Evaluating the Road Safety Design through High Resolution Satellite Image: A Case Study of Karachi Metropolitan

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Abstract. Humanity is suffering from numerous natural, technological and health related hazards. Urban Road crash is one of the growing health issues these days in both developed and developing countries. Pakistan stands 1st in Asia and 48th in the world in this regard. Similarly, the metropolitan city of Pakistan, Karachi; ranks fourth in the list. Various reasons are responsible for these crashes in Karachi. Around 34% of crashes in the city were accounted due to errors in road geometry. In this study use of high resolution satellite imagery made it possible for identifying geometrical errors at the U-turns on major arteries of the city. It was also recognized that most of the U-turns were built on the fastest lane of the roads with average distance of 1.1 Km apart, are marked as vulnerable for considerable number of severe injury and fatal crashes. Moreover, inlet wall of all median U-turns were found broken, suggested that the car crash had occurred at least once. To cross check this observation, nearly 120 U-turns were surveyed and marked on the satellite imagery based on convenience. Trained professionals interviewed the people working/living nearby the U-turns. Out of 120 U-turns studied, 72.5% were without wall/median and 27.5% were with wall/median. Average number of people got injured or died due to crashes were statistically significant ($p<0.05$) between the above mentioned types of U-turns. In order to reduce geometrical errors use of RS (Remote Sensing) and GIS (Geographical Information System) techniques are strongly suggested to be incorporated while planning road design in the city. This would certainly save the resources particularly the lives of the people.

1 Introduction

The Global outbreak of road crashes mortalities and morbidities have emerged as a serious health issue. It costs more than 1.3 million lives and 20-50 million people are either being disabled or injured every year across the globe [1]. Multiple factors are responsible to vehicle collision but inappropriate road designs coupled with speedy vehicle are proven to be the key factors for serious injuries or deaths caused by road crashes [2]. Urban road environment is subjected to severe injury/fatal road crashes. This might be due to the complexity in road design and higher number of road users. Similarly, fast driving/riding in urban metropolitan could be more risky because it reduces the response time to any hazard on road, making it difficult for rider/driver for subsequent control over the vehicle.

However, controlled speed could be beneficial to road users in many ways. It does not only reduce the number as well as the severity of injury caused by the crashes but also increases the response time to road users [3]. Similarly, reduced vehicle speed could also check the fuel consumption, vehicle emission, noise and vehicle functioning cost. It is proved in various studies that controlled speed could reduce the number as well as severity of road crashes irrespective of road design in some instances [4]-[6]. Conversely, increased in travel speed is responsible to increase in the chances of crashes as well as deaths [4], [7]. Some of the studies revealed that speed limit of 14-15km/h is responsible to increase the chances of fatal road crashes to 15% and 26% respectively [8]. However, chances of fatality are 20% less for an adult if collided by a car moving with utmost speed of 50km/h. Therefore, the percentage of death may increase to 60% if hit at the speed of 80 km/h [9]. In UK, decrease in 1.6km/h average speed could reduce the chances of collision by 6% [10], [11]. Considering Urban environment, vehicle speed is subjected to road condition as well [12]. Smoother and wider roads compel drivers to move faster and vice versa [13], thus responsible to higher number of road crashes [14]. In Urban Environment, roads are embellished with multiple accessories. U –turn is an important feature that maneuvers the vehicle to 180 degree turn to direct the travel towards the opposite direction [15]. U-turns are considered as possibly highly dangerous if not situated correctly and could be responsible to greater number of vehicle crashes [16]. Globally, U-turns are considered as most unsafe road feature that is susceptible to severe injury road crashes [17]. Similarly, in Thailand U-truns are considered as one of the key contributors in road crashes and are responsible to increases the crash risk specifically on major highways of the country. In Karachi more than 30% of car crashes are accounted for error in

road design and presence of U- turns are an important reason in this regard [18]. High speed of vehicles could also be responsible for higher chances of fatality to the pedestrian. If a pedestrian is being hit by a vehicle with an average speed of 60km/h, 50km/h or 30km/h than he/she would be susceptible to die with the proportion of 90, 50 and 10 percent respectively. Likewise, chances of severe injury also yield greater if a pedestrian is hit with the following proportion of increasing speed, 65km/h, 70km/h, 75km/h and 80km/h would double, quadruple, ten times and thirty two times more the probability of severe crash [1]. Vehicular speed law is an important parameter to evaluate the occurrence of road crashes. Unfortunately, Pakistan lies among those countries where there is neither any speed limit followed nor any high speed law exists in the urban areas 'Figure 1', making difficult for the road users who face higher probability of road crashes.

