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Conference Paper · January 2017

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A Sketch Planning Approach to Highway Safety Manual Based Crash Prediction Methods Using Road Safety Audit Data in Saudi Arabia

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Word Count: 4799 + 2000 (6 Figures + 2 Tables) = 6799

Prepared for the
Transportation Research Board Annual Meeting 2017 Submitted August 01, 2016

ABSTRACT

Recently a comprehensive traffic safety study for the two main corridors was conducted in Eastern Province of Saudi Arabia. The main aim of the study was to analyze the causes of various traffic safety related issues in the Eastern Province. This was done with regards to traffic crashes with fatalities in-particular; some of the methods employed included collecting data on traffic volumes, highway speeds, travel times, traffic crashes, and conducting the road safety audit. These methods helped develop several countermeasures which targeted to reduce crashes and the severity levels associated with them, and hence improve the overall traffic safety situation in the area. This paper explains a sketch planning approach for the application of Highway Safety Manual (HSM) based crash prediction methods using road safety audit data, to help estimate reduction in crashes due to proposed improvements. The selection of the two corridors was to best represent the transportation network in the Eastern Province which consists of several different types of facilities including urban, suburban, and rural roads. Comprehensive road safety audit was performed on two corridors and the data collected thereof was archived into reporting templates. After thorough evaluation of the data collected in the safety audit process, improvements to root causes of traffic safety concerns were recommended; the HSM based crash prediction methods were applied to see the effectiveness of the improvements suggested. Reports were prepared for each of the data collection items. While the results show reduction in traffic crashes based on improvements to the corridors, this approach could contribute in its true essence when applied in combination with several other traffic safety improvement strategies.

Keywords: Highway Safety Manual, Crash Prediction Methods, Saudi Arabia, Road Safety Audit

INTRODUCTION

Traffic crashes are one of the most common reasons that kill so many people in Kingdom of Saudi Arabia (KSA). The crashes could be caused by drivers' behavior, improper designs of the roads, or a combination of flaws in overall traffic system. The rapid population and economic growth in the Eastern Province of KSA has led to an increase in traffic volume and eventually increase in number of traffic crashes, ranking the province third with respect to road crashes in the KSA as per Saudi Ministry of Interior (MOI) *(1)*. As per the MOI, there were 8,182,794 road traffic crashes between 1970 and 2011 in KSA, and over 12% of them were with injuries and over 2% of them were with fatalities. In addition, the traffic accidents' victims occupy 30% of hospitals beds. Further, the data for 2015 from MOI indicated that there are 28 traffic crash related deaths per 100,000 population every day, and 70 % of the victims are under 25 years of age. By this standard, Saudi Arabia is ranked among one of the worst when it comes to the traffic safety. These statistics are not reported by the MOI only, but the Global Status Report on World Safety by United Nations (UN) summarizes similar findings for Saudi Arabia *(2)*. Keeping this in view, the transportation planning organizations in Eastern Province, in collaboration with researchers are trying to find ways to improve traffic safety in the region. As part of this exercise, a comprehensive traffic safety corridor study was conducted for the two major corridors of King Fahd bin Abdul Aziz Highway and Abu Hadriyah Highway. The objective of the study was to evaluate the study area by conducting analysis on various observed data on the two corridors including traffic counts, speed, travel time, traffic crash data, and road safety audit data. This paper explains the sketch planning level application of Highway Safety Manual (HSM) based crash prediction methods using road safety audit data collected. The process ultimately shows on how much reduction in traffic crashes on different segments of the corridors is possible if improvements are done to the corridors based on the observed data.

Study Area

The King Fahd Bin Abdulaziz Corridor is one of the main highways in the province with 4 lanes each direction; it passes through the Dammam metropolitan area including Dammam City Central Business District (CBD) connecting with Al-Khobar City. The corridor also serves as one of the few routes in the region which lead to Dammam International Airport. It is a principal arterial surrounding the northeastern side of the Dammam Metropolitan area and represents the sub-urban to urban areas. From the traffic congestion standpoint, it is characterized as highly congested and has relatively higher number of traffic crashes and crash fatalities as compared to the other roads in the Eastern Provence *(3)*. Due to multiple intersections along the King Fahd Corridor, there are several weaving sections which cause traffic congestion during the peak traffic. The corridor also serves the traffic heading to and from other surrounding areas, including international traffic through the King Fahad Causeway, between Saudi Arabia and Bahrain, and the traffic going north towards Kuwait, and other cities and provinces within the Kingdom as described in Figure 1. The red colored line demarks King Fahd Highway Corridor while the black colored line demarks Abu Hadriyah Highway (GCC Highway).

