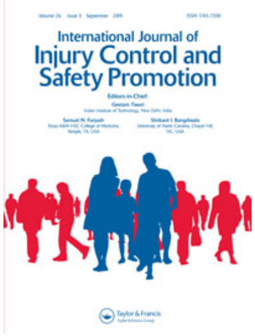

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Analysis of road traffic crashes in the State of Qatar

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ABSTRACT

Road traffic crashes (RTCs) are globally acknowledged as increasing threat to society, because they can affect many lives when they result in severe injury or fatality. In the State of Qatar RTCs are getting more awareness and attention, aiming to improve the traffic safety in the country. This study is an exploratory research providing different analyses of the crash data for seven consecutive years, ranging from 2010 to 2016, which is obtained from the Traffic Department in the Ministry of Interior for the State of Qatar. The objectives aim to evaluate the trend of RTC rate over time and create understanding of the influencing factors related to RTC frequency. Time series analyses show an increasing trend of RTCs leading to severe injury and a slight decreasing trend for fatal RTCs. Secondly, different RTC severity levels are related to diverse RTC causes. Furthermore, the results revealed that crashes with severe injuries or fatality for drivers as well as pedestrians are found to be significantly affected by seasonal weather variations, with the highest vulnerability in winter and autumn season. This study therefore suggests the implementation of strategies to prioritize the traffic safety of road users during the crash-prone winter and autumn seasons.

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KEYWORDS
Road traffic crash; time series; crash severity; crash cause; the State of Qatar

1. Introduction

Road traffic crashes (RTCs) are posing a serious hazard to modern societies, as they result in injuries, disabilities and even loss of lives, along with significant economic and social problems. Globally, RTCs led to about 1.3 million fatalities per year, with an average of 3287 deaths per day as stated by World Health Organization's global status report on road safety (World Health Organization, 2015). In the Arabian Gulf countries, RTCs are recognized as a growing threat to the community and thus received increased importance and attention. Various specified engineering measures are being implemented and awareness campaigns are being carried out in this region with the aim to minimize the severity and number of crashes. One example is Qatar's road safety strategy 2013–2022, which has been developed in accordance with the underlying principle intending to ensure that any crash that occurs does not result in fatality or serious injury.

Despite the reduction in the number of fatal crashes during the last five years, the frequency of personal injuries and material damage caused by road crashes involving a minimum of one vehicle has increased in the State of Qatar (Abou-Amouna et al., 2014). Therefore, it is significant to create understanding about the nature of the fatal crashes and crashes with serious injuries, by identifying different salient factors that influence the number of RTCs. A RTC can be caused by different factors related to road conditions, traffic density, vehicle conditions and human errors. The main causes of RTCs identified in the Gulf region are human factors, such as driver negligence, aggressive driving, violation of traffic regulations and speeding (Ali et al., 1998).

Additionally, external factors such as seasonal variations in weather can influence the RTC rate; for example, approximately 5% of the RTCs occur due to factors related to various weather conditions (Fridstrøm et al., 1995). This is in line with a variety of previous studies in which the RTC rate depends on monthly and daily differences in weather conditions and its consequences (Bergel-Hayat et al., 2013; Eisenberg, 2004; Nofal & Saeed, 1997), such as the effect caused by windy weather (Baker & Reynolds, 1992), rainfall (Keay & Simmonds, 2005; Satterthwaite, 1976), fog (*"113 accidents on the Qatar roads"*, 2016; *"Over 500 accidents due to heavy fog"*, 2018) and the amount of sunshine (Van den Bossche, Wets, & Brijs, 2004). Seasons in the State of Qatar and other Gulf countries are characterized by varying weather conditions and the year could be divided into four seasons (*"Seasons in Qatar"*, n.d.). The beginning of each year starts with a mild winter season during the months December, January and February with lower average temperatures ranging from 22 °C to 24 °C. During the months March, April and May the spring season starts with average temperatures warming up from 27 °C to 38 °C at the end of

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the season. The summer season in the State of Qatar has the most extreme temperatures with 38 °C in June, increasing to an average daytime temperature of 41 °C in July, and August has the highest temperatures of the year reaching 43 °C at noon. The autumn season covers the months September, October and November with daily temperatures decreasing after the summer period from 39 °C in September to 29 °C in November (*"Seasons in Qatar"*, n.d.). In essence, during summer period in the State of Qatar the weather is hot with high humidity and this affects the behaviour of road users. For instance, few pedestrians would go out and walk on the streets as the temperatures are unbearable, in contrast to the autumn and winter period were the number of pedestrians increase due to the pleasant mild temperatures. Rainfall is rare in the State of Qatar, but is most likely to occur during the rainy season also known as 'Wasmi season' which occurs in autumn during the months October and November (Qatar Meteorology Department, 2015). According to the Qatar Meteorology Department autumn and winter season are also characterized by mist or fog at dawn and in the early morning due to northeaster or southeaster winds causing humidity (Qatar Meteorology Department, 2016).