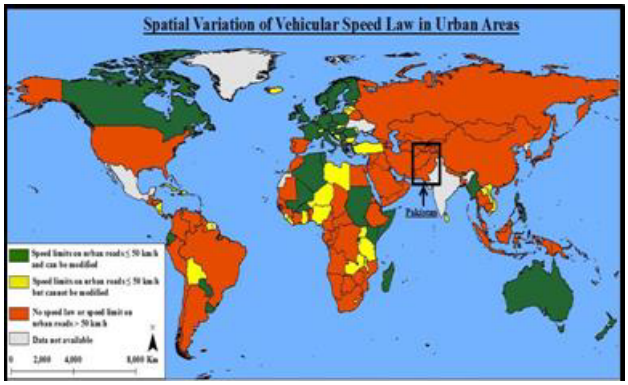


Figure 1. Variation of vehicular speed law source: After Toroyan, 2015.

2 Methodology

Following work flow "Figure 2" was adopted to carry up this research.

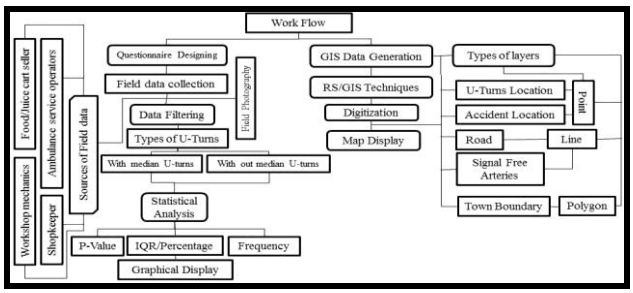


Figure 2. Flow diagram of work flow of the study.

2.1 Field data collection

Questionnaires were designed that hold information regarding various aspects of road crashes that include number of people injured or killed due to crash, time of crash, types of collision, days of accidents with high or low frequency. A cross-sectional interviewer-based survey was conducted to various parts of Karachi by trained investigators in year 2015. Nearly one-twenty U-turns were surveyed and minimum three people working in the close vicinity of each U-turn were interviewed. These include shop keepers, fruit cart seller, workshop mechanics, ambulance service providers who were more exposed to U-turns nearly 10 hours daily.

2.2 Use of RS/GIS techniques

Initially layers of road, towns and accident locations were digitized and Geo-coded data of car crashes of different years were overlaid on high resolution satellite imagery. Later on density mapping was performed to figure out the hotspots of crash areas. It was revealed that most of the U-turns proximity were showing high cluster of crashes. Similarly, with median U-turns had broken wall which is also visible on high resolution imagery, suggesting that the car crash is very common on such U-turns. That inflicted the idea of inquiring about the impact of U-turns on collision cases in Karachi. Figure 4 shows different segments of road in the city. Movement of vehicles is slowest on left lane whereas, it is fastest at the right lane. Presence of median wall reduces the space for vehicles that not only cause consistent traffic jam in rush hours but also result to serious crash cases. Insufficient road accessories made visibility of median wall extremely poor for the vehicle runner thus, ended up with collision.

3 Results and analysis

Data was analyzed to multiple statistical tests using *Statistica Six Sigma*. Firstly, data was put on two-sample Wilcoxon rank-sum test to assess the association between the average numbers of road accidents per week, average number of people got injured or died per week and the two different types of U-turns. Statistical significance was tested by two tailed test with P values of less than 0.05.

Secondly, Pearson's rank correlation was applied to check the ranking order of two different types of samples. It was revealed in all the surveyed U-turns that only one correlation was found positive i.e average number of crashes per week while, rest of the two conditions were found negatively correlated. Similarly, those U-turns situated on Signal Free Arteries positive correlation were found on average number of fatalities per week. Rest of the other two conditions was negatively correlated of the given condition.

Thirdly, Chi-Square test was applied on two types of sample data sets. In this regard it was found out that all the three conditions were found statistically insignificant. Same test was also applied to the dataset extracted for Signal Free Arteries. The test showed significant relationship between the numbers of crashes took place on SFA whereas, rest of the other two conditions exhibited non-significant relationship.

Finally, Geoffrey H. Havers (GEH) test was applied to check the association of crash data. Except one variable of Morning/Evening & Night crashes, all the other variables showed the resultant value of less than 5 that suggest the data collected for this research had a good match. However, the said variable showed the value of 6 may not be a good association of the data.