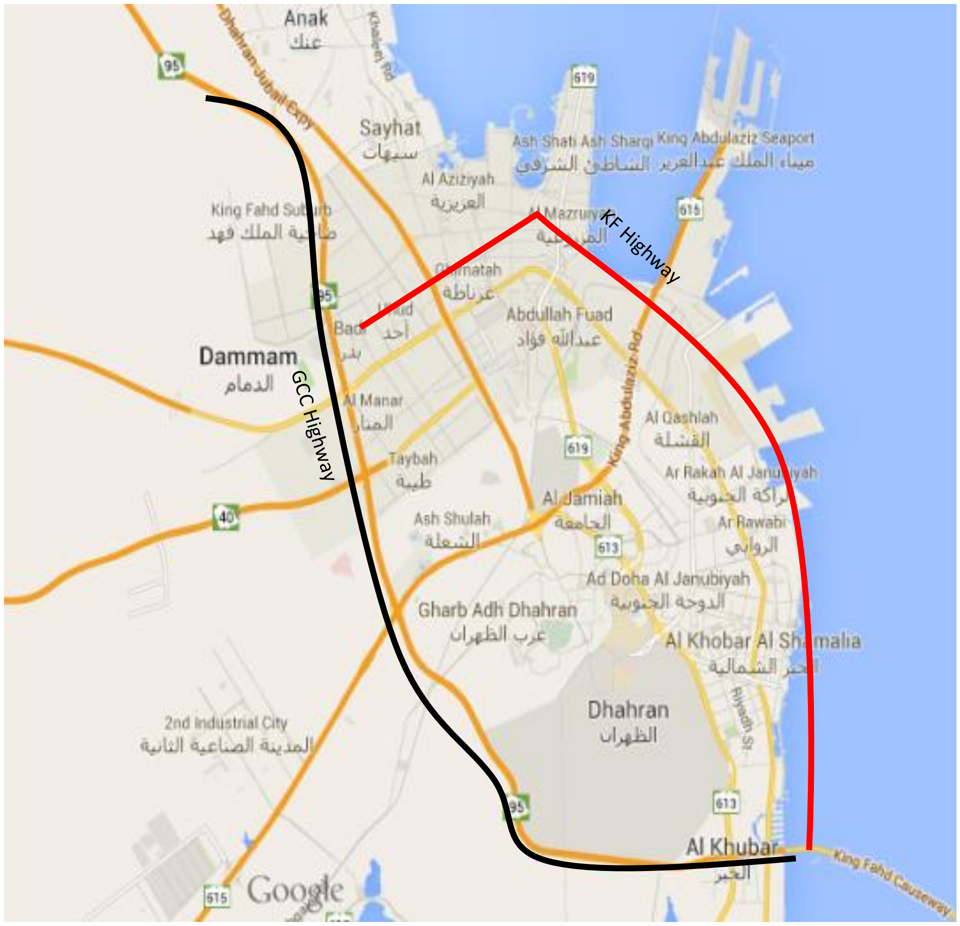


Figure 1 Study Area

The King Fahad Highway also known as Dammam-Khobar road is classified as a principal arterial connecting the Cities of Khobar and Dammam. The posted speed limit along the corridor is varying from 110 km/h to 70km/h in Tunnels and Khobar area. Most of the highway intersections incorporate a highway grade separation (overpass or underpass), except for few signalized intersections along the southern side at Khobar City. The typical section does not vary along selected street. A six-lane curb-and-gutter section exists of total width of 30m with additional left- and right-turn lanes at some locations. Sidewalks exist on both side on the service road in the study area. Lane widths are 3.5m wide. Wider shoulders exist at the newly constructed segments, at the northwestern stretch of this highway (from Dhahran/Jubail Intersection) to Al-Hadraya intersection. There are about fifteen major intersections within the study corridor area. The spacing between interchanges ranges from 0.25 km to 3.5km.