Despite previous studies on the frequency of RTCs and its related causes, there is limited research within the Arab Gulf region examining the relationship between different types of RTCs, their causes and the effect of seasonal variation on the crash rate. For that reason, this study aims to provide a broad exploratory analyses of RTCs in the State of Qatar. The first objective of this study is to assess the long term trend of a 7 year time-series, with special focus on severe injury RTCs and fatal RTCs. The second objective is to investigate the relationship between the occurrence rate of different types of RTCs and seasonal weather variation. The third objective is to create understanding about the victimology of RTCs occurring between 2010 and 2016, for both fatal and severe injury RTCs. The final objective is to evaluate the development of RTC causes over time and its relation to RTC severity.

2. Methodology

2.1. Data

The state of Qatar has an area of 11,437 km^2, with a population of about 2.55 million as of September 2016 where 14% are native Qatari, and 86% are foreigners. More than 80–90% of the population is concentrated in less than 15% of the geographic area as indicated by the red dots in Figure 1 (Ministry of Development Planning and Statistics [MDPS], 2016). Based on the data, the number of active driving licenses in 2016 was 1,328,973 recorded by the Ministry of Interior (MOI). The present study is based on data obtained from the Traffic Department in the MOI which encloses the frequency of RTCs with different levels of severity (material damage, slight injury, severe injury and fatality), different victim types (driver, passenger and pedestrian) and recorded RTC causes. The data contains RTC that occurred within the State of Qatar on a monthly basis for a period of seven consecutive years ranging from 2010 to 2016.

2.2. Long term time-series

RTC data, that is, collected over a longer period of time can be studied with different data collection methods and a variety of statistical analysis. For instance, the monthly evaluation of RTCs is important when considering the evolvement of RTC occurrence over time. Monthly repeated measures of RTC data over a longer period of time make it possible to compare RTC frequency between set time periods. An analysis method suitable for this approach is a time series analysis, such as the classical multiplicative time series decomposition method, also known as the Census I method (*"How to identify patterns"*, n.d.). The general idea behind this method is that a time series is composed of three components; the regular seasonal component (S_t), the underlying trend-cycle component (T_tC_t) and an irregular component (I_t), all measured at a certain point in time (t) for a time series of (N) length. This leads to the following multiplicative time-series decomposition equation (*"How to identify patterns"*, n.d.; McLaren & Zhang, 2010; Makridakis, 1976)

$$X_t = S_t \times T_tC_t \times I_t$$

It is beneficial to decompose each component in a time series to establish the amount of irregularity and distortion by short term variations and to create understanding of the yearly returning pattern also known as seasonality. The time-series decomposition method also makes it possible to calculate the long term trend (T_t), which can provide knowledge about the growth indicator and the direction of a time series over a longer period of time and this can potentially be the basis for forecasting of the time-series future development (McLaren & Zhang, 2010).

In this study, the time series decomposition analysis is conducted using Excel 2016. The time series of RTC frequency resulting in severe injury or fatality are both plotted per month and each component within both time series is calculated manually. The time-series decomposition is based on calculations derived from the ratio-to-moving average method (Macauley, 1930). The first step is to compute the central moving average (CMA) of RTC frequency (X_t) for each 12-month period by calculating the medial average, resulting in the Trend-Cycle component. The Trend-Cycle component (T_tC_t) of a time series can be seen as the baseline without any influences of seasonality or irregularity which leads to variability in a time series. The amount of variability caused by the combined regular seasonality pattern and the irregularity ($S_t \times I_t$) is calculated as follows; dividing the RTC frequency (X_t) by the Trend-Cycle component (T_tC_t). The seasonality component (S_t) is computed as the medial average for each month in the 12-month period, that is, regularly returning for 7 years (2010–2016). This calculation will eliminate the irregularity component. The Trend component (T_t) is the longer term regular pattern of a time series and thereby differs from the yearly returning 12 month seasonality pattern. The trend is computed by adding up the least-square regression coefficients after performing a regression analysis (Makridakis, 1976). Forecast for the years 2017 and 2018, following up the 7 year time period (2010–2016), are predicted by multiplying the

