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A Technical Perspective on Roadway Safety in Eastern Province: Data Evaluation and Spatial Analysis

Muhammad Farhan, Sayed Faruque, Amr Mohammed, Sami Osman, Omar Al-Jabari, Abdul Almojil

***Abstract*—**Saudi Arabia in recent years has seen drastic increase in traffic related crashes. With population of over 29 million, Saudi Arabia is considered as a fast growing and emerging economy. The rapid population increase and economic growth has resulted in rapid expansion of transportation infrastructure, which has led to increase in road crashes. Saudi Ministry of Interior reported more than 7,000 people killed and 68,000 injured in 2011 ranking Saudi Arabia to be one of the worst worldwide in traffic safety. The traffic safety issues in the country also result in distress to road users and cause and economic loss exceeding 3.7 billion Euros annually. Keeping this in view, the researchers in Saudi Arabia are investigating ways to improve traffic safety conditions in the country. This paper presents a multilevel approach to collect traffic safety related data required to do traffic safety studies in the region. Two highway corridors including King Fahd Highway 39 kilometre and Gulf Cooperation Council Highway 42 kilometre long connecting the cities of Dammam and Khobar were selected as a study area. Traffic data collected included traffic counts, crash data, travel time data, and speed data. The collected data was analysed using geographic information system to evaluate any correlation. Further research is needed to investigate the effectiveness of traffic safety related data when collected in a concerted effort.

***Keywords*—**Crash Data, Data Collection, Traffic Safety.

I. INTRODUCTION

THE research was initiated in order to evaluate the traffic safety issues on two major highways of Eastern Province (EP) of the Kingdom of Saudi Arabia (KSA). A traffic safety research group was formed in association with the University of Dammam and the Saudi Aramco. The research group aimed to create traffic safety database for the study area, and thereby use it to identify traffic safety related issues. Four types of data were collected including Traffic Volumes, Crashes, Travel Time, and Speed. The paper provides details on the data collection methods, analysis, and findings. The Methods section of this paper describes the data collection process for each of the data types in details, and the Analyses section will provide insight on analysis for each data type collected.

M. Farhan is Assistant Professor with the Saudi Aramco Chair for Traffic Safety, The University of Dammam, Saudi Arabia (Corresponding Author - Phone: 966-50-897-6785; fax: 966-13-333-1822; e-mail: mfarhan54@gmail.com).

S. Faruque and O. Al-Jabari are Lecturers with the Saudi Aramco Chair for Traffic Safety, The University of Dammam, Saudi Arabia (e-mail: sayed.faruque@yahoo.co.uk, onaljabari@us.edu.sa).

A. Mohammed is Assistant Professor with the Department of Civil Engineering, Institute of Technology, West Virginia University, Montgomery, West Virginia, USA (e-mail: amr.mohammed@mail.wvu.edu).

S. Osman and A. Almojil are Assistant Professors with the Saudi Aramco Chair for Traffic Safety, The University of Dammam, Saudi Arabia (e-mail: sakhair@ud.edu.sa, ahamed@ud.edu.sa).

II. LITERATURE REVIEW

The literature review provides a summary of key research relevant to this topic in order of their publication. Cirillo investigated the relationship of crashes to length of speed-change lanes and weaving areas on Interstate highways. The results indicate that increasing the length of weaving areas will reduce the crash rate and that increasing the length of acceleration lanes will reduce crash rates [1]. In another effort Dart et al. investigated the relationship of rural highway geometry to crash rates in the state of Louisiana. The study concluded that the two geometric variables having the most effect on crash rates are pavement cross slope and traffic conflicts [2]. Hanna and Webb investigated characteristics of intersection crashes in rural municipalities [3]. The research established that a typical intersection with a given volume of traffic will have a higher crash frequency under traffic signal control than under STOP or YIELD sign control. The Federal Highway Administration (FHWA) prepared a Synthesis of safety research related to traffic control and Roadway elements [4]. Cleveland et al. investigated the design and safety on moderate volume two lane roads [5]. Results showed a strong influence of the geometric designs on crash experience. Mathews and Barnes investigated the relation between the road environment and curve crashes [6]. Van der Horst and Godthelp measured road user behavior with an instrumented Car and an outside-the-vehicle video observation technique in 1989 [7]. The research established that drivers directly use time measures for vehicle control and decision making strategies in traffic.