Abu Hadriyah Highway “Highway 95”, is a major highway in the Eastern Province of Saudi Arabia. It extends from King Fahd Causeway, linking Bahrain to Saudi Arabia, to Kuwait's borders serving major cities such as Dammam and Jubail. The highway also serves as an Eastern border for King Fahad International Airport in Dammam. The section under consideration mainly has four traffic lanes of lane width of 3.5 m and shoulders on both sides with two lanes service road on each side of the highway from Abqiq intersection to Nabia village. From Abqiq intersection to Bahrain causeway there is no service road only the main road of three lanes per carriageway as shown in Figure 2 above.

LITERATURE REVIEW

The safety investigations process is a combination of scientific evaluation, the investigator's knowledge and experience, and good judgment. The investigator is essentially piecing together many clues as to why traffic safety issues occurred without having the benefit of any actual first-hand knowledge. For instance, in case of traffic crashes, the investigator must glean clues from a detailed analysis of crash data and a thorough investigation of field data. These clues can then be evaluated by the investigator to identify preventable crashes. For these "target" crashes, the investigator can identify feasible and effective countermeasures, make recommendations, and document the entire process. In parallel to the in-depth investigation of crashes, the road safety aspect is covered by conducting Road Safety Audits (RSA). RSA is defined as "the formal safety performance examination of an existing or future road or intersection by an independent, multidisciplinary team. It qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users." *(4)*. Road Safety Audits are undertaken by teams of specialists trained in the skills of accident investigation or road safety engineering.

In addition to evaluations of crash data, and the RSA process, the Highway Safety Manual (HSM) could also be used to get guidelines on the traffic safety evaluation methods. HSM was published by the American Association of State Highway Transportation Officials (AASHTO) in 2010. It was developed to help measurably reduce the frequency and severity of crashes on highways by providing tools for considering safety. The HSM provides transportation professionals with knowledge, techniques, and methodologies to quantify the safety-related effects of transportation decisions. Further, the HSM also assists practitioners in selecting countermeasures and prioritizing projects, comparing alternatives, and quantifying and predicting the safety performance of roadway elements considered in planning, design, construction, maintenance, and operation *(5)*. By using the HSM, practitioners can quantify crash frequency and severity and integrate that information into roadway planning, design, operations, and maintenance decisions. The highway Safety Manual (HSM) contains available information and methods on evaluating road safety in terms of crash frequency based on practice.

Several studies have been carried out to evaluate the impact of Safety Performance Functions (SPF) on the prediction of collision for road network. SPF as accident prediction models provide professionals with data needed to conduct road safety impact assessment and network safety ranking and accounting for a more realistic relationship between traffic volume and accident occurrence. A research conducted in 2014 showed that the locally derived HSM based Crash Modification Factors (CMFs) for fatal and injury data showed improvement over the HSM default values in Riyadh *(6)*. Further, the frequent angle parking in Riyadh urban road networks seems to increase the fatal and injury collisions by 52 percent. They concluded that the framework provided can be used by other GCC countries which in general have common driver behavior and design standards. Another study was carried out a study in Hungary to define accident prediction models for first-class main roads outside built-up areas using variables that are available and believed to exert an influence on safety performance ***(7)***. They concluded that AADT, roadway width, horizontal curve and segment length significantly influence accident frequency.

In 2013, Cafisco et al. compared the effect of choosing different segmentation methods, they examined using short vs. long roadway segment to calibrate the SPF *(8)*. In addition to the segment selection criteria, new treatment types were also identified beside those which had been included in the HSM. Sacchi et al in 2012 investigate the transferability of the HSM to Italy's road network *(9)*. They used cumulative residual plots for the AADT and for variables related to the CMFs to assess the validity of the models. The results obtained suggested that the implementation of the HSM techniques in road safety impact assessments across Europe should be oriented toward the development of local SPFs and CMFs for the European context. The transferability assessment techniques are relatively complex and require substantial data and analytical resources. Thus, the techniques are not intended for routine use by practitioners who, in the absence of such an assessment in an application context, should still apply the universal baseline HSM SPFs (with local calibration) and CMFs.

In short, HSM predictive techniques and models have been studied in different states in USA, such as Florida, Texas, Louisiana, and Oregon *(10)*. Similar studies also have been carried out in other countries, such as Italy, Hungary and Canada (11,12,13).

METHODOLOGY

Background

Evaluation of such road segments and intersections as defined by Figure 1 in the study area section requires carefully crafted methodologies and techniques to assess their performance with respect to traffic safety. Road Safety Audit (RSA) is a term used internationally to describe an independent review of such projects to identify road or traffic safety concerns. RSA is a pro-active approach with the primary aim of identifying potential safety problems as early as possible in the process so that decisions can be made about eliminating or reducing the problems. The purpose of a Road Safety Audit (RSA) is to identify potential hazards that may affect any type of road users. The Road Safety Audit also identifies the appropriate measures to eliminate or mitigate road and traffic safety hazards.