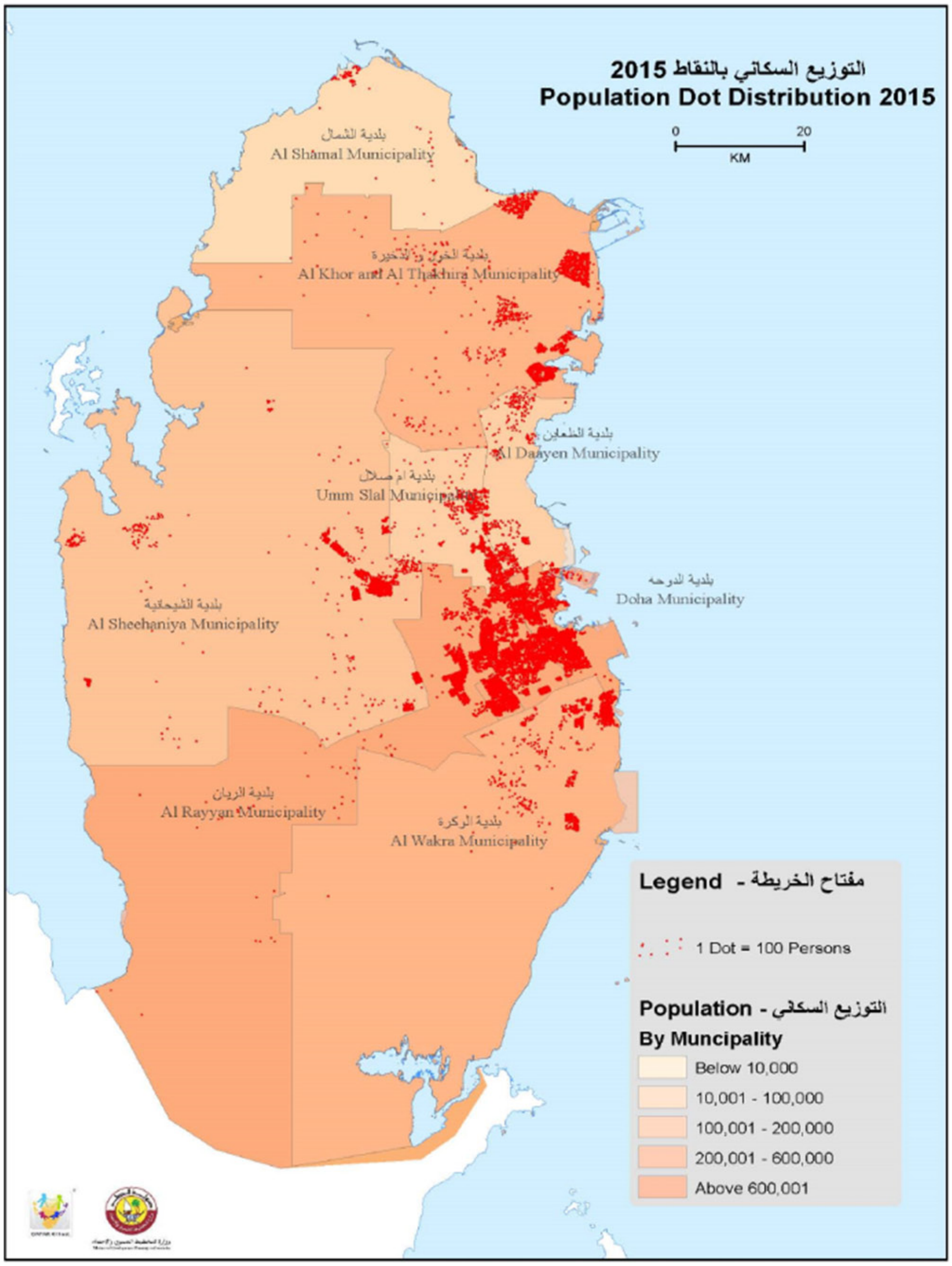


Figure 1. Population density in the State of Qatar (MDPS, 2016).

seasonality (without irregularity) with the Trend component ($S_t \times T_t$).

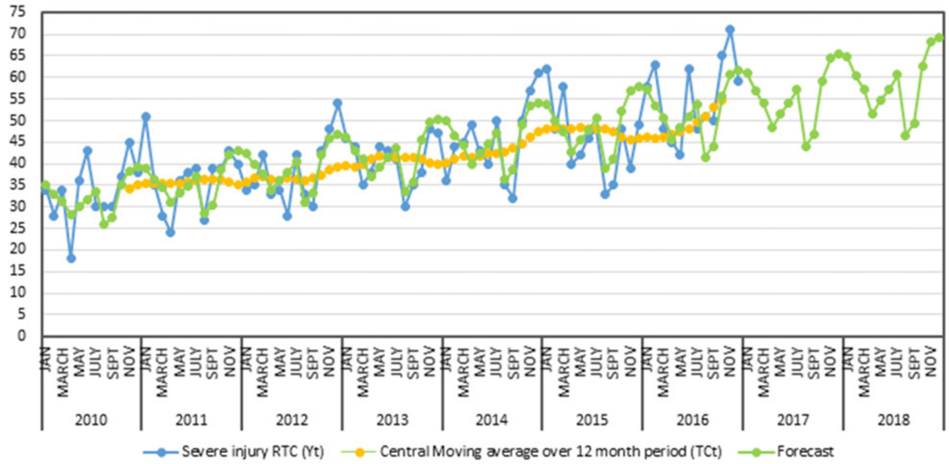
2.3. Statistical analysis

Alongside the time series decomposition analysis, a Multivariate Analysis of Variance (MANOVA) is conducted to investigate the relationship between seasonal weather variations and RTC rate. The MANOVA analysis measures 6 different RTC types (either severe injury RTC or fatal RTC with three victim types being driver, passenger or pedestrian) as dependent variables and the four seasons with different weather conditions as independent variables. For this analysis, the monthly RTC rates from 2010 to 2016 were divided into four seasons (i.e. winter, spring, summer and autumn), the division of months per season was based on the literature (*"Seasons in Qatar"*, n.d.). The crash rate of a specific season is taken as the ratio of the observed crash frequency during that complete season to the total crash frequency recorded for the corresponding year. Furthermore, the victim characteristics of RTCs leading to severe injury and fatality, as well as different RTC causes are evaluated using descriptive analysis. Statistical analysis were performed using SPSS with a significance level of $\alpha = 0.05$.

