In-depth Sampling Study of Characteristics of Vehicle Crashes in Saudi Arabia

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***Abstract*—It is imperative for any traffic safety enhancing effort to collate and analyze detailed data about crashes. This article describes a study that investigated all aspects related to motor vehicle crashes resulting in human injuries or deaths in Riyadh. The database consisted of 295 collisions involving 331 vehicles, 596 fatalities (car passengers and pedestrians) and 2,454 injuries with Abbreviated Injury Scale (AIS) ≥ 1. Results show that only 15.1% of all vehicle occupants were wearing seatbelts at the time of collision which is reflected in having most injuries occurring to upper parts of the body and the spine. It is also reflected in a high incidence rate of 0.22 fatalities per crash. The average age of victims was 33 years with three quarters of them being males. Results also show that human actions, like reckless driving, over speeding, and sudden lane deviations were the causes of most collisions. It is concluded that in order to improve traffic safety conditions in Riyadh and in the whole country, a change in driving culture of all road users is needed. This can only come with improved awareness of the risks involved among road users, better law enforcement and other engineering and hi-tech countermeasures like smart red lights.**

Keywords-motor vehicle crashes; Riyadh; casualties; spinal injuries; driving behavior; injury prevention

I. INTRODUCTION AND BACKGROUND

The Kingdom of Saudi Arabia (KSA) is located in Southwestern Asia and is the largest country in the Middle East. It occupies about the fourth-fifths of the area of the Arabian Peninsula with a total area of 2,250,000km^2 [1] and an estimated population of 34.14 million by the end of 2019 [2]. The oil boom experienced in Saudi Arabia over the past seventy years resulted in a sharp increase in living standards and massive urban development. This inevitably led to a significant increase in the asphalted road network length from a few thousand kilometres in mid-twentieth century to currently more than 71,500km. The number of motor vehicles has also increased from 144,000 cars in 1970 to almost 19 million with approximately 800,000 vehicles being imported every year [2, 4]. This increase in living standards has also resulted in a large increase in the number of traffic crashes and, subsequently, in a tragic jump in the number of deaths due to these crashes. It is estimated that road crash deaths account to 6.53% of the total deaths in Saudi Arabia [3]. Also, about one quarter of all cases transported by the Saudi Red Crescent Society (SRCS) ambulances over the last 20 years were due to road crashes [8]. The official Saudi annual average mortality rate from road crashes for the period of 2010-2018 is estimated to be 19.25 per 100,000 population [2, 7], which is among the highest in the world [5]. Moreover, the rank of Saudi's fatality rate based on its motorization level (vehicles/population) is found to be 11.23 which is approximately three times higher than the average of developed countries [9, 20]. Furthermore, an estimated loss of between 2.2% and 4.7% of the national income due to traffic crashes has been suggested for Saudi Arabia [10, 11]. This deteriorating situation poses a serious threat and has a serious negative effect on economic growth, especially as the majority of losses are among the younger generation knowing that the average age of drivers in Saudi Arabia is 26.7 years [12, 13]. The problem of road crashes has attracted significant research in the last few decades in most developed countries resulting in a reduction of the size of the problem [21-23]. However, one of the most serious problems facing traffic safety improvement effort in most of developing countries such as Saudi Arabia is the lack of epidemiological studies that analyze the extent and the gravity of this problem [5]. Conducting in-depth prospective or retrospective studies involving extensive data collection are also essential in developing safety regulations and programs aiming to reduce road crashes and to minimize the resulting human and economic loss [13, 14, 20]. This study comes to fill in some of these gaps in that it aims to do an in-depth retrospective analysis of crashes that led to human losses or injuries in Riyadh over a period of 18 months.

II. METHODOLOGY

This study was carried out in the city of Riyadh, the capital of Saudi Arabia, and surrounding region (known as Greater Riyadh Area). Riyadh is a large metropolis with an area of 1782km^2 and a population of approximately 8 million people, around a quarter of the total population of Saudi Arabia [2]. Over the last 10 years, the city of Riyadh recorded an average annual population growth rate of 3.53%. Riyadh has a modern road network system but its traffic management system is not fully developed. Out of 957,125 new registered vehicles in Saudi Arabia in 2016, 129,513 were found in the Greater Riyadh Area. It is estimated that there are about seven million trips daily in the city, with over 85 percent by private car. Bus trips only represent two percent of the total, whilst goods movements make up the remainder [4, 16]. The study

