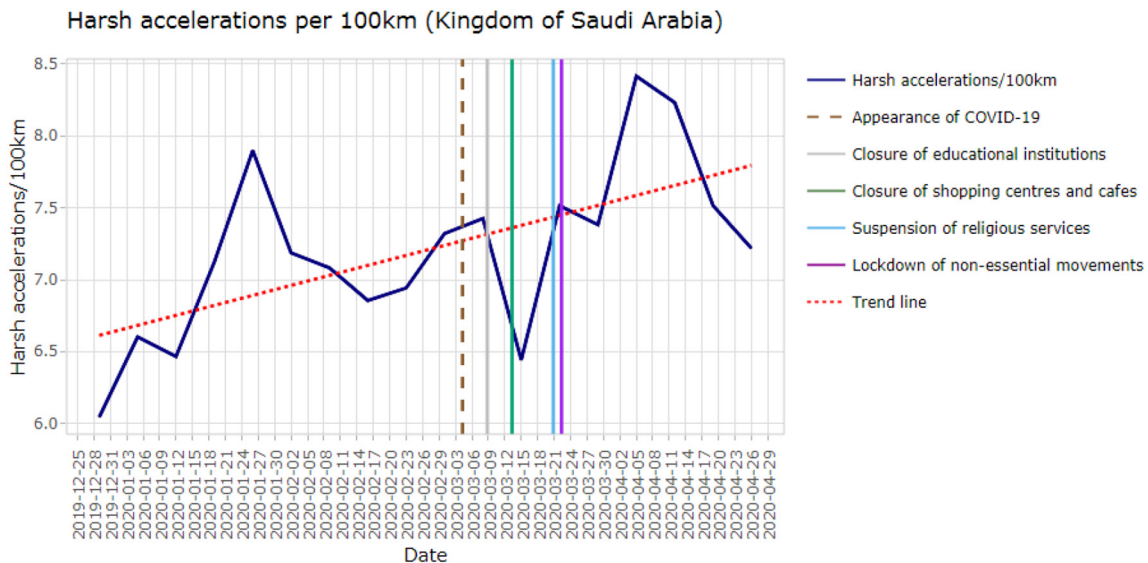


Fig. 16. Harsh accelerations per distance per week in KSA.

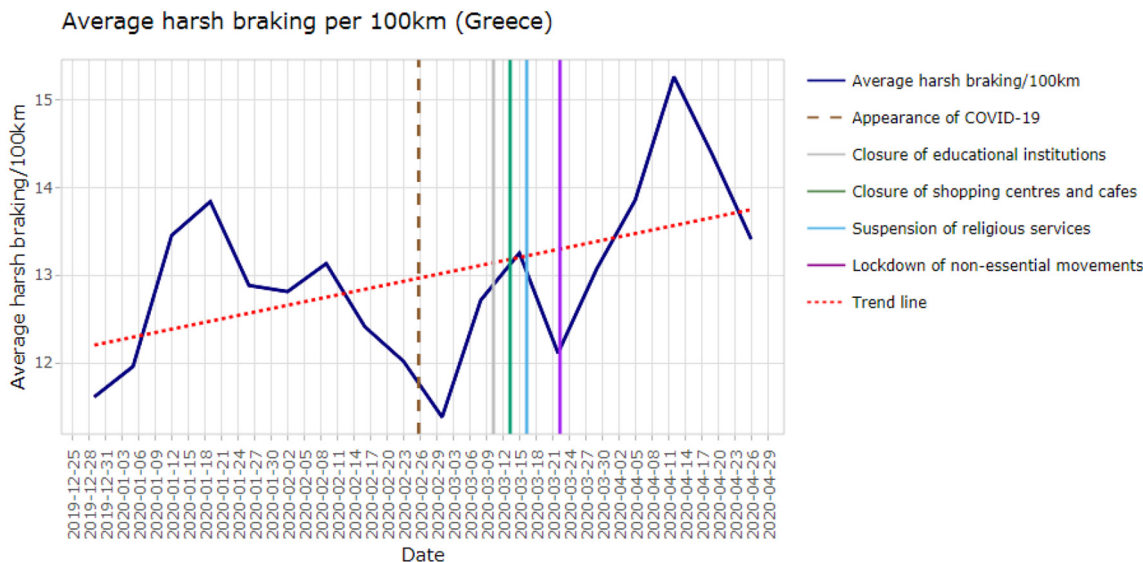


Fig. 17. Harsh braking per distance per week in Greece.

in the ratio of mobile phone usage duration per driving duration was found in March while a 21% increase in the ratio of mobile phone usage duration per driving duration was found in April for Greece and an 11–42% increase was observed in KSA.

5.5. Summary

Table 10 summarizes the changes in driving behavior and trip characteristics during the months of COVID-19, when compared with January and February 2020, when the coronavirus did not have an impact on everyday life.

From Table 10, it is evident that the most significant effects of COVID-19 with regards to road safety, in Greece were the increased speed as well as the increase on the frequency of speeding, as well as a slight increase in harsh braking events/100 km. Trips were appreciably shorter both in distance and duration, which is obviously due to the prohibitions imposed by the Greek government and essentially less trips were done during risky

hours. Finally, the increased mobile use by Greek drivers is evidence of decreased road safety during the time of the COVID-19 response measures.