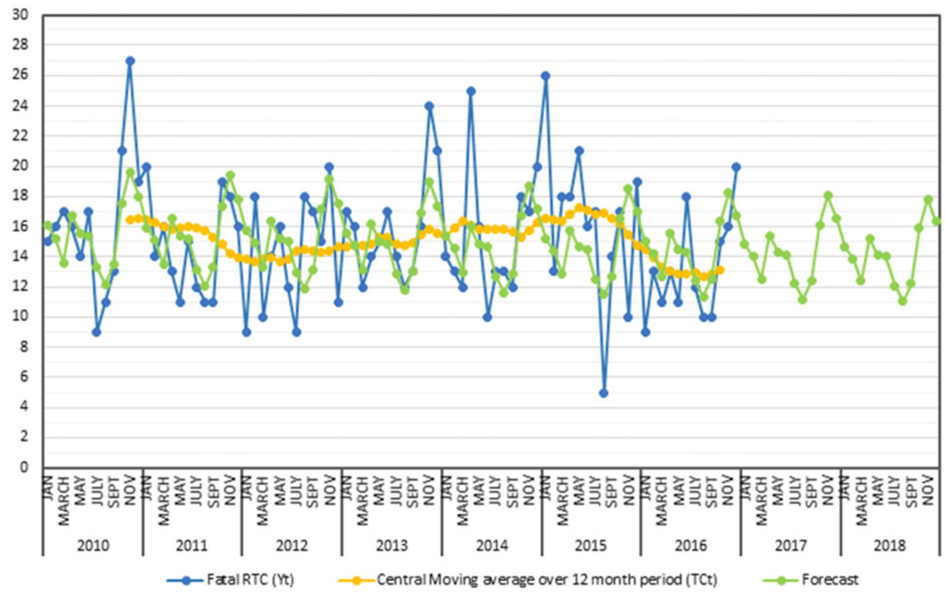
3. Results and discussion

3.1. Time-series decomposition analysis

The first objective of this study is to assess the long term trend of a 7 year time-series. Figure 2 plots the time series



(a) Time series plot with monthly RTC frequency for severe injury RTCs



(b) Time series plot with monthly RTC frequency for fatal RTCs

Figure 2. Time series analysis for RTCs leading to severe injury or fatality.

of two RTC severity levels, with Figure 2(a) showing severe injury RTCs and Figure 2(b) showing fatal RTCs. For both time series, the recorded RTC frequencies are displayed per month in blue markers connected with a blue line, revealing the time history from January 2010 till December 2016. The yellow line on both time series plots shows the calculated central moving average (CMA) for each marker revealing the Trend-Cycle (T_tC_t) baseline without variability caused by seasonality (S_t) or irregularity (I_t). The green line on the time series plots reveals the computed forecast ($S_t \times T_t$) based on a combination of the yearly returning regular pattern of seasonality and the long term trend pattern over the complete study period, extended by two years to provide a prediction of the time series' development.

The time series plot in Figure 2(b) for RTC resulting in fatality shows an obvious decrease in RTC frequency after 2015 visible from the Trend-Cycle (yellow line, with continuous reduction of RTCs forecasted up to 2018 which is shown by the green line having a decreasing pattern of peak RTC frequencies. This confirms that the implementation of the Qatar National Traffic Safety Strategy which started in 2013 has been successful in reducing the occurrence of RTC fatalities. On the other hand, it is clearly visible from time series plot in Figure 2(a) that the Trend-Cycle (yellow line) displays an increase in RTCs resulting in severe injury. In line with the projected forecast up till 2018 the frequency of severe injury RTCs keeps increasing over time. The trend for the time series of fatal and severe injury RTCs is in line with previous research conducted in Qatar, stating a decrease in fatal RTCs over the last 5 years, but an increase in personal injuries caused by RTCs (Abdella et al., 2016; Abou-Amouna et al., 2014). In line with this, Figure 3 provides an overview of the total number of RTC frequencies per year, for RTCs leading to severe injury in comparison to fatal RTCs. Results over the 7-year period confirm similar trends as described above; an increasing trend for severe injury RTCs and a decreasing trend for fatal RTCs.

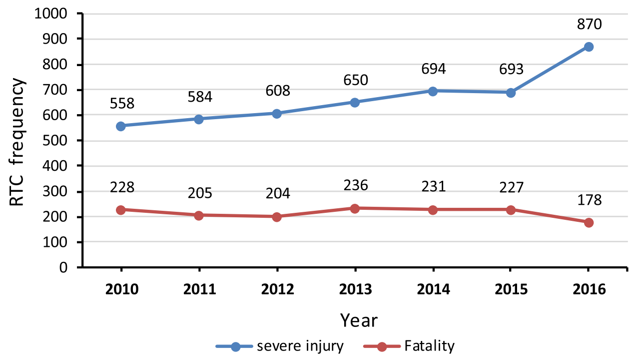


Figure 3. Total number of road traffic crashes per year.