This paper aims to apply the HSM based crash prediction methods on two main corridors in the Eastern Province of Kingdom of Saudi Arabia using RSA data collected in order to estimate the reduction in crashes when improvements are made with respect to RSA data findings. For this aim RSA survey were tabulated on the two corridors. Highway Safety Manual based crash prediction method was used to estimate reduction in number of crashes as compared to observed data because of the proposed improvements. Appropriate HSM methods were\selected and calibrated by taking into account the road condition and local conditions. The RSA team evaluated various data collected for the two corridor studies to identify the problem-spots with respect to traffic safety. Based on the Geographic Information Systems (GIS) evaluations process of Crash Data shown in Table 1, Traffic Volume Data, Spot Speed Data, Travel Time Data, and User Questionnaire data, the team identified 12 locations along King Fahd Highway, and 4 interchanges on Abu Hadriyah (GCC highway) including King Saud, King Fahd, Riyadh, and Abkake Interchanges as the key points for traffic safety concerns. Figure 2 shows the 12 locations in ovals and corresponding segments on King Fahd Highway and Abkake Interchange location in black triangle on GCC Highway, selected for Road Safety Audit and the HSM based crash prediction methods application. In addition, Figure 3 displays the 4 interchanges where the RSA was conducted on GCC highway.

Table 1 Crash data by year and by crash severity

Crash Data By Severity				
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

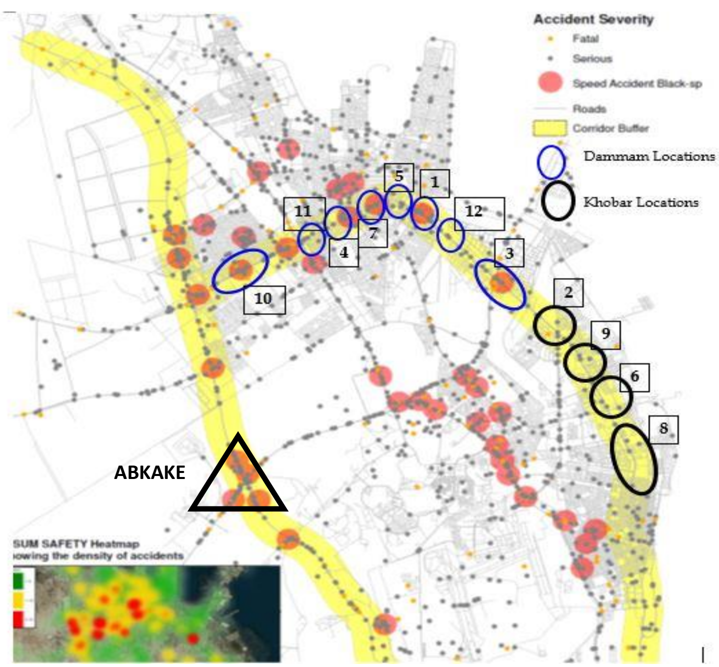


Figure 2 Safety Audit Survey Intersection and Segment Locations for the two corridors