Out of those 120 U-turns survey locations, seventy-three percent were without wall/median and twenty-seven percent were with wall/median. Similarly, Thirty percent

of all the surveyed U-turns lied on SFA and rest of the seventy percent were situated other than SFA of Karachi. Mean values computed for the responses based on numerical dataset were average while frequencies were chalked out of categorical dataset that included type of severity, the time and days and types of vehicle involved in those accidents. P-values were calculated for mean-weekly number of different types of road crashes i.e. only injury reported accidents and fatal accidents. The mean-weekly number of accidents found statistically insignificant with p-value is greater than 0.05. However, mean-weekly number of injury based crashes and fatal crashes were statistically significant having P-value less than 0.05. With-wall U-turns caused more injury based and fatal crashes than without-wall U-turns. Night time and evening hours were found out as most common times for road crashes of both types of U-turns. On without wall U-turns, occurrence of road crashes were highest on week-days i.e. (41.4%) from Monday to Friday. However, occurrences of road crashes were observed high at all the seven days of week i.e. (48.6%). Percentage involvement of loading pick-up, rickshaw and truck on other than SFA showed the value of 2% each. Rest of the vehicles involvement in road crashes was very meager in terms of percentage. Different types of vehicles were involved in road crashes near U-turns of both types. Involvement of cars/bike depicted the highest percentage i.e. (27% and 37%) on with wall and without wall U-turns. Similarly, involvements of bike on two different types of U-turns were 21% and 25% while, involvements of Bike/Car/rickshaw were 24% and 8%. Whereas, cars contribution in road crashes on both types of U-turns were computed 9% and 1.1% respectively. Percentage of bike/rickshaw on without wall U-turn were 12.6 and involvement of rest of the other types of vehicles in road crashes were less than 5% near both the types of U-turns.

Table 1. Profile of road safety status.

Profile of road safety status by type of U-turns.							**Profile of road safety status by type of U-turns on SFA.**					
Questions	U-turn with Wall (N=33) Median Frequency (IQR/Percent)	U-turn without Wall (N=87) Median Frequency (Percent)	*P-Value	Pearson Correlation (r)	Chi-Square Test	GEH Value	U-turn With Wall (N=25) Median Frequency (IQR/Percent)	U-turn Without Wall (N=11) Median Frequency (IQR/Percent)	*P-Value	Pearson Correlation (r)	Chi-Square Test	GEH Value
Avg. No. of crash/week	4.2 (3.6)	3.5 (4.2)	0.2702	0.117	0.109	2.529	6.3 (4.4)	6.3 (9.4)	0.008	-0.286	0.016	2.612
Avg. No. people injured/week	4.0 (3.5)	2.3 (3.5)	0.0043	-0.040	0.664	2.348	5.3 (4.5)	5(4.3)	0.01	-0.043	0.191	2.039
Avg. No. people dying/week	0.0 (1.0) @	0.0 (0.0) @	0.0047	-0.188	0.994	1.814	12 (87)	1.75 (24)	0.03	0.336	0.146	1.215

Record of All U-turns.				**Record of U-turns on SFA.**		
Most frequent time of crashes	U-turn with wall (Percent)	U-turn without wall (Percent)	GEH Value	U-turn with wall (Percent)	U-turn without wall (Percent)	GEH Value
Morning	4 (12 %)	7 (8.1 %)	1.27	4(28.5%)	1(7.1%)	1.89
Morning/Afternoon	1 (3 %)	0 (0 %)	1.41	1(7.1%)	1(7.1%)	0.00
Morning/Evening & Night	3 (9.1 %)	27 (31 %)	6.19	1(7.1%)	5(35.7%)	2.30
Afternoon	3 (9.1 %)	6 (6.9 %)	1.41	2(14.2%)	1(7.1%)	0.81
Evening & Night	12 (36.4 %)	30 (34.5 %)	3.92	1(7.1%)	1(7.1%)	0.00
Afternoon/Evening & Night	5 (15.2 %)	5 (5.7 %)	0.00	2(14.2%)	2(14.2%)	0.00
Anytime (Morning/Afternoon/Evening & Night)	5 (15.2 %)	12 (13.8 %)	2.40	3(21.4%)	3(21.4%)	0.00
Most frequent day of roadside crashes						
Working days of week	11 (33.3 %)	36 (41.4 %)	5.01	10(71%)	3(42.8%)	2.74
Weekends	4 (12.1 %)	10 (11.5 %)	2.26	2(14%)	1(14.2%)	0.81
Monday	1 (3 %)	1 (1.1 %)	0.00	0(0.0%)	0(0.0%)	-
Wednesday	0 (0 %)	1 (1.1 %)	1.41	0(0.0%)	0(0.0%)	-
Thursdays	1 (3 %)	0 (0 %)	1.41	0(0.0%)	0(0.0%)	-
Friday	0 (0 %)	2 (2.3 %)	2.00	1(7.1%)	1(14.2%)	0.00
Every day of week	16 (48.6 %)	35 (40.3 %)	3.76	1(7.1%)	2(28.5%)	0.81
No answer	0 (0 %)	2 (2.3 %)	2.00	0 (0.0%)	0 (0.0%)	0.85