Especially for the fatal RTC frequencies plotted in Figure 2(b), there is a high variability visible with extreme peaks around November 2010 and 2013, April 2013 as well as around January 2015. However, an outlier analysis was performed which revealed no outliers above three inter-quartile from the mean values, among the monthly and yearly frequencies for both severe injury RTC or fatal RTC. For that reason, based on the green forecast line, which shows long term and yearly returning pattern without variability caused by irregularity, it is possible to evaluate the trend of both time series plots and make inferences about the monthly peaks and drops over the 7-year time period. This trend can be interpret as follows; for severe injury RTCs a regular increasing pattern in RTC frequencies is visible from the months May to July, with a drop from July to August, followed by another increasing pattern over autumn season for September, October and November, till a peak in RTC frequency in the month December. After this peak around the months November, December and January (winter season) the RTC frequencies reveal a decreasing pattern over spring till the month April. When interpreting the regular trend over 7 years plotted for the fatal RTCs, Figure 2(b) shows an RTC peak at the month November with high RTC frequencies during winter season, followed by a RTC reduction till the month March. With an increase in RTC frequency during April the fatal RTCs show a fluctuating pattern over spring season, but reveal another drop in RTC frequencies during summer season from May till the lowest number of RTCs during the month September. The autumn season reveals an increase in fatal RTCs from September up till a peak in November.

3.2. Seasonal weather influences on different RTC types

The time series trend for both fatal and serious RTCs clearly reveal a pattern of variable frequencies for different months and seasons. This indicates the importance of seasonal influences and for that reason this study investigates the relationship between different types of RTCs and seasonal weather variation. A MANOVA analysis was carried out to investigate the relationship between seasonal variation and monthly crash frequency, for crashes of passenger, driver and pedestrian resulting in severe injury or fatality. Table 1 provides the result of the analysis. The results indicate that there is no significant relationship between the seasonal variation and crashes that yielded to casualty or severe injury for the passenger. However, seasonal variation does have a significant effect on the frequency of crashes that yielded to fatality or severe injuries for the driver and crashes with severe injuries and fatalities for pedestrians as listed in Table 1.

The impact of seasonal weather variation on RTC rate indicates the importance for further evaluation of the most crash-prone season and how this season differs from the rest. Therefore, Table 1 also lists the comparison of the four seasons' average RTC rate for the fatal crash and severe injury crash types that reveal a significant relationship with seasonal variation. From the results, it is observed that autumn and winter season are most prone for both severe injury and fatal RTC for drivers. During these seasons the weather in the State of Qatar is characterized by a heavy wind and dense fog, especially during the night and early morning, resulting in reduced visibility (Qatar Meteorology Department, 2016). Also during autumn season the State of Qatar is also most likely to have short but sudden rainfall during 'Wasmi season' (Qatar Meteorology Department, 2015). These results are contrary to a study conducted by Nofal and Saeed (1997) in the Kingdom of Saudi Arabia, who also found seasonal weather influences but discovered the highest RTC rates during the hot sunny summer months, which they prescribed to heat stress on the drivers. This discrepancy in results can be explained by time difference in year of research, because nowadays and especially in the State of Qatar, cars are standard equipped with air-conditioning, which reduces the effect of high temperatures on drivers. Furthermore, news reports during winter and autumn season are likely to state high numbers of crashes due to dense fog and reduced visibility, which confirms current results stating the effect of weather variations during the crash-prone winter and autumn season; for example, the Peninsula in January 2016 (*"113 accidents on the Qatar roads"*, 2016).

Winter season followed by autumn spring season are also the most crash-prone seasons for pedestrian victims with the highest number of severe injury RTC and fatality RTC. During winter and autumn season temperatures are pleasant which encourages walking, besides during these seasons more outdoor activities are organised which leads to an increase of pedestrian flow. Furthermore, schools are closed for summer season and many residents spend time indoors or leave the country for holiday, which leads to significantly less pedestrian fatality or severe injury RTCs during summer season. A previous study on the impact of crashes on pedestrians, it was concluded that the diverse population with different cultural backgrounds that characterizes the State of Qatar, leads to different pedestrian walking and road crossing behaviours which contributed to severe traffic conflicts between vehicles and pedestrians (Saleh, 2016). In general, it can be concluded that pedestrians are vulnerable to RTCs, therefore efficient management of pedestrian flows is essential to reduce the number of pedestrian fatalities.

In conclusion, the combined effect of reduced visibility and pleasant outdoor temperatures during winter and

Table 1. Summary of MANOVA for significant relationships between seasonal variation and different RTC types, comparing average RTC rate.

	Seasonal effects			Average crash rate				
RTC types	*F*	*df*	*Significance*	*Winter (1)*	*Spring (2)*	*Summer (3)*	*Autumn (4)*	*Ranking RTC prone seasons*
Driver (severe injury)	6.989**	3	$p = .002$	0.270	0.218	0.249	0.263	1-4-3-2
Driver (fatal)	3.490*	3	$p = .031$	0.257	0.220	0.226	0.298	4-1-3-2
Pedestrian (severe injury)	3.514*	3	$p = .030$	0.281	0.240	0.224	0.255	1-4-2-3
Pedestrian (fatal)	3.013*	3	$p = .050$	0.298	0.273	0.190	0.239	1-2-4-3

*Significant at $\alpha < 0.05$; **Significant at $\alpha < 0.01$.

Table 2. Descriptive analysis of victim characteristics per RTC severity over 7-year period (2010–2016).