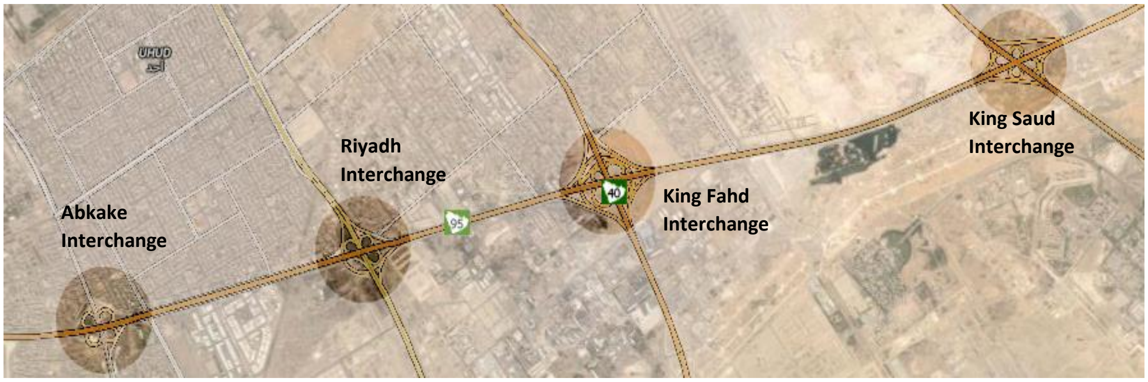


Figure 3 Road Safety Audit Survey Interchange Locations

HSM Crash Prediction Method

As per the HSM crash prediction method, the expected collision frequencies calculated by using the baseline safety performance functions (SPFs) must be modified with CMFs listed in the HSM Part D to help account for differences in features from the baseline conditions, such as lane or shoulder width for two-lane roads (HSM 2010). Equation (1) summarizes the predictive crash modelling procedure to predict the number of collisions (Npredicted) at a site before the application of this method:

$$N_{predicted} = N_{SPF} \times (CMF1 \times CMF2 \times CMF3 \ldots \text{up to} \ldots \times CMF6) \times C \quad (1)$$

Where:

$N_{predicted}$ = predictive average crash frequency for given conditions.

N_{SPF} = predicted average crash frequency for given conditions on intersection.

CMF = crash modification factor.

C = calibration factor

The calibration factor can be calculated from the total number of crashes for a sample set from the jurisdiction of interest divided by the sum of the predicted crashes for the sample by using Equation (1) without the calibration factor. Minimum sample sizes of 30 - 50 sites, with 100 crashes per year can be used for calibration procedure. However, there is no methodology to assess the validity of the results. The Average Annual Daily Traffic (AADT) volumes and geometric characteristics of the road are the main data required for the use of the HSM models. According to the HSM, a highway must be divided into individual homogenous roadway segments with a minimum length of 160 meters to apply Equation (1) above. The observed data was combined with satellite imagery and various GIS map layers to estimate parameters such as driveway density, roadside hazard rating, lane width, shoulder width and type.

The Field Study

During the field-study at least three persons participated in the evaluation. The driver read off the trip meter, where obstacles or hazards are identified when driving along the corridor. The observers identified different obstacles and hazards along the road and took notes about the locations. During the trip, the observer made comments on observations. Every time a deficiency or hazardous obstacle is observed, the observer recorded what kind of deficiency or obstacle it is. The driver tells the reading of the trip meter. The observers also made an audio-video recording. Audio recording makes it easy to use the video to add more information to the investigation form in the back office. Sometimes it is necessary to stop the car and take a more detailed look of the obstacle, for example, to determine the distance from the road to the obstacle or to take additional photos. The photos were then helpful in describing the obstacle in more details. Some of the photos also be used as illustrations in the report. From the notes of the field-study, information that can be gathered from the videotape were added. The collected data was then tabulated and using HSM factors to predicts the crash using different scenarios.

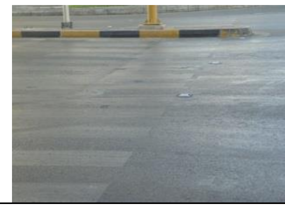
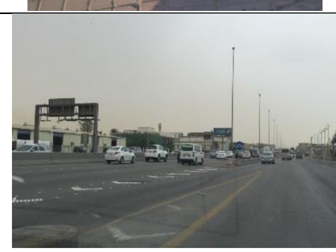
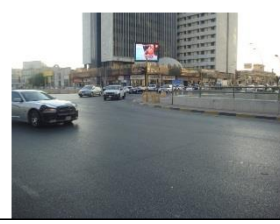
RESULT AND DISCUSSIONS

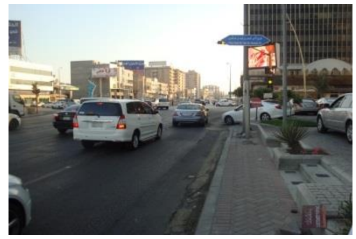
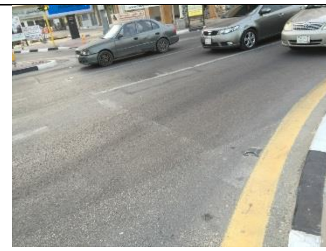
Application of HSM on Two Corridor Study Area