Hall and Pendleton investigated the relationship between Volume to Capacity (V/C) ratio and crash rates [8]. The study established that crash rates increased as a function of V/C ratio. Garber and Gadiraju investigated the factors influencing speed variance and its influence on crashes [9]. The results showed that a major influence on speed variance is the difference between the design speed and the posted speed limit. Jones et al. conducted the analysis of the frequency and duration of Freeway crashes in Seattle [10]. The study focused on crash analysis and prevention used the analysis to guide management strategies that seek to reduce the traffic-related impacts of crashes. Shankar and Barfield investigated the effects of roadway geometrics and environmental factors on rural freeway crash frequencies [11]. This paper offered insight into potential measures to counter the adverse effects of weather on highway sections with challenging geometrics. Khattak et al. investigated the role of adverse weather in Key Crash Types on limited access roadways [12]. The results indicate that for the selected crash types, drivers appear to compensate for increased injury risks. Vogel did a comparison of headway and time-to-collision as safety indicators [13]. The research recommends using headway and time-to-collision for enforcement and traffic safety improvements.

Caird et al. investigated the effects of cell phones on driving by means of driver performance studies [14]. The research findings showed that using a cell phone while driving results in deterioration of driving performance. Charlton et al. investigated the influence of chronic illness in crash involvement of motor vehicle drivers [15]. The study highlighted the need for a cooperative international approach to advance scientific knowledge linking medical conditions and crash risk. Eby and Kostyniuk investigated the 2001 Crashworthiness Data System to see how distracted driving can impact traffic safety [16]. The effort did a thorough review of the literature on the topic and assessed the available data. Hoerrey and Wickens studied the impact of Cellular Phone Conversations on driving and found that the cell phone conversations while driving can impact the driving capability and control [17]. Dingus el al conducted phase II of 100-Car Naturalistic driving study [18]. The results of 100-Car field experiment were initiated to provide an unprecedented level of detail concerning driver performance, behavior, environment, and driving context.

III. Study Area

Two major highways, with a total of 81 Kilometer (KM) in length, were selected as the study area. Fig. 1 shows the study area. The two highways include King Fahd Bin Abdul Aziz (KF) Highway with a 39 KM long stretch, and portion of Gulf Cooperation Council (GCC) Highway with a 42 KM long stretch. The two corridors were selected because of relatively higher number of traffic crashes and crash fatalities compared to the rest of the highways in EP. In addition, they represent a vast spectrum of land-use types ranging from rural along the GCC highway and sub-urban to urban across the KF highway. The study area also covered all the intersections and interchanges, and any intersecting roads that are located within a distance of 800 meters from the two main highways.

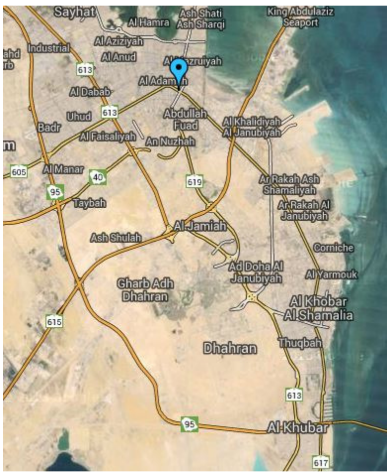

Fig. 1 Study Area with KF Highway and GCC Highway

IV. Methods

From the literature review it is clear that for traffic safety data collection, several avenues have been explored by the researchers including the geometric conditions, traffic operations, environment, and driver behavior. Past research provides valuable insight on how different elements impact traffic safety individually yet there is a void when it comes to performing collective efforts on various elements that may impact traffic safety altogether. This paper attempts to collect key traffic data elements in concert and then assesses the data simultaneously to identify the impacts on traffic safety. The data collection was classified into three broad levels including road traffic, traffic crash, and behavioral data. Within the broad levels, four categories of key data were collected including data on traffic volume, crashes, travel times, and speed. Intersection characteristics, pavement conditions, and traffic flow videos were also collected during the field trips. Data on red light camera violation and road user stated preference survey was also collected. However, this paper will focus on four key categories of data mentioned above. Separate articles would be submitted for other data types collected as the analysis on them becomes available. Fig. 2 describes the data collection steps in the flow chart.

