Proposing and Analyzing the Effects of a Road Work Zone Mobile Application with User Interface and Rerouting on Level of Service

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Abstract: - Work zones are common on roadways either for construction or maintenance purposes. They usually cause a drop in the capacity, as well as the level of service (LOS) of the road, and result into traffic congestion. In this paper, a free-flow segment of 222 m along the eastbound movement of Sheikh Jaber Al Ahmad Al Sabah (SJAS) Highway was studied as it went under road construction. The acceleration lane was closed which resulted in a drop of capacity from 2472 pc/h/ln to 2396 pc/h/ln and dramatic drop in LOS from A to D. The paper proposes a mobile application to improve LOS along roadways with workzones. The proposed application will provide information to the road user along with alternative routes. A survey was done which covered 1025 vehicle users in Bahrain. It aimed to understand and analyze traveler's willingness to reroute in case of previous knowledge about work zones along their route. The survey showed that 96% of the sample was willing to reroute. Calculations were made based on certain assumptions to get LOS at work zone back to A. It showed that to improve the LOS to A, 50% to 54% of the vehicles along the road should reroute, which is way below 96% and gives us a huge margin of error. In conclusion, it could be said that the proposed application could improve the work zone LOS, when developed and implemented according to the recommendations of this research.

Key-Words: - Workzone, Capacity, Level of Service, Mobile application, Rerouting

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1. Introduction

Work zones are areas within the roadway that are undergoing or affected by maintenance and construction operations resulting in interruption of traffic flow and reduction of road capacity. Depending on the layouts and traffic management schemes available at work zones, the maximum traffic capacity could decrease by approximately 30% due to work zones [1]. During lane closures and when the demand exceeds the new reduced capacity, traffic can easily become congested, and queues start forming which results in more capacity reduction [2]. Furthermore, work zones cause drop in operating speed which also influences the capacity [3]. The effect of work zone on capacity could be measured quantitively using level of service (LOS). LOS measures the quality of operational conditions within a traffic stream and represents it in terms of letters ranging from A to F, "A" being the best operating condition and "F" being the worst [4].

Kingdom of Bahrain faces a major problem regarding traffic congestion due to many reasons including high traffic volume and inadequate infrastructure [5]. Infrastructure improvement is always needed to satisfy the traffic demand. These improvements include construction of new roadways and maintenance of existing ones [6]. The presence of work zones along the roadway has a negative impact on traffic flow that is observed through increased traffic congestion [7], travel time, accident rates, and road users' level of dissatisfaction [8]. Therefore, the purpose of this paper is to discuss capacity reduction and LOS for roads with work zones and propose a mobile application to reduce the effect of these work zones. An attempt has also been made to gauge the effects of the proposed mobile application on the users using the stated preference survey.

The rest of the paper is organized as follows. In the proceeding section, a literature review is presented with four main sections: effect of work zones on roadways and their capacity, safety at work zones, LOS, and available mobile applications used for work zones and transportation. In the third section, research methodology is described, and material obtained is provided. Then, capacity of the roadway, LOS before and during work zones, and survey results are presented and discussed. The discussion included the effect of providing a mobile application on improving LOS of roadways with work zones. Finally, conclusions are drawn based on the discussion and results.

2. Literature Review

2.1 Effect of Work Zones on Roadways and their Capacity

Work zones have an adverse effect on the capacity of a roadway, which is influenced by prevailing roadway, traffic [9], and control conditions [8], [10]. In addition to these, work zone capacity is found to be affected by several factors including work zone intensity, presence of heavy vehicles, proximity of ramps [11], driver population, lighting condition, environmental conditions, and work zone configuration [6]. Work zone capacity tends to decrease as the intensity of the work increases [12]. Presence of heavy vehicles at work zone has a significantly negative impact on its capacity. Heavy vehicles increase the headway and have negative psychological and physical influence on other drivers [13]. Driver composition of commuter and noncommuters could affect work zone capacity, as regular drivers are more familiar with work zone configuration than occasional drivers. Therefore, noncommuters might cause reduction in work zone capacity [10]. Moreover, construction work zones on the roadway are found to influence the driver's behavior to be more conservative, which results in drop of the speeds and capacity along the roadway. These work zones are one of the most sensitive zones in the road network and should be properly planned to avoid the creation of bottleneck [14]. Work zone lane width and lateral clearance could reduce speed and number of vehicles entering the work zone and thus, its capacity [15]. The presence of work zones results in additional cost to road users, as the capacity reduction causes traffic delays, and increases travel time and vehicle operating cost, which adds up to road users initial cost [16] – [18].