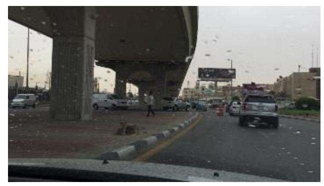
Based on the data collected from the RSA forms, and from the recorded suggestions for improvement to the given traffic safety concerns thereof, Crash Modification Factors were selected from the HSM manual on CMF. Those CMFs were then applied to the equation 1 explained above, and improvements were estimated in terms of reductions in crashes as explained in Figure 3 for each segment and intersection along the corridor. For each location, a detailed RSA was performed. Data was collected on the RSA asset collection instrument which was developed in consultation with the RSA team and the possible traffic safety concerns for the selected intersection or road segmented. The information was recorded in the form of written comments, images, and in some cases video recorded data was also collected and archived into the saved database for each location.

During the collection of data, various CMFs for HSM application were also kept in mind, as they will be later used for the HSM application and analysis. All the data collected was archived into an electronic file format in the main servers, as well was saved into Compact Disc ROM format, and DVD format as well. For this research paper twelve intersections, 4 interchanges and corresponding road segments have been studied thoroughly and detailed road safety audit survey have been carried out and tabulated as samples of findings summarized in Table 2 below. Based on findings a Highway Safety Manual was used to predict number of crash accident. An appropriate HSM methods were chosen and calibrated taken into account the road condition and national factor.

Table 2 Observations and samples of findings at different locations.

No exclusive Right turn lane for traffic	
Bad pavement condition and road marking	
On street parking, just at corner creating hazards for right turn traffic	
Bad and in proper cover for manholes on crosswalk	
Exit problems at night and violators using the exit to enter the main traffic	
Driver cross at red light	

Car park exit open at the intersection creating safety problem	
Through traffic can blocked right turn traffic	
Road marking for exit and no reflector signs at night on ramps	
Blocking the exit to prevent driver to use it as an entrance but still damaged blocked area used for entering the main traffic	

problem of exit and guard rail hazards	
Driving on shoulder and Unprotected side for high embankment on ramps	
Unsafe side walk with blocking left lane to give room for U-turn traffic	

Prediction of Crashes using HSM for the Two Corridors

Assumptions for CMF are proposed based on the intersection condition and performance. Two scenarios were proposed using different modifications factors to increase safety for the interchanges and intersections. First scenario based on geometric improvements to the facilities, while the second scenario included improvements to the traffic signal controls as well as geometric design improvements. The effects of geometric design and traffic control features on crash frequency are accounted through the CMFs while the effect of traffic volume (AADT) is considered through the SPF itself. Specifically, any feature associated with higher average crash frequency than the SPF base condition shows a CMF with a value greater than 1.00; any feature associated with lower average crash frequency than the SPF base condition shows CMF value less than 1.00. HSM Predictive method was applied on each of the 12 locations and related road segments. The CMFs were selected from the HSM based on the traffic safety related issues reported on the RSA Asset Data collection forms.

Figure 4, 5, and 6 show summaries of results for interchanges, intersections, as well as road segments. Figure 4 shows that out of the two scenarios, the second scenario reduced the number of traffic crashes to maximum except for Abu Hadriyah interchange where the scenario 1 with only geometric improvements demonstrate maximum reduction in crashes.

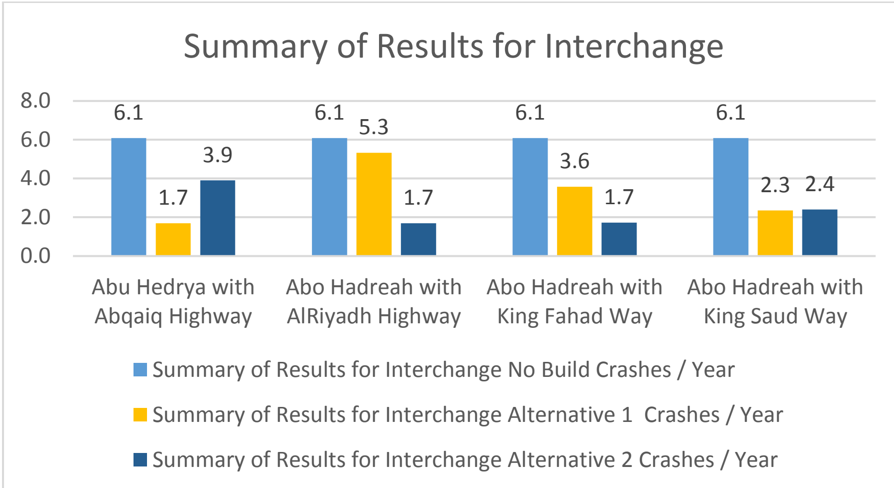


Figure 4 Summary of Results for Interchange

Figure 5 shows the maximum reduction in crashes at all intersections for scenario two except Alfoqan intersection and Almojil intersection show maximum reduction in crashes with scenario 1 where only geometric improvements were proposed.