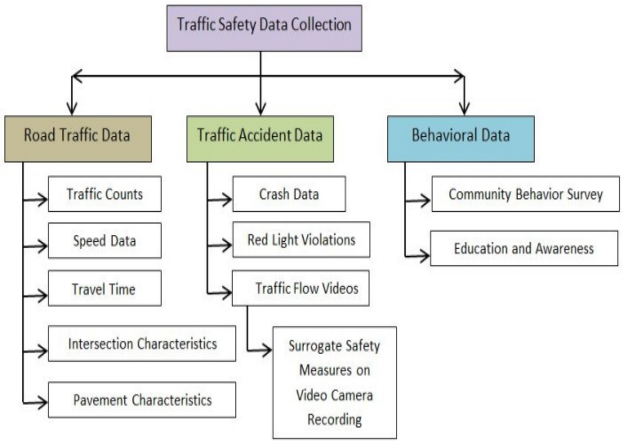

Fig. 2 Data Collection Steps

A. Traffic Volume Data

The traffic volume data is helpful in evaluating the speed, delay, travel times, queue lengths, intersection turning movements, and the travel demand. For this paper, the Average Daily Traffic (ADT) was observed on the study corridor for six months period starting December 02, 2013. Fig. 3 shows the study area with bands of traffic volume. Due to the spatial variations in traffic flow, the data collected was grouped into categories such as data for Exit and Entry of highways, weaving sections, main highway sections, and intersections turning movements. Since the GCC Highway is limited access, the volume there was collected at three locations including the intersection between KF highway and GCC Highway in north, at the Abkake Interchange in the central section, and at the southern end of GCC highway where it meets with KF highway again. The land use around

GCC highway is mostly rural, and the three data collection locations were selected keeping in view the key interchanges with other important facilities. The data were collected using two different counter technologies including the Automatic Traffic Counters (ATC) and Radar Counters.

The selection of the equipment was based on the use to get higher accuracy as much as possible. In some cases the pneumatic tubes attached to the ATC were damaged due to heavy traffic load and extreme weather conditions, and the data on those locations had to be recollected. In such cases, radars were used for the data recollection. At few locations radar equipment was mishandled by the law enforcement personnel thus making the data collected by that equipment obsolete. Some other obstacles in collection of the data include safety of road users and data collection staff.

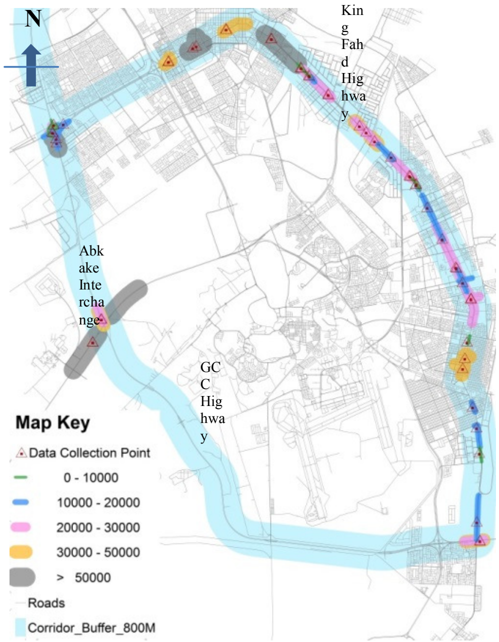

Fig. 3 Traffic Volume Collected with magnitude

B. Crash Data

Crash data is useful to study the causes of crashes and to develop traffic safety strategies. Crash data for this paper was collected to identify high crash risk areas and to find a correlation between the collected data with respect to traffic safety. Crash data collection in KSA is the done by Traffic Police. The traffic police collect the data for internal use only and the data is not intended primarily for research use. For this paper, the crash data was collected from the Police. The data was then processed by the staff at the University of Dammam. The crash data was grouped into four classes according to severity including Fatal, Major, Minor, and Damage only. Table I describes the crash data collected by year and by four classes.