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population consisted of motor vehicle collisions in Greater Riyadh Area that resulted in an injury of AIS ≥ 1 of one or more vehicle occupant(s) and/or pedestrian(s) between September 2017 and February 2019 (18 months). The data collection procedure entailed performing an in-depth technical examination of vehicles, extracting related information from police records and collecting detailed injury information from medical archives. Each vehicle was inspected and photographed extensively both internally and externally. Where possible, the damage profile of the vehicle was measured so that severity indicators known as collision Delta-V (ΔV) and/or Equivalent Test Speed (ETS) were used [17]. The rollover speed and impact speed on pedestrians were reconstructed based on the physical evidence present at the scene. For pedestrian crashes, the procedure developed by NHTSA [18] and CCIS [14, 15] was followed. Impact direction was classified based on the standardized Collision Deformation Classification (CDC) code as recommended by 'SAE Practice J224b' [6]. This method used the Principal Direction of Force of the impact (PDoF). Directions were front (PDoF = 1, 11 and 12), side (PDoF = 2, 3, 4, 8, 9 and 10) and rear (PDoF = 5, 6 and 7). Vehicle body types were classified into two categories. The first category included passenger cars, light trucks and vans and the second included sport utility vehicles (SUVs). Vehicles were also classified according to curb weight (small for weight less than 1,089kg, mid-size cars weighting 1,090 – 1,587kg, or large weighting more than 1,588kg). Information including age, gender, restraint use, and seating position was obtained for each attended casualty. The use of airbags and seatbelts was primarily determined through crash scene vehicle inspection, police records, and interviews. Details of the injuries were obtained from medical and emergency department records. Injury severity was classified according to the AIS Rev 2005 [19]. Descriptive statistics, bar chart, Pearson χ^2 test, one-way analysis of variance and association analysis (cross tabulation) were used, where applicable, to present and assess the data. Also, Mann-Whitney *U* and median tests were used for comparisons of means. SPSS version 23 was used for this purpose. Significance level was set at 0.05.

III. RESULTS AND ANALYSIS

In Saudi Arabia, the number of road accidents and the resulting human and financial losses are still enormous. The official statistics show that 22,545 people were killed and 69,018 were injured as a result of the 533,380 accidents that happened on Saudi roads during the last three years [7]. The average fatalities and injuries per accident were 0.22 and 0.68 respectively. This means that one person dies and 3 people get injured for every 4 accidents. Table I presents the recent statist of accidents, fatalities and injuries of road traffic accidents in Saudi Arabia.

TABLE I. VITAL STATISTICS OF RTAS IN KSA DURING 2017-2019

Year	Non-fatal accidents	Fatal accidents	Serious injuries	Fatalities
2017	511,649	38,120	21,731	9,031
2018	438,068	33,199	22,420	7,489
2019	327,597	30,217	24,867	6,025
Total	1,277,314	101,536	69,018	22,545

Over the study period, a total of 295 collisions involving a total 331 motor vehicles have qualified to be included in the current study. In those 295 collisions, there were 596 casualties including 568 vehicle passengers and 28 pedestrians who received between them a total of 2,454 injuries (AIS ≥ 1).

A. Collision Characteristics

Figure 1 presents the type of collisions in this study. Out of those 295 collisions, 61.2% were collisions between vehicles, 14.54% due to colliding with fixed objects, 10.9% due to motor vehicle rollover, 10.9% due to motor vehicles hitting pedestrians and 2.9% due to colliding with camels. Maximum number of accidents was recorded on Thursdays and minimum on Sundays. This may be attributed to the increase in activities during weekend and decrease suddenly after. Figure 2 shows the severity of accidents for various impacts. Police records show that 6% of the crashes as slight, 53.5% as serious, and 40.5% as fatal crashes. Crosstabulating severity of crashes over impact reveals that almost all fatal and serious crashes had either frontal or lateral impact. It was found that there is an association between the severity of accident and the type of impact. The majority of accidents happened within the carriageway. The site of accident does not affect the type of impact. Almost 61% of the accidents were recorded on the highways in urban areas. There is no statistically significant relationship between impact direction and the area of accident. Most of frontal impacts (62%) and side impacts (73%) frequently occurred on straight roads and slope layouts. There was a statistically significant relationship between the type of impact and road layout. The distribution of weather condition at the time of crash is presented in Table II.