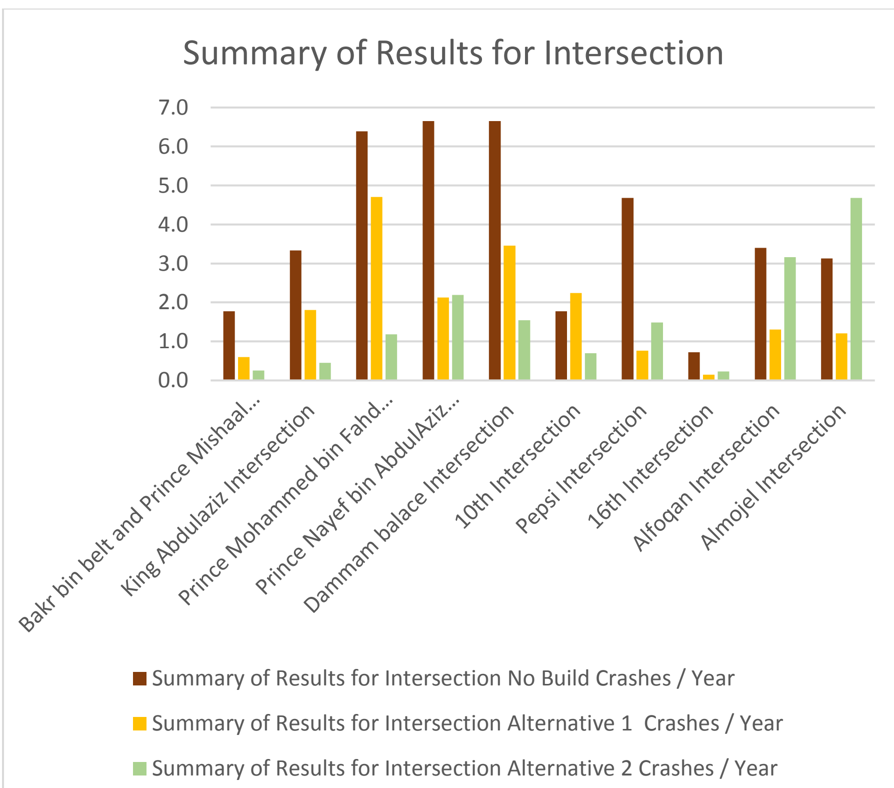


Figure 5 Summary of Results for Intersection

Figure 6 shows that the maximum crash reduction at the road segments is for scenario 1 where the road segment between Dammam Iskan and Dammam Palace dropped from 15.8 to 1.0. The road segment between Dammam Palace and Prince Naif road also showed significant drop in crashes in scenario 1 from 25.1 to 4.0.