Record of All U-turns.			**Record of U-turns on SFA.**	
Most Frequent vehicle involved in road crash	U-turn with wall (Percent)	U-turn without wall (Percent)	U-turn with wall (Percent)	U-turn without wall (Percent)
Bike	7(21.2%)	22(25.2%)	5(20.8%)	1(11.1)
Bike/Car	9(27.2%)	33(37.9%)	8(33.3%)	5(55.5%)
Bike/Car/Rickshaw	8(24.2%)	7(8.0%)	6(25%)	1(11.1%)
Car	3(9.0%)	1(1.1%)	3(12.5%)	0(0.0%)
Rickshaw	1(3.0%)	2(2.2)	1(4.1%)	0(0.0%)
Loading pickup/bus	2(6.0%)	2(2.2)	0(0.0%)	1(11.1%)
Taxi	0(0.0%)	1(1.1%)	0(0.0%)	1(11.1%)
Any	1(3.0%)	1(1.1%)	1(4.1%)	0(0.0%)
Bike/Rickshaw	0(0.0%)	11(12.6%)	0(0.0%)	0(0.0%)
Bike/others	0(0.0%)	5(5.7%)	0(0.0%)	0(0.0%)
Truck	2(6.0%)	2(2.2%)	0(0.0%)	0(0.0%)

* P-values are based on two-sample Wilcoxon rank-sum (Mann-Whitney) test, Pearson Correlation and Chi-Square Test

@ Wide variation was observed with mean and standard deviation of 0.47 (SD: 0.78) and 0.12 (SD: 0.36) for U-turns with and without median, respectively.

3.1 Analysis of U-turns on signal free arteries (SFA)

From the same data set multiple queries were applied to filter out the crash cases incurred on SFA only. On U-turns situated on SFA, number of Road crashes at with-wall U-turns and without-wall U-turns were 25 and 11 respectively proved that with-wall U-turns are more susceptible to road crashes than without wall U-turns. Averaged numbers of accidents on both types of U-turns were same i.e 6.3. Similarly, average numbers of injury

cases were nearly same i.e. 5.3 and 5.0. However, number of fatal crash showed substantial difference i.e 12 reported by the respondent near with wall U-turns, suggested that faster road are more vulnerable to road users. While, number of fatal accidents were only reported 1.75 on without wall U-turns on same arteries, proved that this type of U-turn has lesser susceptibility of collision occurrence because of their median free design. One possibility of higher number of road crashes on with wall U-turns is that median wall is situated on fastest traffic lane that reduces the reflex time of the drivers, thus increases the probability of road crashes. Responses of above three questions specifically on Signal Free Arteries were statistically significant with P-value less than 0.05.

At the U-turns (with wall) morning hours were considered the most susceptible to road crashes (i.e. 28%). However, on without median U-turns morning/evening and night time cases showed the highest proportion of 35%. Afternoon and evening hours depicted 14% of crashes on both the types of U-turns on SFA. Unidentified times of the day were reported as 21%. While, rest of the times of the day reported 7% crashes on both the types of U-turns. Different types of vehicle were involved in both types of U-turns (i.e with wall and without wall U-turns). Involvement of bike alone cause 21% and 11% crashes along with cars and rickshaw is 58% and 66% crashes on two different types of U-turns respectively. Cars alone constituent 12.5% of road crashes on with wall U-turns whereas, no case of car crash was reported on without wall U-tunrs. Loading pickup and taxi combine to cause 11% road crashes on without wall U-turns. Figure 4 shows some of the with-median U-turns situated on different arteries of Karachi. Different colored arrows show different segments of road and arrow direction show the direction of traffic flow. Yellow arrows depict that the left lane which is the slowest traffic lane in the city. Green arrow show right most lanes in the city. It is noteworthy that most of the with-median U-turns are situated on right lane which is also the fastest traffic lane in the city that reduced the reflex time of the driver and increases the certainty of crashes. In all three figures red arrows highlight the broken walls of the with-median U-turns. It is clear from the field pictures that considerable part of the median wall has been broken which proves that the car crashes is frequent on such spots. Furthermore, consistent traffic jam is also observed on such location because median wall reduce the space of forward moving vehicles. This result to higher number of Property Damage Only (PDO) crashes.