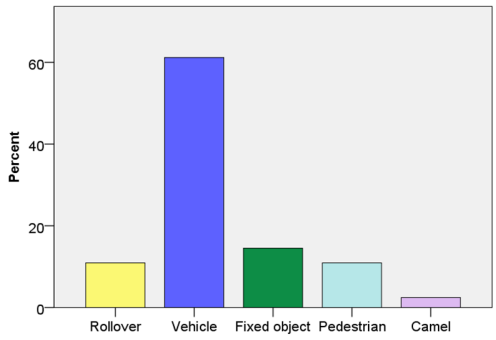

Fig. 1. Distribution of collisions by type

TABLE II. DISTRIBUTION OF CRASH BY WEATHER CONDITION

Weather conditions	Percentage
Fine no high winds	68.8
Dust	12.7
Raining, no high winds	11.7
Raining and high winds	4.4
Fine and high winds	1.8
Fog or mist	0.6

The majority of accidents occurred in fine weather conditions (69%). The weather conditions had a significant effect on the types of impacts. Most severe crashes due to traffic accidents occurred on lit roads or during day time. Pedestrian crossing facilities are crucial as some of the areas

are reserved for parking, gardening, etc. and some areas should not be accessible by pedestrians. More than half of the pedestrian collisions occurred on the nearside of drivers.

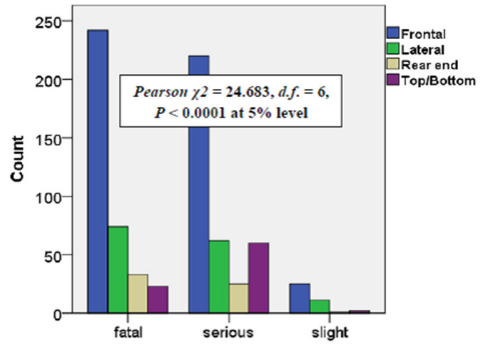

Fig. 2. Impact direction vs. severity of the accident

B. Vehicle Characteristics

There were 331 vehicles involved in the accidents considered in this study. The type of vehicle has the potential of playing an important role in causing accidents and their consequences. Passenger cars form the vast majority of traffic crashes (87%). The direction or location of impact plays an important role on the severity and type of injury. Figure 3 shows the distribution of types of impact for crashes between vehicles. It can be seen that frontal impact represents 62.6%, side impact 18.9%, top/bottom impact 10.9% and rear end impact 7.6%.

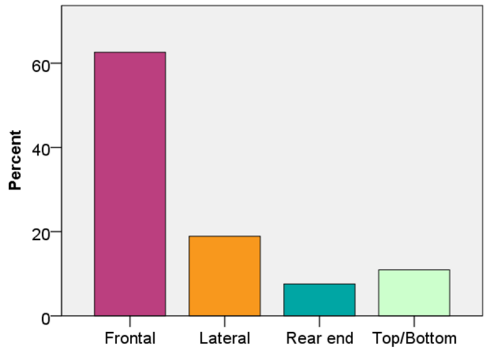

Fig. 3. Direction of impact for vehicle crashes

Most of the vehicles were small size cars (55%) followed by medium size cars (41%). The statistical analysis showed that there is an association between the type of impact and vehicle size as presented in Figure 4. Hatchback was the motor vehicle with most traffic crash-induced injuries (60%). Table III shows the major causes attributed to the vehicle crashes in KSA. The causes have been categorized according to driver, vehicle, and road. The drive behavior was responsible about most of these accidents (93.80%), followed by technical defects (5.30%) and roads works (0.90%). The major causes of accidents by driver's action were found to be careless driving (24%), over speeding (21.6%) and sudden deviation (16.6%) accounting for 61% of car accidents in this study. Of the sampled vehicles, the unacceptable condition of tires, brakes, and lights accounted for 43%, 36%, and 8% of all vehicle faults respectively. Analyzing tire-related collisions lead to aging defects, unacceptable tread depth and illegal tires being the most common types of defective tires contributing 37%, 21%, and 14% of tire-related collisions respectively.