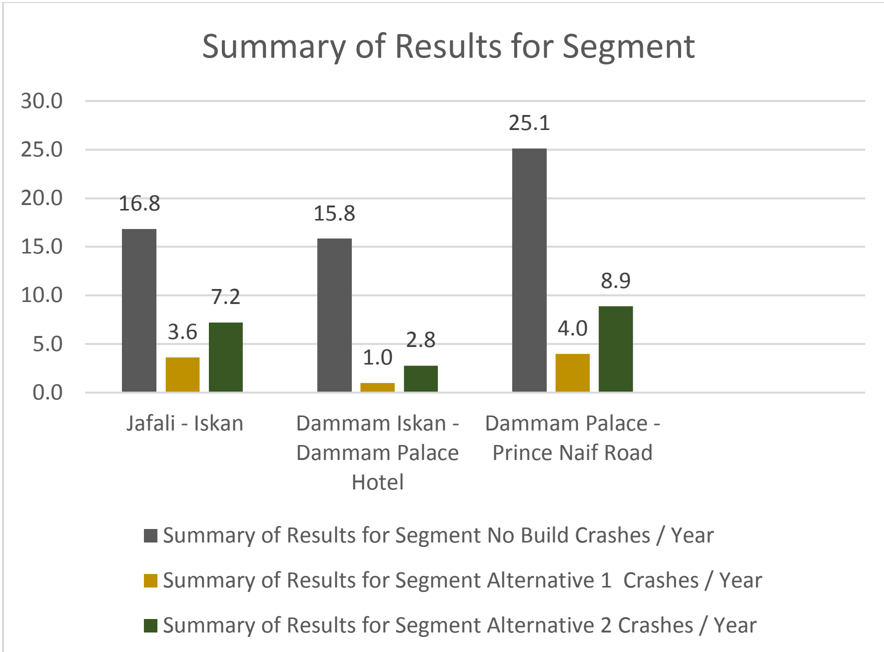


Figure 6 Summary of Results for Segments

Notable Observations from RSA

During the Road Asset survey data collection process, the team found several serious traffic safety related issues throughout the study area. Some of them included the following:

1. Most of the road segments and intersections surveyed by the RSA team showed poor road markings. In many cases the road markings have completely vanished posing a serious traffic safety concern. There could be many reasons of poor quality road markings including the number of vehicles passing through, the age of the striping, and quality of the striping material.

2. At several places the walk area had pot holes, coverless man holes/gutters, and in some cases, broken patches of the surface that extend all the way to the road surface. The walk areas should be maintained up to highest standards, that way the pedestrians don't have to get off the walk way and walk on the road

3. Angled Parking (60 degree) is one of the main factors causing traffic congestion and traffic safety related issues on the roads in the study area. It should not be allowed, and should be strictly enforced

4. At almost all the intersections, the location of the traffic signal controls are on the nearer side of the intersection instead of farther side. This poses a potential traffic safety risks. The signal controls should be installed at appropriate locations.

5. At many intersections, or weaving locations the traffic signs showing posted speeds or yield message were found missing. The signs should be properly installed; this will help make the roads safer.

6. Traffic signal control timings at many of the intersections are out, or not at least optimized for the intersection. Optimizing the signal control timings especially during the peak period flows will mitigate the traffic congestion significantly and will also help reduce the cycle failure problem at many of the intersections during the peak periods.

7. Pedestrian Zebra Crossing should be provided at every intersection with enough gap between the traffic stopped at the red signal light and the pedestrian. At several locations surveyed, the Zebra crossing markings were in poor conditions, and the crossings were not strategically made to assist the pedestrians or wheel chair users.

8. Where possible, provide pedestrian signals at the zebra crossing. This will ensure maximum safety of the pedestrians.

9. Exclusive lanes should be provided as part of the improvement process for the U-turn and left turn traffic movement. Between the U turn and the left turn, the two traffic streams should also be separated way before reaching the intersection. This will save the through movements from excessive long queues.

ACKNOWLEDGEMENTS

The authors acknowledge Saudi Aramco Chair for Traffic Safety Research at the University of Dammam for supporting this research. The cooperation of all stakeholders like Municipalities, Amana, Traffic Police Department, Ministry of Transport and Ministry of Interior, who kindly made the data sets available and made the data available for the analysis.

CONCLUSIONS

The HSM application of predictive method shows that if the improvements are made to the KF corridor based on the suggestions provided on the Asset Data Collection forms, and based on the Crash Modification factors identified, there could be an overall drop in crashes by down to 34%. This percentage may vary based on the types of crash modification factors introduced to the area. Thoroughly surveying and studying of twelve intersections and segments on King Fahad highway and Abu Hadriyah Highway (GCC Highway) evaluating their performance, it was found that several car accidents happen due to engineering design issues of the intersections or road segments.

Road engineers generally should pay attention to driveways design, and on street parking management. HSM based Crash Modification Factors were used to predict traffic crashes. Most of the results indicates positive outcomes. Two scenarios were considered for each intersection, each scenario having different CMF. The applied models and scenarios can be used to estimate severe collisions at segments between intersections.

Based on road safety audit carried out for the two corridors several countermeasures can be proposed to reduce the severe crashes, such as: control exits and entrances, Limiting the number of driveways, using of acceleration and deceleration lanes that are of sufficient length to accommodate speed changes, and the weaving and maneuvering of traffic, Ensure sufficient distance/spacing between driveways to provide drivers sufficient perception time to identify locations where they expect another conflict point, median width can be reduced to the standard width in order to increase the lane widths.. This study is one of the attempts to investigate the applicability of calibrating HSM models and developing new models in the KSA.

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