TABLE I
CRASH DATA COLLECTED FROM THE EP POLICE

Year	Fatal	Major	Minor	Damage Only	Total
2008	1	23	0	1	25
2009	276	1157	3	137	1573
2010	213	1132	7	406	1758
2011	232	1161	20	10156	11569
2012	346	2088	76	18026	20536
2013	225	1687	77	4954	6943
2014	16	86	10	1	113
Total	1309	7334	193	33681	42517

Table I shows a large variation in "damage only" category. On further investigation, it was revealed that the "damage only" group had data entry discrepancies originating at source and re-collecting the data or data correction would not be possible at source. It was therefore decided to drop the damage only group from the analysis for this paper. The EP Police department started the data collection in the mid of 2008 and the collection work for the year 2014 was not completed as yet. Therefore, the data for the year 2008 and 2014 were filtered out as well. From the perspective of geo- spatiality, the raw data was grouped depending on the availability of geo-coordinates. Table II shows the crash data with or without geo-coordinates.

TABLE II
CRASH DATA WITH AND WITHOUT GEO-COORDINATES

Year	Geo-coded	Non Geo-coded	Total
2008	2	23	25
2009	318	1255	1573
2010	430	1328	1758
2011	2992	8577	11569
2012	16366	4170	20536
2013	6350	593	6943
2014	80	33	113
Total	26538	15979	42517
Percentage	62	38	100

Table II also shows that 38% of all the collected crash data were without geo-coordinates. This could be because either at the crash scene the forms were not completed appropriately or the global positioning device at the location malfunctioned. The data without geo-coordinates could not be allocated to any locations in the study area. Even if the writers try to get the location of the data by address mentioned in the form, the crash data still cannot be allocated at the exact crash location. The data without geo-coordinates was therefore discarded. The following points were inferred from crash data cleaning process:

1. Only fatal, major, and minor injuries data seemed plausible due to the inconsistency with damage only data.
2. Crash data from 2008 and 2014 were incomplete as the data collection started in the mid of 2008 and the year 2014 is still on-going.
3. Crash data with no geo-coordinates was filtered as it cannot be allocated.

Table III shows the final output of data cleaning process by year and by crash severity.

TABLE III
FILTERED CRASH DATA BY SEVERITY AND BY YEAR

Severity	Fetal	Major	Minor	Total
2009	82	216	2	300
2010	64	246	2	312
2011	62	382	5	449
2012	222	1381	64	1667
2013	170	1377	63	1610
Total	600	3602	136	4338

It is also noted that out of the total 42,517 crash records from Table I only 4,338 crash records shown in Table III were useable. The rest of the data were discarded due to inconsistencies, one of the limitations of this paper.

C. Travel Time Data

Total travel time and delay were also collected on the two corridors by means of active test vehicle technique (floating cars) [19] equipped with video cameras and Global Positioning System (GPS). Travel times, trip delays, traffic signal delays, congestion delays and average speeds on selected segments were collected. The study area was divided into nineteen segments with ten segments on KF Highway and nine on the GCC Highway. The segments were selected to represent homogeneous cruising conditions. Test vehicles were then dispatched to drive with the traffic stream on the segments on AM peak direction from 6:00 AM to 9:00 AM and in PM peak direction from 3:00 PM to 6:00 PM periods. Video camera footage was recorded with the drivers' own voice remarks. Travel time data were then extracted from the video recordings. Drivers maintained the test vehicle speed by means of "floating car" technique [19] in which the vehicle was driven by safely passing as many vehicles as pass the test vehicles.

D. Speed Data

Speed analysis was an imperative input to this paper as the literature suggests that speed impacts traffic safety [20]. Speed data were collected from 88 sites, on at least 150 vehicles at each collection site along the KF and GCC Highways. Locations and times chosen for speed data collection were based on crash data and traffic volumes. Different technologies, including fixed and handheld radars, and pneumatic road tubes were used for the data collection.