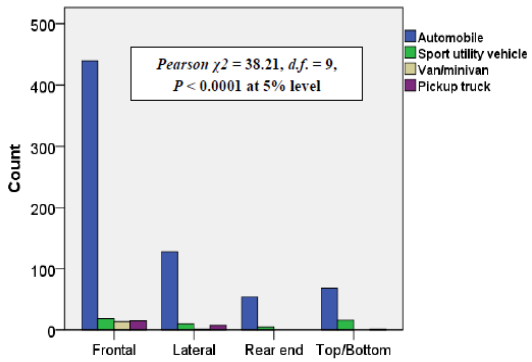

Fig. 4. Impact direction vs. type of vehicle

TABLE III. DISTRIBUTION OF CRASH CAUSES

Crash Cause	Percentage
Driver's violations (93.80%)	
Over speed	21.4
Run traffic light	9.4
Wrong overtaking	3.4
Wrong U-turn	1.9
Wrong parking	1.5
Alcohol	4.4
Falling asleep	0.6
Exhaustion	1.1
Careless driving	24.6
Driving on the wrong side of the road	1.7
Stop sign crossing	1.9
Disobeying priority rules	3.4
Sudden deviation	16.6
Tailgating	0.4
Recklessness driving	1.5
Vehicular Faults (5.30%)	
Bad tires	2.28
Brakes defects	1.90
Lights faults	1.12
Roads Obstacles (0.90%)	
Total	**100%**

C. Causlaty Charatcteristics

As stated earlier, the 295 crashes included in the current study resulted in 596 casualties. Casualty medical details were collected from hospital records, emergency medical service providers and trauma centers. Three quarters of injuries due to traffic crashes were males. The average age of the victims was 33.2 (stdev=17.3) years. People aged 15-44 years sustained the bulk of traffic crash-related injuries (66%). In this study, 568 occupants were included. Figure 5 shows that the majority of injured occupants were drivers (54.2%) followed by front seat passengers (20.1%). Only 15% of vehicle occupants who sustained an injury were restrained. Restraint use was found to reduce significantly the injury severity. Out of the 596

casualties included in the current study, 57.7% were admitted to hospital, 6.7% were treated as outpatients, 24.9% died upon arrival to hospital and 10.7% died before admission (Figure 6). Out of those admitted to hospitals 71.6% had AIS level of 2, 13.2% of 3 and 15.2% level or 4+.

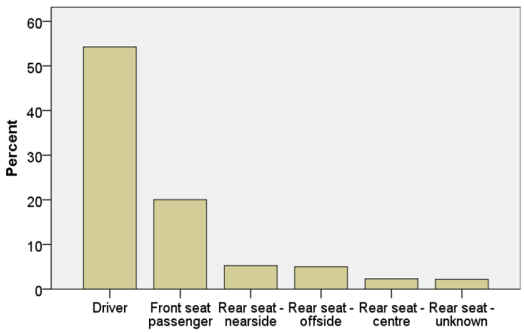

Fig. 5. Position of vehicle occupants during the crash

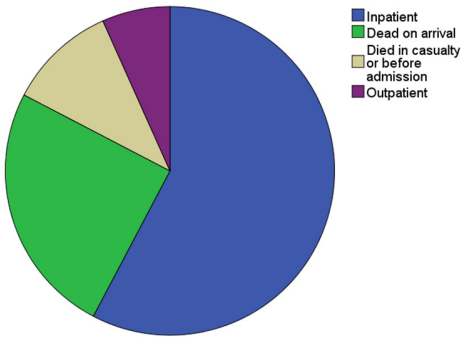

Fig. 6. Place of death for victims in the study

D. Injury Characteritsics

Most of Injury details of the 596 casualties were collected from the medical records of the main hospitals in Riyadh where the casualties were admitted and the severity of each injury was assessed using the AIS scale. In total, there were 2,454 injuries (with AIS > 1) and 596 casualties. Table IV shows a summary of the severity of the injuries for each type of collision. As can be noted, 25.2% of injuries due to collisions with fixed objects and 23.1% of injuries due to collisions with other vehicles lead to injuries of AIS ≥ 4. This reflects the greater risk of injury upon hitting a fixed object or a vehicle as compared to hitting a pedestrian (16.2%), in case of rollover (13.1%) and hitting a camel (13.1%). There were a total of 588 head injuries recorded. Pearson χ^2 test revealed that there is a significant association between head injury severity and impact direction (p=0.001). Most of severe head injuries (with AIS ≥ 3), mainly believed to be injuries to the cervical spine, occurred in front and lateral impacts. It was found that most of the head injuries in frontal impact occur due to head contact with the windscreen and frame while in lateral impacts occur due to contact with the side rail above the window. It was also noticed that injuries to the cervical spine are mainly non-contact ones occurring due to high forces being transmitted to the spine. A total of 87 face injuries were recorded in the crashes analyzed in this study. As the vast majority of face injuries had AIS ≤ 2, Pearson χ^2 test result gave a non-significant relationship between face injuries and AIS value (p > 0.05). Also, there were 487 thorax injuries recorded. Pearson χ^2 test revealed that there is a significant relationship between thorax injury severity and impact direction (p < 0.05) where most thorax injuries occurred in frontal and lateral impacts. The abdomen injuries were 400. The relationship between the abdomen injury severity and impact direction was examined. Pearson χ^2 test revealed that there is no significant relationship between abdomen injury severity and impact direction (p > 0.05). It can be seen also that more than 80% of abdomen injuries had AIS ≤ 3. In total, there were 329 recorded injuries to the limbs. Cross tabulation of limb injury severity and impact type was found to be significant (p < 0.001) with lateral impact crashes resulting, generally speaking, in higher AIS level than other crash types.