3.2 GIS work

Geo-coding of 120 surveyed U-turns were done by taking their coordinates while doing the field work. Town map of Karachi was made with the help of scanned maps through different government sources. However, road network and Signal Free Arteries (SFA) were also made by digitizing on high resolution satellite imagery. It is noteworthy that SFAs initiated from peripheral parts of the city, passing through medium to high population density towns (Figure 3-b) making higher chances of road accidents within the city. Inverse Distance Weighted (IDW) technique was applied on U-turns layer in Arc GIS 10.1 environment to figure out the concentration of U-turns in Karachi (Figure 3-c). Results imply that most of the U-turns are situated on roads where fast flow of traffic is observed; therefore, increasing the risk of road crashes coupled with the injury and fatality cases. On contrary central parts of the city have fewer U-turns that reduce the chances of severe injury and fatal road crashes within the city.

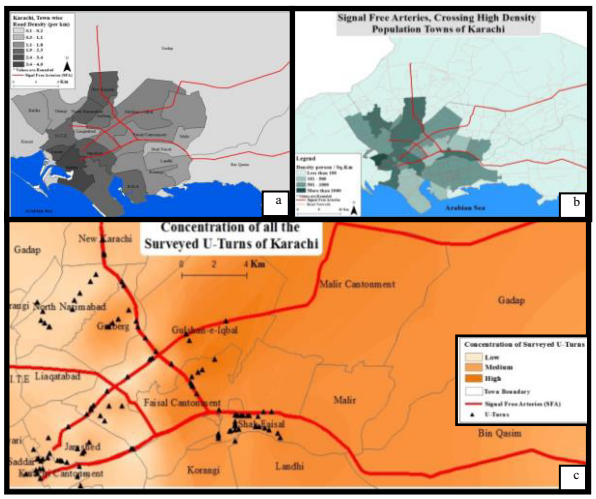
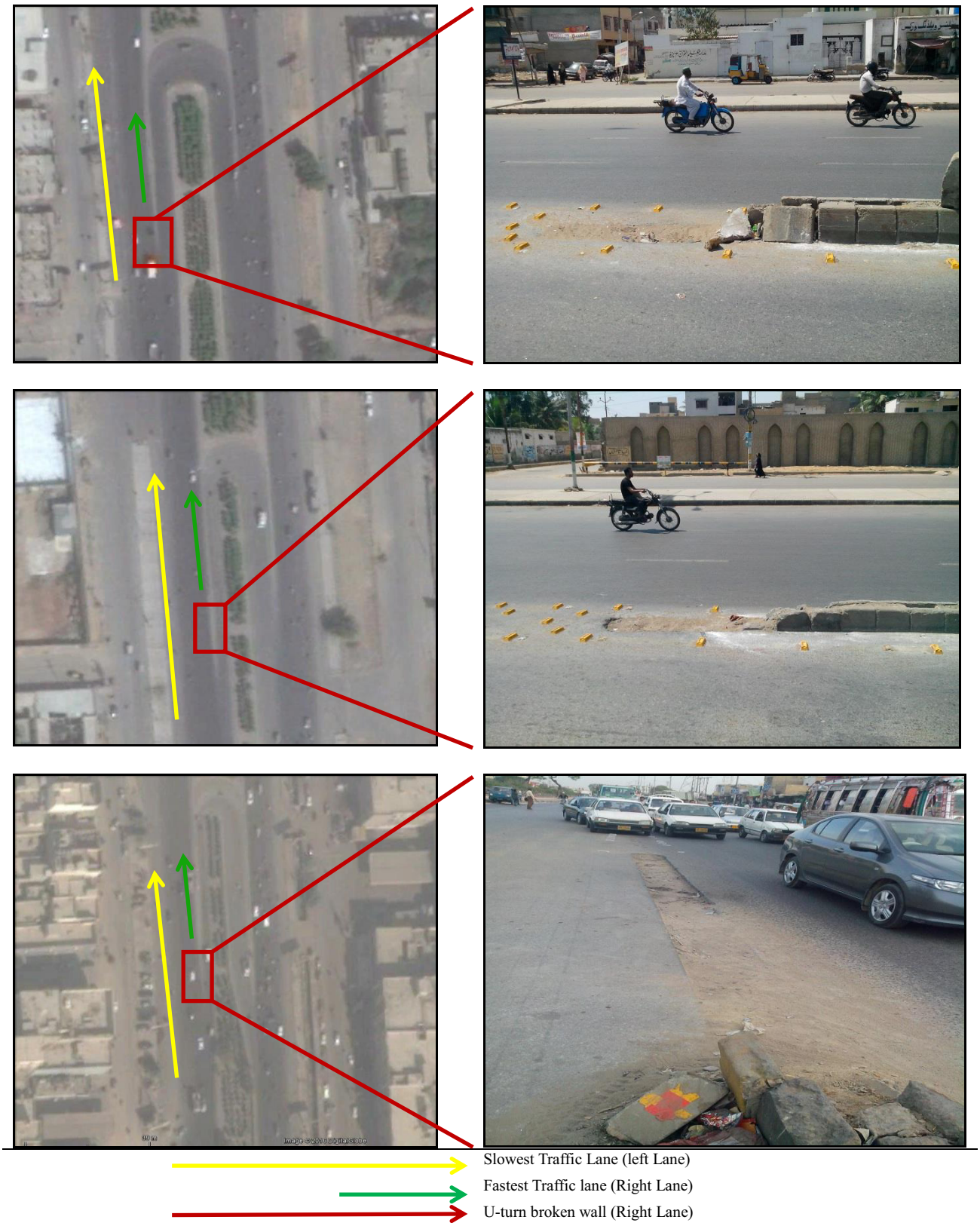