With regards to KSA, speed was also slightly increased during the months of March and April, and both harsh accelerations and harsh braking were increased by roughly 10%. This is probably due to the fact that roads were emptier and drivers could accelerate more while obstacles or pedestrians crossing the empty road infrastructure lead to a combination of harsh acceleration and braking. Trips in KSA, were also significantly shorter (in distance and time) similarly with Greece, but during risky hours had a major reduction of 33–81%. Mobile phone usage especially during April, was significantly increased by 42% during, which denotes risky driving behavior.

5.6. Accidents in Greece during COVID-19

Table 11 illustrates the difference in accident rates between February and March 2020. It is shown that a 41% reduction in total number of road accidents was observed during March 2020, when the majority of response

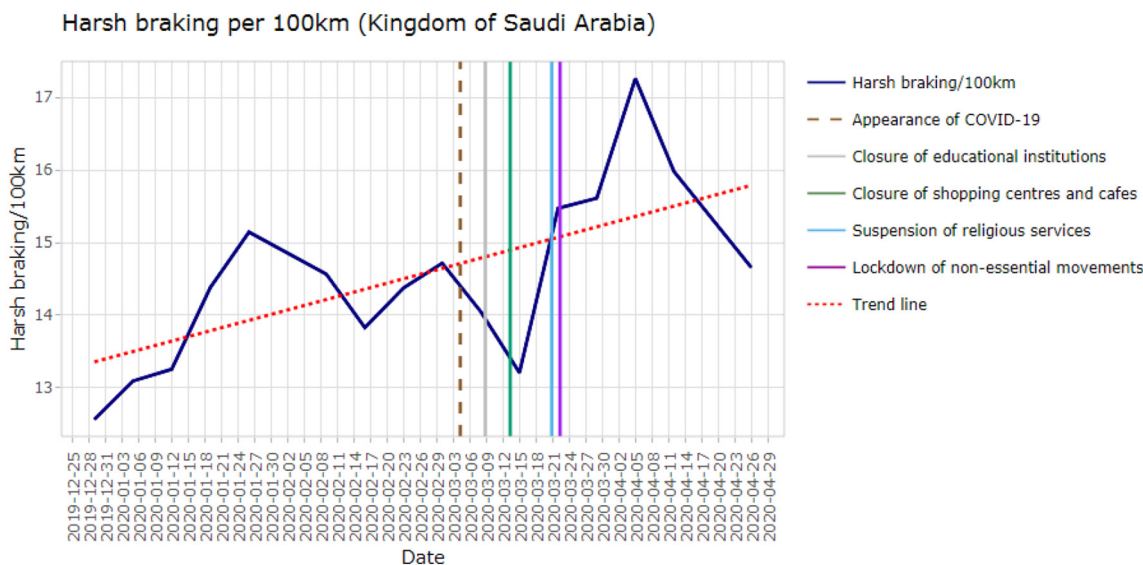


Fig. 18. Harsh braking per distance per week in KSA

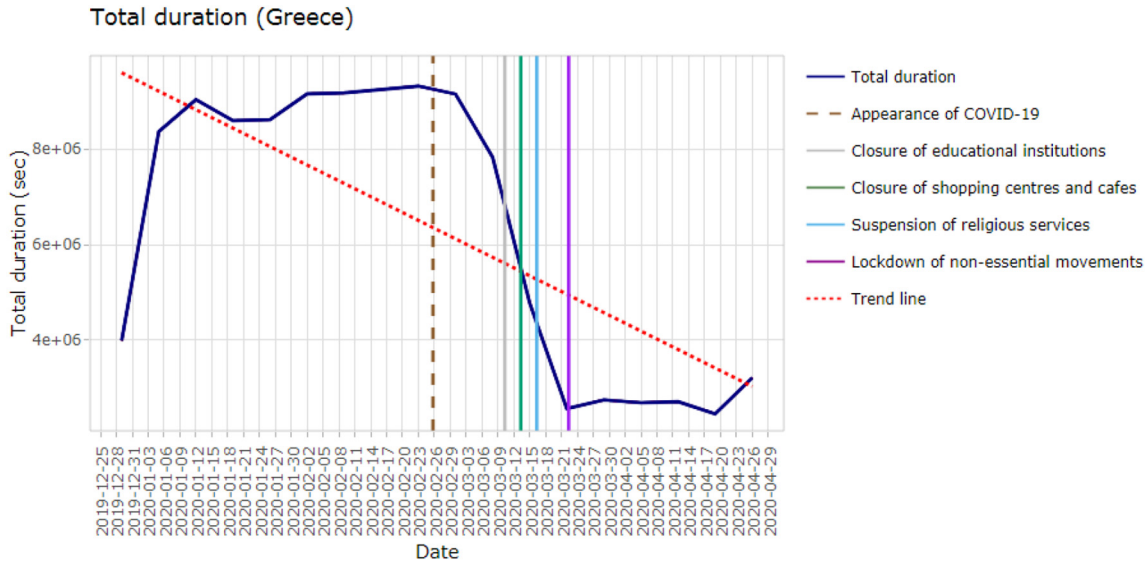


Fig. 19. Total duration per week in Greece.

measures regarding COVID-19 took place. Furthermore, during March 2020, the total number of fatal accidents was decreased by 41%, severe injured dropped by 8%, while slight injured accidents were reduced by 42%.