			YEAR													
			2010		**2011**		**2012**		**2013**		**2014**		**2015**		**2016**	
RTC severity	**Victim characteristics**		*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
Severe injury RTCs	*Gender*	Female	19	6	38	11	26	7	31	9	42	11	38	10	64	13
		Male	291	94	309	89	322	93	327	91	336	89	354	90	437	87
	Nationality	Qatari	91	29	103	30	110	32	101	28	81	21	120	31	127	25
		GCC	8	3	9	3	5	1	12	3	15	4	20	5	14	3
		Other	211	68	235	68	233	67	245	68	282	75	252	64	360	72
	Victim type	Driver	92	40	83	41	73	36	107	45	93	41	92	41	66	37
		Passenger	63	28	62	30	76	37	73	31	75	32	69	30	55	31
		Pedestrian	73	32	60	29	55	27	56	24	63	27	66	29	57	32
Fatal RTCs	*Gender*	Female	4	3	14	12	13	11	8	6	10	7.8	19	14	7	7
		Male	125	97	107	88	110	89	134	94	119	92	120	86	95	93
	Nationality	Qatari	37	29	39	32	38	31	52	37	41	32	44	32	22	22
		GCC	5	4	3	2	4	3	8	6	9	7	4	3	1	1
		Other	87	67	79	65	81	66	82	58	79	61	91	65	79	77
	Victim type	Driver	242	43	231	40	278	46	267	41	310	45	312	45	379	44
		Passenger	184	33	202	35	173	28	214	33	216	31	190	27	290	33
		Pedestrian	132	24	151	25	157	26	169	26	168	24	191	28	201	23

autumn are seasonal factors which lead to different behaviours among road users and could explain the higher rate of severe injury and fatal crashes for both pedestrians and drivers.

3.3. Descriptive analysis for victimology of road traffic crashes

The third objective is to create understanding of the victimology between 2010 and 2016, for both fatal and severe injury RTCs. Therefore, this study investigates the victim characteristics that are most prone to high levels of RTC severity (severe injury or fatality) and how the RTC frequency per victim attribute develops over time. Table 2 provides an overview of the descriptive analysis of the victim characteristics per RTC severity over the 7 year study period with regard to the gender and nationality of the RTC victim and the type of victim being the driver, passenger or a pedestrian.

Results in Table 2 reveal that for both fatal and severe injury RTCs the frequency of male victims per year is much higher in comparison to the female victim RTC frequencies. This finding is logical and can be explained by the higher number of male drivers on the Qatari roads with a very high proportion of foreign male workers. This is confirmed by the monthly statistics provided by the Qatar Ministry of Development Planning and Statistics (MDPS) stating that the active driving licences in the State of Qatar per July 2016 were distributed between 7573 male drivers in comparison to 1052 female drivers (MDPS, 2017). Moreover, previous research by Soliman et al. (2018) has indicted that female drivers in the State of Qatar report fewer driving violations, errors and lapses in comparison to male drivers and also females report more safe driving habits such as seatbelt use.

In addition, the higher proportion of RTC victims with nationality other than Qatari or Gulf Cooperation Council (GCC) as visible in Table 2 can be explained by large number of expatriate drivers in the State of Qatar. This finding is confirmed by the statistics of the MDPS revealing 8077 active driving licences for non-Qatari drivers in comparison to 548 Qatari nationals recorded on July 2016 (MDPS, 2017). In line with this, the high variability of nationalities among the driving population in the State of Qatar has previously found to influence traffic safety in the State of Qatar, as professional drivers with origins other than Qatari have a higher likelihood to commit certain risky driving behaviours (Timmermans et al., 2019).

Furthermore, Table 2 reveals that each year the proportion of RTCs in which the driver itself became the victim is highest for severe injury as well as fatal RTCs, followed by the proportion of passengers becoming RTC victim. Despite the high vulnerability of pedestrians, the lowest proportion of RTCs with pedestrian victims is recorded every year in comparison to drivers or passengers as RTC victim. This might be explained by the constantly high number of vehicles throughout the year, but pedestrians traffic reduces over the summer period. Nevertheless, Table 2 also indicates that the proportion of pedestrian victims has increased over the 7-year study period, emphasizing the importance for effective management of pedestrian traffic flow and related traffic safety policies. Moreover, the high proportion of RTCs with driver as victim and the increasing proportion of drivers- and passengers suffering severe injury as a result of RTCs over the 7-year period, suggests that the vulnerability

Table 3. Yearly frequency and percentage of RTCs caused by recorded RTC causes.