V. ANALYSES

A. Traffic Volume Data

Traffic volume data was populated on the study area highway network and was overlaid with the crash data to see any correlation. Fig. 4 shows the traffic volume bandwidth overlaid with crash data grouped in fatal injury and major injury category only. It was noted that the crashes with major injuries existed all along the KF and GCC highways. Fatal crashes were higher at segments with higher traffic volumes. A number of fatal crashes did show up on the collector facilities where the traffic volume data was not collected. Higher volume bandwidth area of Abkake Interchange on GCC highway had highest number of fatal crashes compared to the rest of the study area. It was also noted that low volume segments on KF highway had fewer fatal crashes.

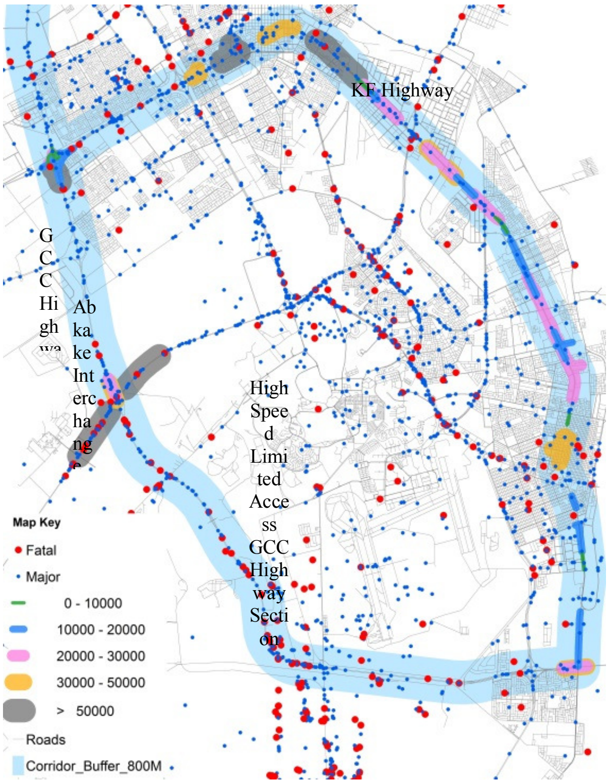

Fig. 4 Crash Data with Traffic Volume Bands

B. Crash Data

The crash data was evaluated for the causes reported with the data. Fig. 5 describes the proportions of 10 of the top causes reported including driver distraction, speeding, red light running, illegal overtaking, not giving way, sudden turning, insufficient distance, pedestrian crossing, violating pedestrian sign, and others.

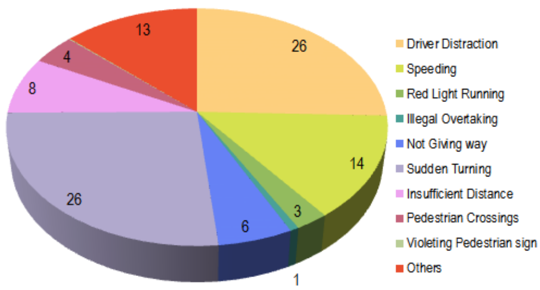

Fig. 5 Percentages of Crash Data with Reasons

The pie chart shows that the driver's distraction at 26% is a major category for crashes. Speeding at 14% and speed related issues (Red light running at 3% and sudden tuning at 26%) sum up to be the biggest cause totaling 43%. Geo-spatial method to evaluate the visual trends of road crash density was also applied over the study area. PTV Software VISUM Safety version 13.0 was used to develop heat maps based on the data starting 2009 to 2013. To understand the variability of crash clustering on heat maps, a direct count method within a search radius of 500 meter was applied. The number of crashes "n" within the search radius defined the crash risk level. The following criteria were used:

a. Low risk area with n< 5
b. Moderate risk area with 5<n<10
c. High risk area with n≥ 10

Figs. 6 (a)-(e) show crash densities in the study by year:

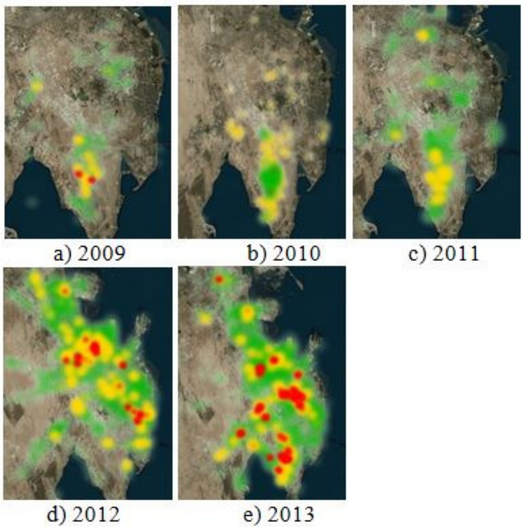

Fig. 6 Heat Map of Crash Densities (a) 2009, (b) 2010, (c) 2011, (d) 2012, and (e) 2013

The red color represents the high crash density, the yellow is moderate, and green is low crash density. Figs. 6 (a)-(c) describe that the crash densities do not vary much from 2009 to 2011. Figs. 6 (d) and (e), however, show several crash density areas where the high crash densities spread all over. With improvements to crash data collection process with respect to inconsistencies we noted, the data in Fig. 6 can be further enhanced.

C. Travel Time Study

The travel time data gave clues on the problematic locations with delays in peak directions of traffic flow. The spatial information on AM delay was overlaid on GIS map of the two corridors with crash data. Figs. 7 (a) and (b) show the delay overlaid with overall crash data and speed related crash data respectively. The results show more crashes in low delay areas compared to the areas with high delay as seen in (a). Also (b) shows that the high speed segment of the corridor had higher number of crashes compared to the low speed segment of the corridor with relatively higher delays. It was also observed from Fig. 7 (b) that the numbers of fatal crashes were lower in high delay areas when compared to the areas with high speed.