6. Conclusions on road safety and policy recommendations

COVID-19 “invaded” everyday life abruptly, which induced a significant change in everyday life commuting and travel behavior. The measures taken by local governments to restrict the spread of the coronavirus were immediate and strict, but eventually seem to have positive effects on diminishing the exponential dispersion of COVID-19 and ensure public health. For example, as of May 4th 2020, Greece has started to loosen the lockdown status gradually.

During the two months that COVID-19 was spreading in Greece and KSA, it affected aspects of road safety and driving behavior. Trips were found to be shorter, but speeds were slightly increased. Harsh event frequency during the lockdown phase was increased, and especially harsh

braking. This was probably an indirect effect of the increase in driving speed. It was observed that drivers reduced the number of trips taken between midnight and 05:00, thus reducing the risk of accidents, but a great increase of 21–42% was identified in the ratio of mobile phone usage duration per driving duration.

The increase of speeds, speeding rates, frequency of harsh events and mobile phone denotes a potential deterioration of the level of road safety, however, additional analyses (e.g. correlation analysis or explanatory modelling) could further validate the findings. Furthermore, this potential deterioration of road safety, is not illustrated in accident numbers in Greece, such behaviors could become the target objective of policy interventions on the “epidemic”-like phenomenon of traffic accidents (Hazen and Ehiri, 2006; Sharma, 2008). Whereas road infrastructure safety improvement and safer vehicles penetration require several years before witnessing major results, traffic behavior can certainly be controlled and improved much faster, if social acceptance is raised and political will is strong and sincere. Managing efficiently (by police enforcement and

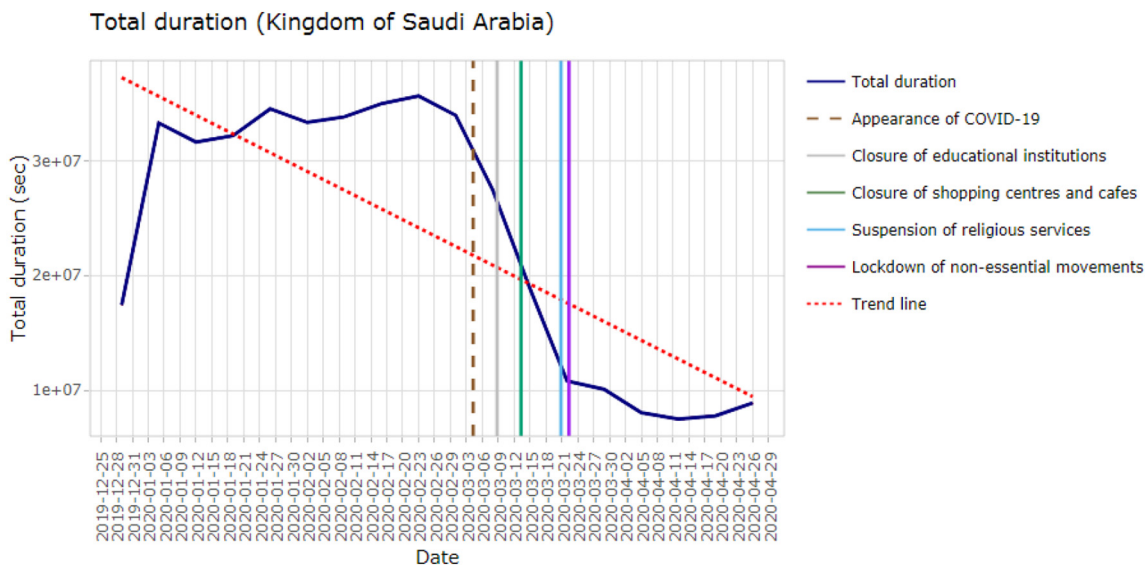


Fig. 20. Total duration per week in KSA.

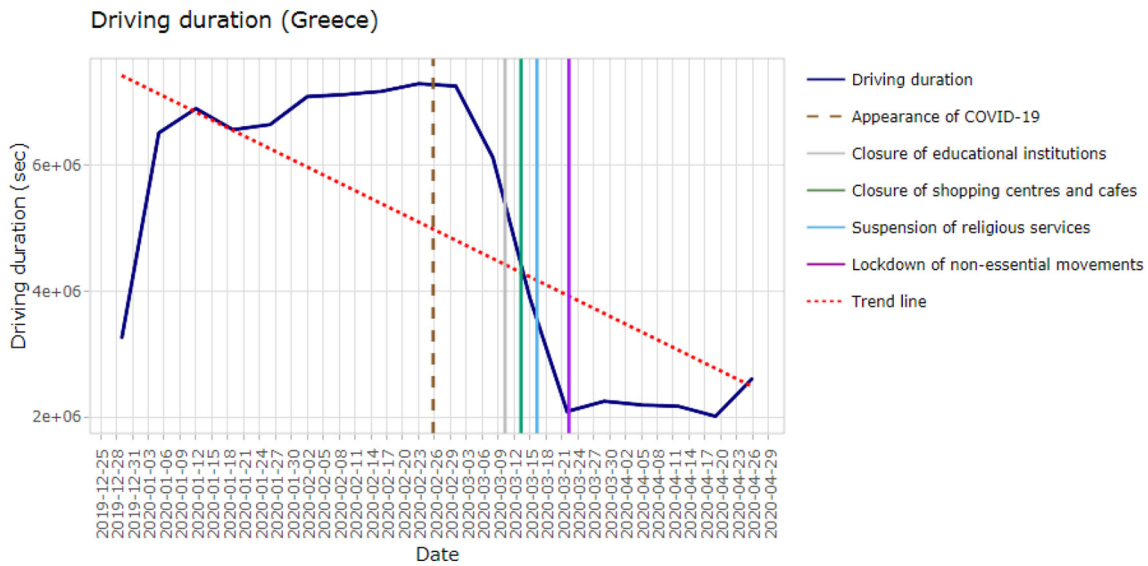


Fig. 21. Driving duration per week in Greece.