Figure 3. (a) Karachi - road density with SFA, (b) Karachi-population density, (c) concentration of U-turns in Karachi

4 Discussion

Concentrating on driver skill alone for the complex issue of acquiring road safety would smog the distinction between infrastructure design and its influence on drivers. Globally, more than 1.2 million people are killed every year. This problem is the ninth leading cause of death for all-aged group people and is the leading cause of death among the group of 15-29 years age people, spoiling up to 5% GDP share in low and middle income group countries of the world. Pakistan stands first in Asia [24] in terms of leading RTA death conceiving countries of the world with more than 8,000 casualties reported in 2013 by Police. Likewise, Karachi ranks fourth [25] in this regard with more than 1,000 road accident causalities in the year 2012. It is estimated that the actual cases are much higher than the reported figures. It is because, every road accident does not get registered by the traffic police, as parties involved in such accidents resolve the conflicts on their own [26]. Results from the study suggest that with wall U-turns are more likely to encounter higher number and severe intensity of road crashes thus, causing to higher number of fatalities. Further, same U-turns are more suitable for 180 degree maneuvering of vehicle on other side of the road as compared to without wall U-turns. In Karachi most of the with wall U-turns are located on Signal Free Arteries aimed for faster traffic movement and are responsible to higher number of mortality cases. However, without wall U-turns experience lesser frequency of fatal crashes.



Source: Authors

Figure 4. High resolution satellite images showing placement of U-turns.

It was postulated that faster vehicular traffic are more susceptible to severe injury and fatal road crashes due to the presence of two different types of U-turns on selected arteries of the city. This shows a significant positive relationship with road crashes hence this particular feature (i.e. U-turn) on road compromise the road safety within the city.

5 Conclusion

It was concluded that this is the first study conducted in this region that computed the impact of U-turn on road crashes. Various statistical tests were executed then it is finally suggested that presence of U-turns especially (with-wall) is a pitfall on major arteries of the city. However, safer road design should be the top most priority for the road designers. Planners can incorporate the use of latest technologies and recent research work before taking final decision regarding changes in the infrastructure. Strong and timely coherence among different departments such as health, planning and development, traffic and communication department and academician is needed to promote the culture of productive research and concrete planning. Mass transit systems should be launched as at the earliest due to growing demand of population in Karachi. This would reduce the consumption of valuable resources as well as the adverse impact on the environment and will certainly help to get better solutions of the real world problems like Road crashes.

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