	YEAR													
	2010		2011		2012		2013		2014		2015		2016	
RTC causes	*No.*	%	*No.*	%	*No.*	%	*No.*	%	*No.*	%	*No.*	%	*No.*	%
Dangerous driving behaviour	74	1	43	1	48	1	32	1	46	1	39	1	7	0
Crossing a road without giving priority	1004	18	646	16	760	17	785	16	875	17	829	14	785	13
Cutting lights	165	3	76	2	98	2	71	1	90	2	144	2	210	3
Deviation from driving lane	592	11	429	10	467	10	528	11	541	10	612	10	538	9
Driffiting	4	0	2	0	5	0	6	0	7	0	5	0	2	0
Driving the car in a dangerous way (racing)	38	1	2	0	1	0	1	0	13	0	7	0	0	0
Driving under the influence of alcohol	48	1	74	2	54	1	86	2	84	2	70	1	57	1
Driving without valid license	63	1	26	1	15	0	36	1	30	1	38	1	19	0
Driving in the opposite direction	12	0	8	0	7	0	4	0	12	0	3	0	2	0
Escape from the crash scene	39	1	43	1	47	1	57	1	49	1	44	1	32	1
Failure to follow the right lane	28	1	25	1	31	1	28	1	73	1	82	1	58	1
Not securing vehicle load	9	0	8	0	10	0	10	0	7	0	11	0	10	0
Vehicle stop with hand brake	16	0	8	0	14	0	5	0	10	0	14	0	12	0
Reckless driving (incl. negligence & lack of attention)	2091	38	1862	45	1930	43	2134	45	2139	40	2556	43	2734	45
Not leaving sufficient distance	929	17	609	15	708	16	763	16	1042	20	1284	21	1400	23
Overspeeding	40	1	32	1	27	1	16	0	18	0	7	0	5	0
Reversing	121	2	80	2	72	2	65	1	83	2	90	1	84	1
Sudden stop	5	0	1	0	2	0	3	0	2	0	0	0	2	0
Wrong overtaking	100	2	75	2	82	2	82	2	108	2	101	2	117	2
Others	52	1	65	2	53	1	53	1	46	1	51	1	59	1
Total frequency	**5452**		**4137**		**4453**		**4785**		**5294**		**6007**		**6140**	

of drivers and passengers should not be underestimated and should remain a point of attention during traffic safety policy development.

3.4. RTC causes

It is vital to clearly identify the causes of RTCs in order to provide compatible countermeasures. Therefore, the final objective is to evaluate the development of RTC causes over time. The data used for this study only includes RTCs caused by factors related to the driver. In the database, 20 different types of RTC causes are reported, as listed in Table 3. Table 3 shows the RTC frequencies and the percentages per year from 2010 to 2016 for causes reported to be related to all RTC severity levels (RTCs resulting in material damage, slight injury, severe injury and fatal combined).

Results in Table 3 show that reckless driving, which includes driver's negligence and lack of attention, is the major cause of RTCs in the State of Qatar. In line with this, study by Timmermans et al. (2019) shows that the lack of attention and level of distraction caused by handsfree phone use while driving is an underestimated safety hazard among professional taxi and public bus drivers in the State of Qatar. The number of RTCs caused by reckless driving shows fluctuation over time but remains almost half (43%) of the total RTC frequency every year. This indicates that further investigation should be done to identify causes that might lead drivers to increase their willingness to drive recklessly, show negligence and reduce their attention while driving, in order to identify proper countermeasures with effective implementation procedures. In addition, other major RTC causes such as crossing the road without giving priority, not leaving sufficient distance, and deviation from driving lane should be emphasized. These three causes in combination lead on average to around 45% of the total RTCs per year. An obvious increase of RTCs caused by not leaving sufficient distance is visible from 2010 to 2016, while the proportion of RTCs caused by crossing the road without giving priority is clearly decreasing over time. The develop of RTC causes over a 7-year period in the State of Qatar also shows that there is an increase in RTCs caused by cutting lights, which is in line with an increased number of violations in Red-light running based on the data provided for this study by the Traffic department in the Ministry of Interior. On the other hand, data also shows that violations for speed radars have increased from 2010 to 2016; however, the number of RTCs caused by overspeeding have been largely reduced over the 7-year period. Overall, evaluating the total RTC frequencies per year (RTCs affected by all the 20 different RTC causes) Table 3 shows an initial decrease from 2010 to 2011, but this is followed by an increase in RTC frequency for all RTC causes in total, up till the year 2016. This increase in total rates for all RTC causes might be explained by Qatar's national traffic safety strategy putting more emphasis on crashes and traffic safety and thereby creating a better evaluation and record of RTC causes.

The final objective is also to investigate different RTC causes in relation to RTC severity. Hence, Figure 4 displays the proportion of RTC causes for four levels of RTC severity (material damage, slight injury, severe injury and fatality) over the total study period (7 years) in percentages of the total frequency of all RTC causes combined. Results show different percentages of similar RTC causes per RTC severity level, indicating that certain causes are more related to less severe RTCs while other causes are very common among RTCs with severe injury outcomes. For instance, with an increase in RTC severity the percentage of RTCs caused by reckless driving also increased. On the other hand, high proportions of RTCs caused by crossing a road without giving priority or RTCs caused by not leaving sufficient distance are related to lower levels of RTC severity.