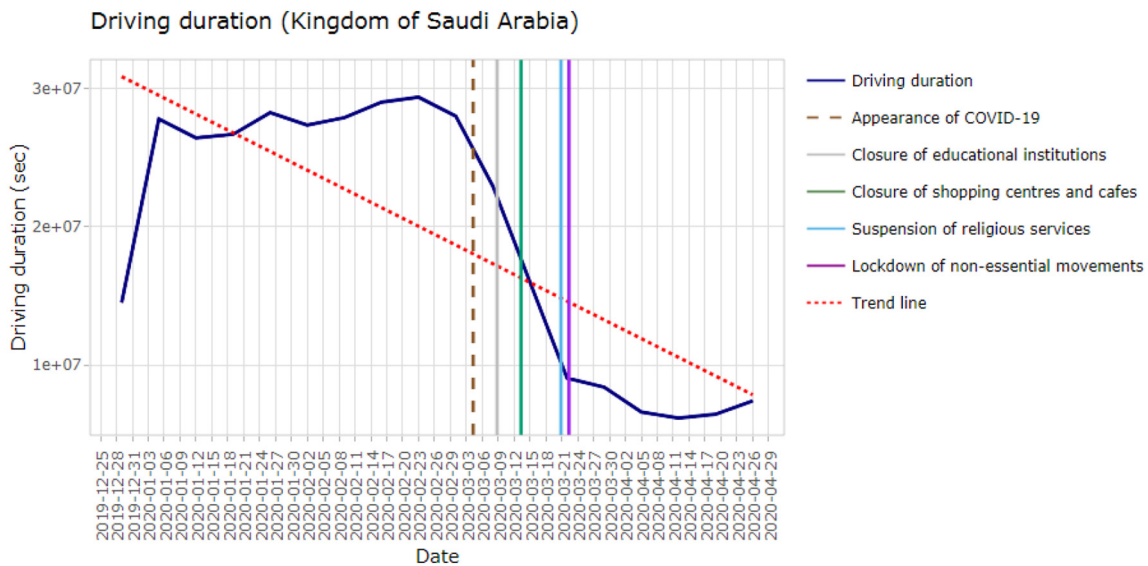


Fig. 22. Driving duration per week in KSA.

massive campaigns) the five major traffic killers (speeding, mobile-phone-use, drink-and-drive,<sup>1</sup> seat belt and helmet non-use) can be proved highly beneficial with a great number of lives saved even at short term.

It is highly important that during the COVID-19 period as well as shortly after, the national health systems are not further overloaded by road casualties. Therefore, efficient traffic safety measures should be taken as soon as possible, so that traffic accident rates are not increased again.

Focus should specifically be given by policymakers to the major traffic killers (speeding being the most important) and to measures bringing results quickly. For instance, these measures could concern:

- New speed limits applying to all roads horizontally (with important benefits also for the environment):

- 30 km/h in urban areas (50 km/h in major urban axes), similar to the practices applies in major European cities (ETSC, 2020a, 2020b; ITF, 2020)
- 50 km/h at rural roads
- 80 km/h at major interurban roads
- 100 km/h on motorways

- Speeding enforcement should be massively implemented through cameras (always on) and fines massive processing should be efficiently upgraded if necessary with new legislation urgently put in place.
- Intensification of enforcement of mobile-phone use and non-use of seat belts and helmets, eventually with any other COVID-19 related traffic controls.
- Implementation of massive campaigns (within those for the COVID-19) raising public awareness on speeding and the other major traffic accidents factors.

<sup>1</sup> Drink-and-Drive applies for Greece in this paper since there is no alcohol consumption in KSA.