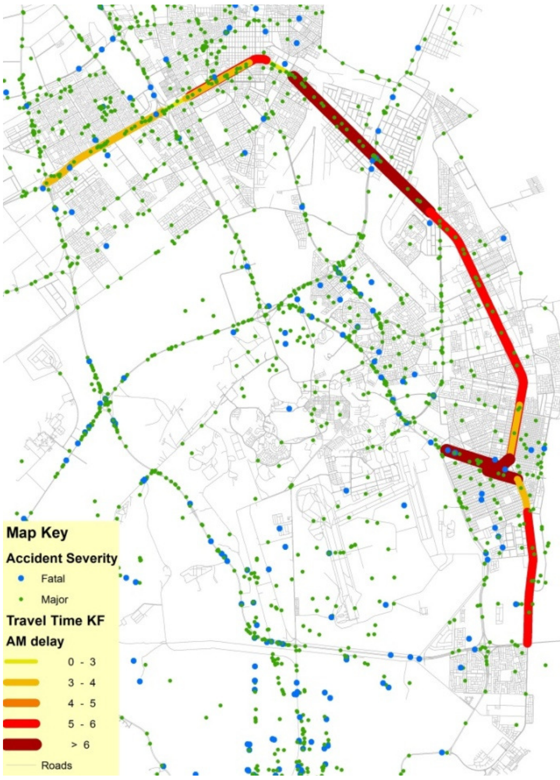

Fig. 7 (a) Delay overlaid with Crash Data

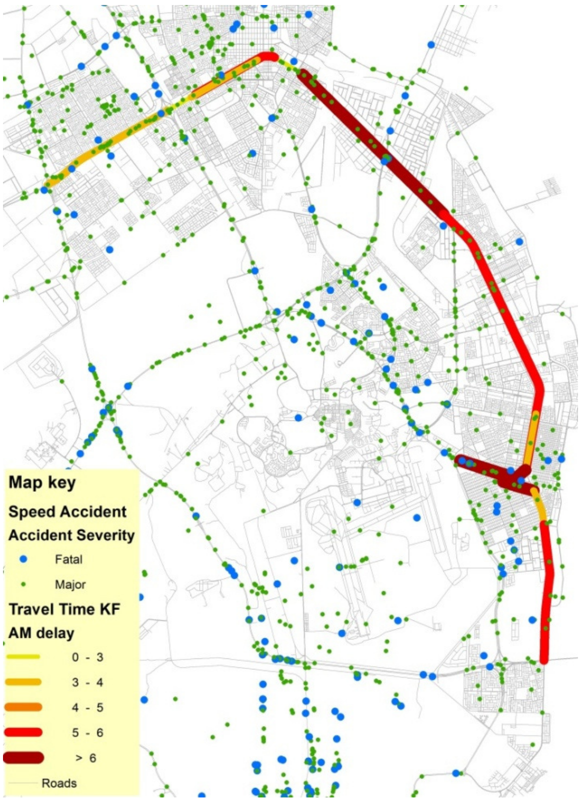

Fig. 7 (b) Delay overlaid with Speed Related Crash Data

D.Speed Data

Spot speed studies were used to determine essential statistical measures such as speed distributions, the pace, median speeds and percentiles. The analysis was carried out for the speed data collected under prevailing flow conditions from the 88 sites across the two corridors. Results show variations of 85th percentile speeds at different locations of the "segments with same posted speed limits". In addition, the study showed an average of 20% rate of speed limit "noncompliance" along the two corridors. Fig. 8 describes the speed data showing percent difference between posted speed and observed speed overlaid with the crash data showing fatal and major injuries. From Fig. 8, it is clear that speed noncompliance areas are the fatal and major crash high risk zones.

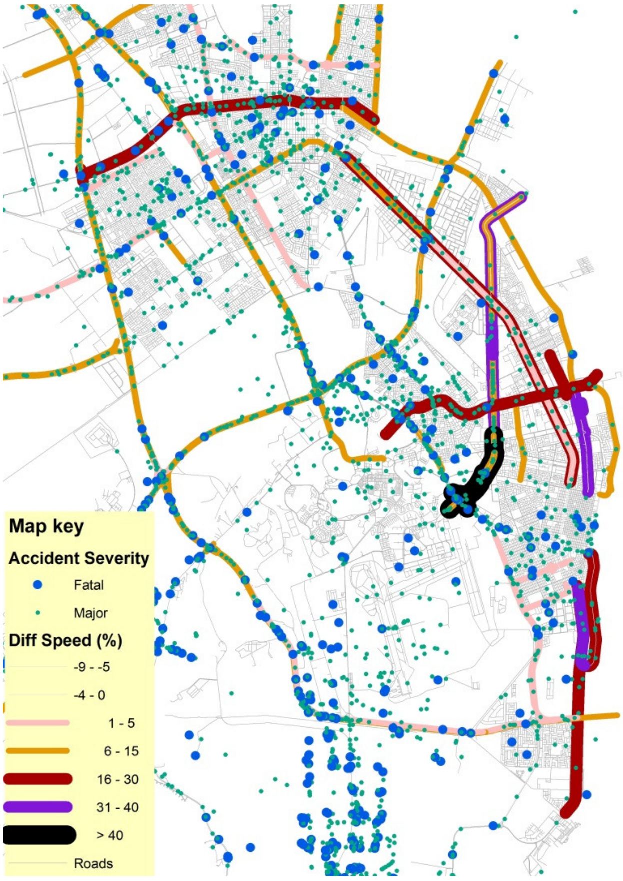

Fig. 8 85 Percentile Speed Difference overlaid with Crash Data

VI. Conclusion

The concerted effort of collecting the traffic safety related data is powerful when the data is overlaid using geographic information system for safety analysis. The data such as speed, traffic volume, and travel time when overlaid and compared with crash data show clear correlation. The segments with higher speeds showed more fatal crashes compared to the ones with higher delays. The crashes with major injuries occurred all along the corridors more so at segments with higher bands of traffic volume. It was also noted that pre-collected crash data may not be suitable for comprehensive traffic safety studies, especially in countries where infrastructure is still developing and the data may not have been collected with traffic safety research in mind. In-depth crash data collection would be the best approach to address the limitations of inconsistencies in crash data for traffic safety studies. We recommend increasing the public awareness campaigns that target speeding issues, increasing the level of enforcement and the development of a traffic operation center for better traffic safety related data collection and analysis.

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