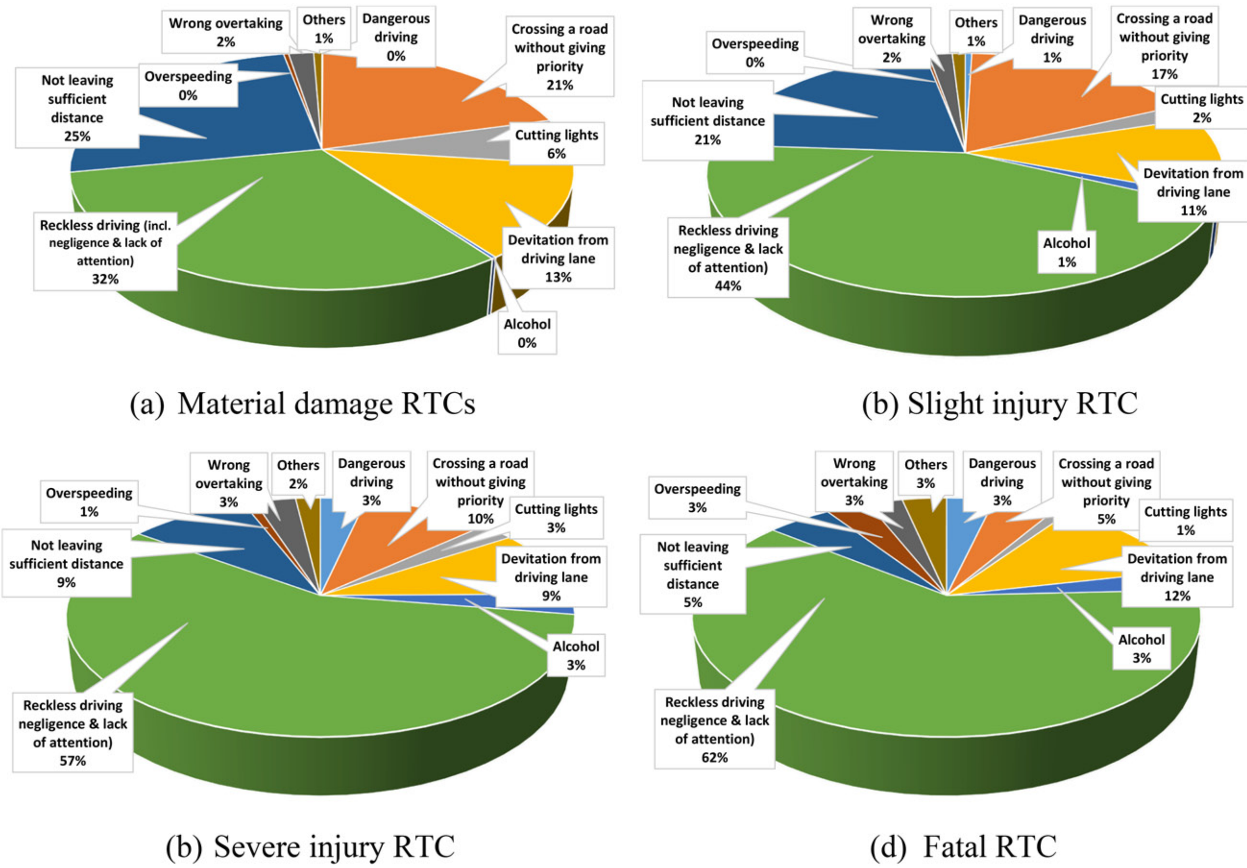


Figure 4. RTC cause per RTC severity level (years 2010–2016).

For example, RTCs resulting in material damage have the highest percentage of these specific RTC causes in comparison to increasing RTC severity levels. RTCs caused by driving under influence of alcohol or RTCs caused by overspeeding are found to be related to fatal or severe injury RTCs, but are in this study not found to cause material damage or slight injury RTCs.

In essence, these results show that differences between RTC causes per severity level are important and beneficial for the implementation of traffic safety strategies, especially in line with the Qatar National Traffic Safety Strategy 2013–2022 which aims to reduce the number of severe injuries and fatalities caused by TRCs.

4. Conclusion

This study investigates RTCs in the state of Qatar for a period of seven consecutive years from 2010 to 2016, aiming to provide an exploratory study that can be beneficial for the development of traffic safety strategies and countermeasures. Results of time series analysis reveal that the total number of RTCs leading to severe injuries show an increasing trend from the year 2010 to 2016 and were calculated to continue increasing until the year 2018. Nonetheless, the total number of fatal RTCs reveal a slight decreasing trend from 2010 to 2016 time and were calculated to continue reducing until the year 2018. Furthermore, the effect of seasonal weather variation on six different types of RTCs (severe injury or fatality of either drivers, passengers or pedestrians) has also been investigated. The results of the MANOVA analysis reveal that there is a significant relationship between RTC type and seasonal weather variation for crashes resulting in severe injury and fatality of both the driver and pedestrians. Moreover, in combination with the time series monthly pattern the analysis indicates that winter and autumn season are most prone to RTC crashes for both driver and pedestrian. Additionally, it is found that reckless driving, which includes lack of attention and drivers' negligence is the most common cause for all different types of RTCs. Nevertheless, the proportion of RTC causes differs per RTC severity; for instance, crossing a road without giving priority or not leaving sufficient distance are more frequently causing RTCs that result in material damage and slight injury, while reckless driving, driving under the influence of alcohol or overspeeding are more frequently causing RTCs with severe injury or fatal outcome.

This study has the limitation that the dataset does not contain detailed information about individual crash cases, but instead it contains aggregated data for RTC frequency based on several categories. A set of detailed victim characteristics per crash type or per RTC cause is not available, therefore it is impossible to provide statistical correlations or predictions between different aspects of RTCs, such as victimology and RTC cause, or between different aspects of victim characteristics. However, this study does provides an exploration of RTCs in the State of Qatar and thereby delivers information that can give direction and guidance in the development of a critical and strategic plan to prioritize traffic safety, especially following the crash-prone winter and autumn season. To identify proper countermeasures to improve safety levels, future research is required and suggested with in-depth analysis of crash patterns, victimology and crash causes within the State of Qatar. Moreover, it would be interesting for future research to provide more elaborated forecasting analyses to predict future RTC expectancy.

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