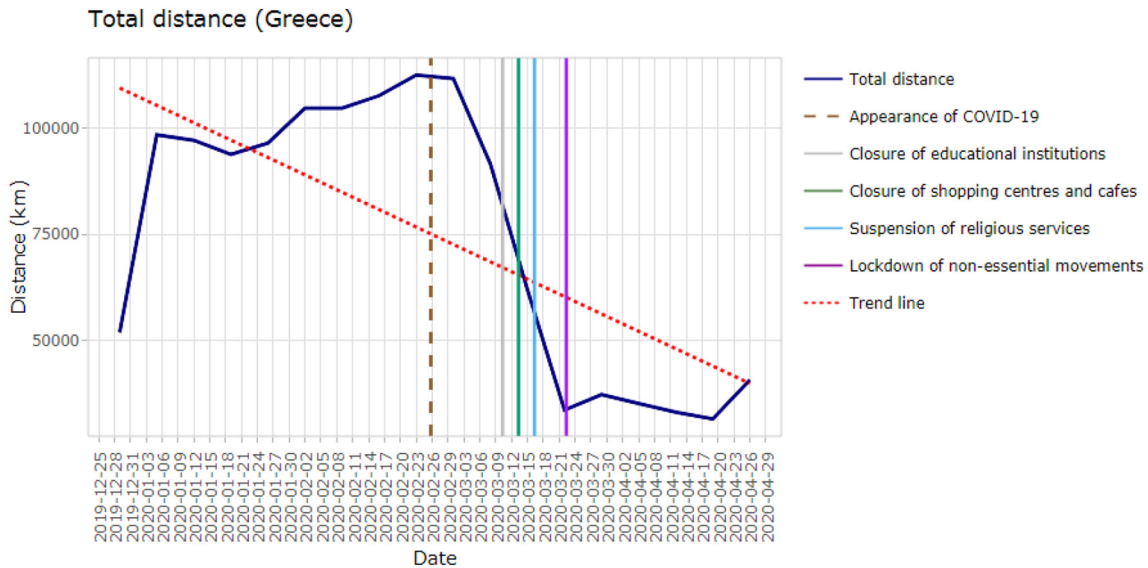


Fig. 23. Total driving distance per week in Greece.

- The data driven approach that has been followed against the COVID-19 pandemic has been proved very effective. Yet, in driving behavior and road safety, public authorities do not have sufficient data to take any proactive measures for the optimization of the resources for road infrastructure improvement and the optimum implementation of road safety policies. Therefore, the wider implementation of telematics and tech enabled approaches, can significantly increase the insight of public authorities towards road safety, whereas it can also improve driving behavior via coaching, training and gamification approaches.

Finally, as everyday life and more specifically travelling and commuting shortly after the lockdown could induce stress on COVID-19 transmission (Porcelli, 2020) policymakers should also seek out alternatives to public transport such as trams, metros and buses. It is hoped that allocating road space to bicycles and pedestrians, and reducing the space available for cars, will encourage people to cycle or walk rather than taking the car (ITF, 2020).

It should be mentioned that the aforementioned policy proposals are not COVID-19-specific, as there is not a direct relationship between driving behavior and COVID-19 spreading. However, as mentioned before, safer driving behavior would lead to less accidents and therefore to less casualties and injured people. As a result, additional patient load will not be imposed on public health systems. To that purpose, campaigns focusing on safer driving behavior and highlighting findings from the current pandemic period could be promoted in potential future waves of the pandemic.

Safer road traffic and no accidents should be the first priority during and after the COVID-19 pandemic. The current circumstances must act as the trigger for a new and serious behavior by both the authorities and citizens for safer roads for all, everywhere in the world.

6.1. Limitations

The purpose of this work was to investigate the effect of COVID-19 pandemic on driving performance and road safety as well as identify driving behavior changes as a function of COVID-19 restrictions. Due to the fact,

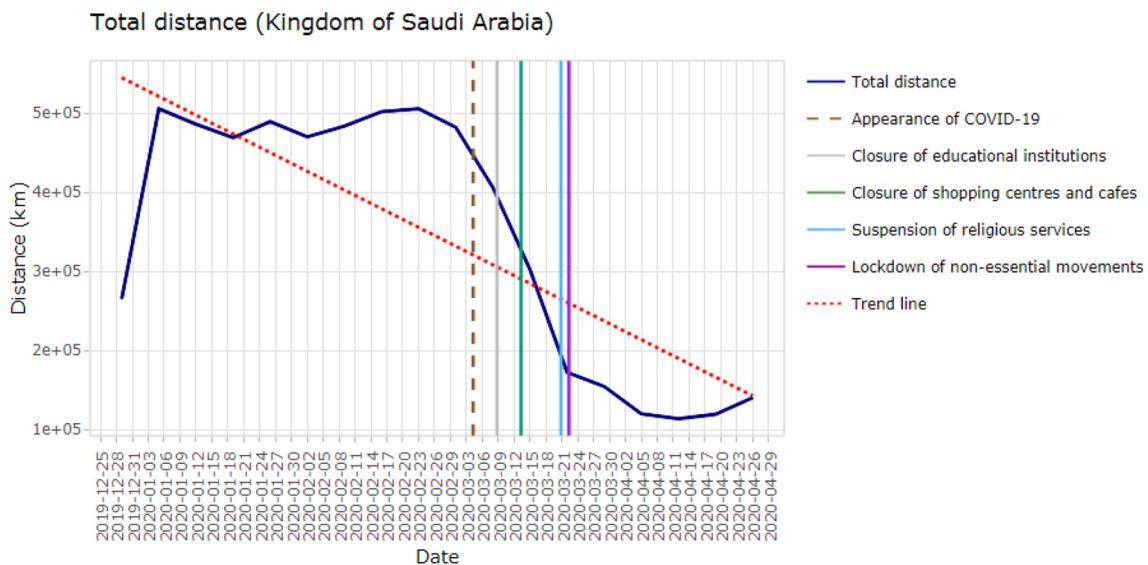


Fig. 24. Total driving distance per week in KSA.