TABLE IV. DISTRIBUTION OF SEVERITY OF INJURIES ACCORDING TO COLLISION TYPES

Impact	AIS					
	1	2	3	4	5	6
Rollover n=239	36.8%	37.2%	12.9%	9.2%	3.3%	0.6%
Vehicle n=1597	28.5%	28.6%	19.8%	11.6%	6.8%	4.7%
Fixed object n=393	31.6%	24.4%	17.8%	12.4%	9.1%	4.7%
Pedestrian n=179	36.9%	37.4%	9.5%	8.3%	4.4%	3.5%
Camel n=4	69.6%	17.4%	2.2%	4.3%	4.3%	2.2%

IV. DISCUSSION AND CONCLUSIONS

High losses due to road traffic crashes in Saudi Arabia highlighted earlier can be reduced by introducing intervention measures. Such measures have helped to decrease the rates of road crashes in motorized countries like UK, Australia, Sweden, and USA [5]. In this study detailed information on 295 collisions that occurred in the city of Riyadh and resulted in an injury of AIS ≥ 1 were analyzed. The results show that most of the casualties were young in age, 75% of them were males, and 54% were drivers. This can be attributed to the fact that this group of drivers accepts greater risk than others which is reflected through their lower rate of seatbelt use, higher rate of reckless driving and their greater proneness to disobey traffic rules than others [10, 12]. Over half of the injuries sustained are head and cervical, and a significant number of those involve cord damage. Thoracic and lumbar spinal injury is predominately fracture, without associated cord damage [9, 20]. While at all levels of injury severity, car to car impacts accounted for about 61% of the collisions in the study. It was interesting to note that a third of injuries (34%) were caused due to collisions with vehicles other than cars [15]. This suggests that these injuries may not be adequately addressed by the European or US test standards and tests since the mass and the height of the test barrier in either test cannot compare to the mass and height of a standard European/US heavy goods vehicle [17, 20]. Also for crash characteristics, it was found that the majority of crashes leading to deaths or injuries in Riyadh were from frontal impact, recorded on highways, in urban areas, in the presence of road light or sun light and on

straight roads, while they occurred in fine weather conditions. Such findings can be further justified when reported causes of these crashes are considered [21-23].

Moreover, only 15.1% of vehicle occupants were reported to be restrained in police records regarding the 568 casualties. This explains the high rates of upper body (mainly in head and thorax) injuries reported in hospital records of the same casualties. Even injuries to the spine occurred, reportedly, as result of head contact during which a translational force is transmitted along the spine from the head [13, 20]. Keeping in mind the good road network that exits in Greater Riyadh Area, it is therefore concluded that human behavior is the main contributor to these crashes. Although it was clear that human behavior is responsible for the majority of crashes, assessing crash vehicle characteristics revealed that some technical problems are also contributing to the high road crash rate. Improper maintenance of tires and brakes as well as underinflated, illegal or ageing tires were the most commonly recorded crash causes related to vehicle characteristics, which is in-line with previous research studies. This study demonstrated several important aspects that should be addressed in order to improve the state of safety in Saudi Arabia. A detailed database would give strong indicators to policy makers as of the state of road safety and how the related issues are emerging. It is also recommended for future research work to incorporate crash analysis and reconstruction to better understand how crashes happen in Saudi Arabia and what can be done to minimize their number and severity.

ACKNOWLEDGMENT

This study was supported by King Abdulaziz City for Science and Technology - General Directorate of Research Grants Program (grant number AT-34-220).

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