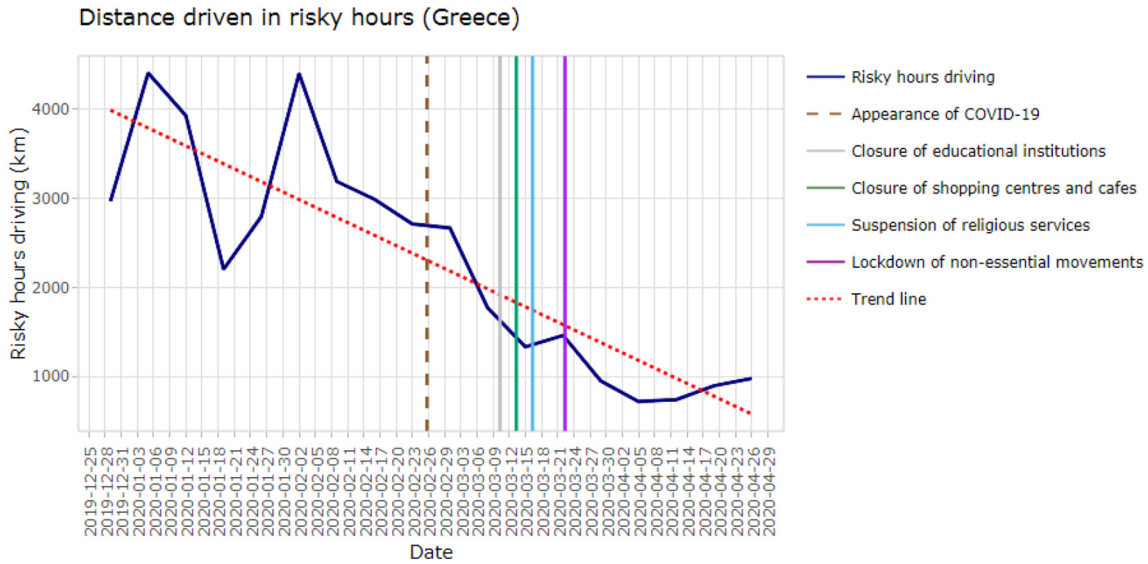


Fig. 25. Distance driven in risky hours (00:00–05:00) per week in Greece.

however, that insights were provided on eleven driving behavior indicators and the number of crashes in Greece, more sophisticated methods such as regression and correlation analyses did not take place due to paper size considerations and should be included in future work. Furthermore, it should be noted that an appropriate number of data, obtained from OSeven, were available only for Greece and KSA, so the analysis was conducted only for these two countries. A more comprehensive picture of the effects of COVID-19 lockdown driving indicators on road safety could be drawn if enough high quality data are available in more countries (i.e. average speed, speeding, changes in traffic volumes, total number of road crashes along with the corresponding deaths, severe and slight injuries accidents, changes in road user behavior etc.). Moreover, as explicit geolocation information (e.g. road type) was missing from the dataset, the effect of road type on driving behavior could not be analyzed. With respect to road crashes, data on road accidents (i.e. deaths, severe and slight injuries) for the period February–April 2020 were available only for Greece and there was no evidence on this information with regards to road accidents in KSA, making the comparison between two countries seems impossible. Finally, it is

worth mentioning that confounding factors of drivers, such as gender, age, educational level or mental health state were not taken into consideration in this study due to the anonymization procedure during the mobile phone application data collection, but could be pursued in future research.

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**Author statement**

The authors confirm contribution to the paper as follows:  
**Christos Katrakazas:** Conceptualization, Methodology, Writing, Review, Editing  
**Eva Michelaraki:** Software, Writing, **Marios Sekadakis:** Software, Writing, Visualisation **George Yannis:** Resources, Review, Supervision.

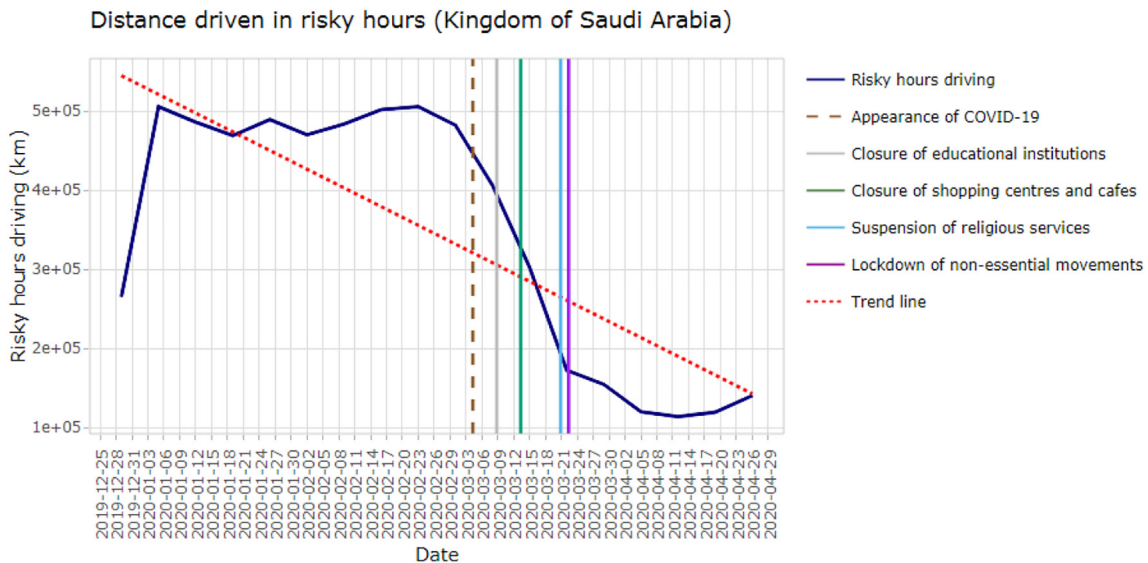


Fig. 26. Distance driven in risky hours (00:00–05:00) per week in KSA.

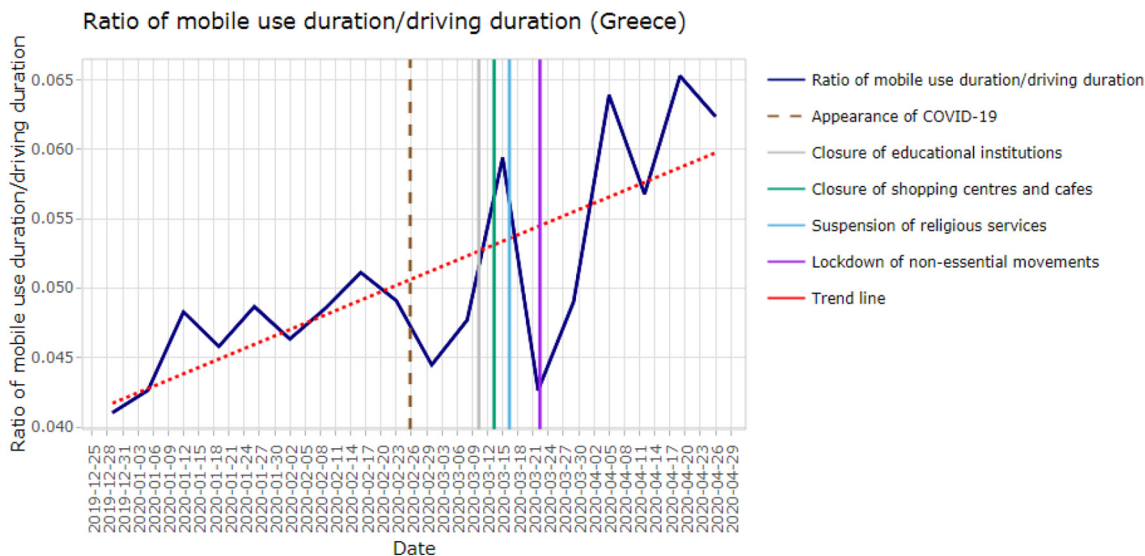


Fig. 27. Ratio of mobile phone usage duration/driving duration per week in Greece.

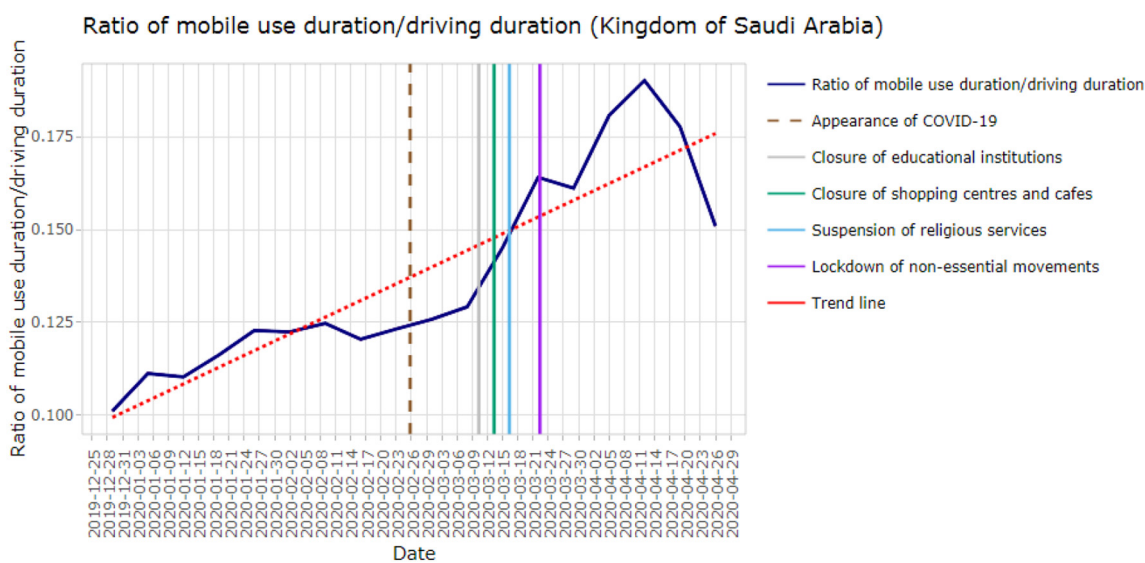


Fig. 28. Ratio of mobile phone usage duration/driving duration per week in KSA.

**Table 11**  
Road safety in Greece during February and March 2020 (Source: Greek Traffic Police).

Road accidents	February 2020	March 2020	Change
Fatal	48	20	-41%
Severe injured	24	22	-8%
Slightly injured	633	365	-42%
Total	691	407	-41%

**References**

Anderson, R.M., Heesterbeek, H., Klinkenberg, D., Hollingsworth, T.D., 2020. How will country-based mitigation measures influence the course of the COVID-19 epidemic? *Lancet* 395, 931–934.

Apple, 2020. COVID-19 - Mobility Trends Reports - Apple [WWW Document]. Apple.

Budd, L., Ison, S., 2020. Responsible transport: a post-COVID agenda for transport policy and practice. *Transp. Res. Interdiscip. Perspect.* 6, 100151.

Cai, J., Xu, Bo, Chan, K.K.Y., Zhang, X., Zhang, B., Chen, Z., Xu, Bing, 2019. Roles of different transport modes in the spatial spread of the 2009 influenza A(H1N1) pandemic in mainland China. *Int. J. Environ. Res. Public Health* 16, 1–15.

Clarke, S., 2020. The Traffic Data that Shows the Road into - and out of - Covid-19 Lockdown. *World News - the Guardian*. Guard.

De Vos, J., 2020. The effect of COVID-19 and subsequent social distancing on travel behavior. *Transp. Res. Interdiscip. Perspect.* 5, 100121.

ETSC, 2020a. COVID-19: cities adapting road infrastructure and speed limits to enable safer cycling and walking. <https://etsc.eu/covid-19-cities-adapting-road-infrastructure-and-speed-limits-to-enable-safer-cycling-and-walking/>.

ETSC, 2020b. COVID-19: the impact of covid-19 lockdowns on road deaths in April 2020. [https://etsc.eu/wp-content/uploads/PIN-Corona-Briefing\\_final.pdf](https://etsc.eu/wp-content/uploads/PIN-Corona-Briefing_final.pdf).

Garten, R.J., Davis, C.T., Russell, C.A., Shu, B., Lindstrom, S., Balish, A., Sessions, W.M., Xu, X., Skepner, E., Deyde, V., Okomo-adhiambo, M., Gubareva, L., Barnes, J., Smith, C.B., Emery, S.L., Hillman, M.J., Rivaviller, P., Smagala, J., Graaf, M.De, Burke, D.F., Fouchier, R.A.M., Pappas, C., Alpuche-aranda, C.M., López-gatell, H., Olivera, H., López, I., Myers, C.A., Faix, D., Blair, P.J., Yu, C., Keene Jr, K.M., Boxrud, P.D.D., Boxrud, D., Sambol, A.R., Abid, S.H., George, K.S., Bannerman, T., Ginsberg, M., Kriner, P., Waterman, S., Smole, S., Guevara, H.F., Belongia, E.A., Clark, P.A., Beatrice, S.T., Donis, R., Katz, J., Finelli, L., Bridges, C.B., Shaw, M., Jernigan, D.B., Uyeki, T.M., Smith, D.J., Klimov, A.I., Cox, N.J., 2009. Antigenic and genetic characteristics of swine-origin 2009 A(H1N1) influenza viruses circulating in humans. *Science* (80-. ) 325.

Google LLC, 2020. Google COVID-19 Community Mobility Reports [WWW Document] [WWW Document] Accessed 11/06/20.

Hazen, A., Ehiri, J.E., 2006. Road traffic injuries: hidden epidemic in less developed countries. *J. Natl. Med. Assoc.* 98, 73–82.

ITF International Transport Forum, 2020. Re-Spacing our Cities for Resilience.

- Molloy, J., 2020. MOBIS Covid19 Mobility Report [WWW Document].
- Papadimitriou, E., Filtness, A., Theofilatos, A., Ziakopoulos, A., Quigley, C., Yannis, G., 2019. Review and ranking of crash risk factors related to the road infrastructure. *Accid. Anal. Prev.* 125, 85–97.
- Porcelli, P., 2020. Fear, anxiety and health-related consequences after the covid-19 epidemic. *Clin. Neuropsychiatry* 17, 103–111.
- Sharma, B.R., 2008. Road traffic injuries: a major global public health crisis. *Public Health* 122, 1399–1406.
- Stavarakaki, A., Tselentis, D.I., Barmounakis, E., Vlahogianni, E.I., Yannis, G., 2020. Estimating the Necessary Amount of Driving Data for Assessing Driving Behavior.
- Stavrinos, D., McManus, B., Mrug, S., He, H., Gresham, B., Albright, M.G., White, D.M., 2020. Adolescent driving behavior before and during restrictions related to COVID-19. *Accid. Anal. Prev.* 144, 105686.
- TomTom, 2020. COVID-19 response | TomTom [WWW Document] [WWW Document].
- Tselentis, D.I., Vlahogianni, E.I., Yannis, G., 2019. Driving safety efficiency benchmarking using smartphone data. *Transp. Res. Part C* 109, 343–357.
- Vingilis, E., Beirness, D., Boase, P., Byrne, P., Johnson, J., Jonah, B., Wiesenthal, D.L., 2020. Coronavirus disease 2019: what could be the effects on road safety? *Accid. Anal. Prev.* 144, 105687.
- World Health Organization, W, 2018. Global Status Report on Road Safety 2018.
- World Health Organization, W, 2020. WHO Director-General's Opening Remarks at the Media Briefing on COVID-19 - 11 March 2020. WHO Dir. Gen. speeches.
- Worldometer, 2020. Worldometer Coronavirus Update (Live) [WWW Document].
- Xu, Bo, Tian, H., Sabel, C.E., Xu, Bing, 2019. Impacts of road traffic network and socio-economic factors on the diffusion of 2009 pandemic influenza A (H1N1) in mainland China. *Int. J. Environ. Res. Public Health* 16, 1–14.
- Zhang, D., Hu, M., Ji, Q., 2020. Financial markets under the global pandemic of COVID-19. *Financ. Res. Lett.* 101528.
- Zhu, N., Zhang, D., Wang, W., Li, X., Yang, B., Song, J., Zhao, X., Huang, B., Shi, W., Lu, R., Niu, P., Zhan, F., Ma, X., Wang, D., Xu, W., Wu, G., Gao, G.F., Tan, W., 2020. A novel coronavirus from patients with pneumonia in China, 2019. *N. Engl. J. Med.* 382, 727–733.