2.2 Safety at Work Zones

Work zones are considered as hazardous locations due to the increase of accidents rate at such locations [19] – [21]. Accidents occurring at work zones could injure road users as well as construction workers [22], [23]. Rear-end collision are the most common type of accidents in work zones, these accidents as other types vary in severity from simple injury to being a fatal accident [24], [25]. Safety in work zones and severity of accidents depends on various factors including traffic conditions, driver behavior [26], vehicle type, lighting conditions, roadway characteristics [27], and work zone activity [28]. Traffic volume is positively related to the risk of accidents in work zones [29], [30]. Moreover, driver loss of control and speed at work zones have a direct impact on the severity of crashes at work zones [28]. Visibility at night decreases which adds to the complexity of the work zone and shortens the time for proper reaction [31]. Thus, work zones at nighttime are more dangerous than at daytime [32]. Also, the number of vehicles involved in an accident adds to its severity, and the accidents become more severe in case of truck involvement [25].

2.3 Level of Service

LOS is a concept used to relate quality of transport service to the given flow and speed from traveler's perspective [33]. LOS is a quantitative measure that takes into consideration various factors that could influence quality of service perceived by the traveler. These factors include speed, delay, travel time, number of stops, freedom of maneuver, comfort, and convenience [4]. LOS is represented in the form of letters and there are six levels of service ranging from A to F. LOS A represents the best operating conditions from a traveler's perspective, and LOS F is the worst. For various reasons, including cost and environmental impact, the roadways are not usually designed to provide LOS A during peak hours, but a lower level that balances traveler's desire against society's desire and financial constraints. However, they might operate at LOS A during the rest of the day [34]. LOS is difficult to quantify as it includes a complex interaction between many traffic parameters as well as traveler's perception [35]. Therefore, standards such as Highway Capacity Manual (HCM) are used for calculating capacity and LOS for various highway facilities [36]. LOS is widely used as a form of communication between traffic engineers and decision makers as it gives them an indication about road's performance in a convenient and simple manner [4]. Due to the presence of work zones, roadway capacity decreases and traffic delays increase [37].

2.4 Mobile Applications Available for Transportation and Work Zones
Azadi et al. [38] have done a thorough review of the existing mobile applications for transportation management. Smartphone applications have numerous uses in the field of transportation including route planning, traffic safety and parking information. These applications have been introduced lately to work zones. For example, a work zone safety application has been released by the American Traffic Safety Service Association to help users with decisions in case of stationary lane closures. These decisions include minimum needs for merging, shifting, shoulder and flagger operations. Virginia Department of Transportation released VDOT 511 which informs users about incidents and constructions along their routes. Also, the Federal Highway Administration and United States Department of Transportation launched the Work Zone Data Exchange (WZDx) program for collecting and sharing work zone activity data.
The same paper suggests a program for real-time work zone data collection. Users such as contractors and work zone managers could use it to add new work zones, update existing ones and perform geolocation. The proposed program would offer reliable information about work zones that could be used for work zone management, traveler information, contract monitoring, safety analysis and project coordination.

Fig. 1. SJAS Highway and the stated study area, Google Earth

There is little literature available discussing mobile applications related to work zones, especially related to travelers' perspective. To our knowledge, there is no paper discussing a mobile application which provides users with information about ongoing work zones activities and offers rerouting, and how the availability of this type of information could improve LOS of roadway during work zones availability. This paper will be offering some insights on these topics.

3. Materials and Method

3.1 Study Area
The present study is performed on Sheikh Jaber Al Ahmad Al Sabah (SJAS) Highway, which is one of the main highways in Bahrain that is connecting Sitra and Manama islands. The study area was limited to a free-flow segment of 222 m along the eastbound movement of SJAS, and it had 3 lanes and an acceleration lane before construction. During construction, the acceleration lane was closed. Fig. 1 shows the study area, and the highlighted blue line is the segment of the highway in which the study took place.

3.2 Traffic Counts
Traffic counts were done manually for the roadway before and during work zone activities. Traffic counts before the work zone activities were obtained from the Ministry of Works (MOW) in Bahrain [39], while done as part of this study for during work zone activities. The manual traffic counts are shown in Table below.

Table 1. Traffic Counts for The Study Area Before and During Work Zone

Peak Hour	AM Peak 1	PM Peak 2	PM Peak 3
Time	6:30 – 7:30	2:00 – 3:00	4:30 – 5:30
Before	3141	3238	2927
During	3061	3295	3057

For average flow speed during work zone, it was obtained from the field as 75.5 km/h for peak 1, 70.8 km/h for peak 2, and 59.6 km/h for peak 3.

3.3 Obtaining Capacity and LOS

Traffic counts were used to calculate capacity and LOS along the roadway before and during work zone. The equations were obtained from Highway Capacity Manual 6th edition – HCM2016 [4] to calculate the capacity.

Eq. (1) is designed for capacity during work zone activities, but due to the lack of general capacity equation in HCM2016, it was used for before and during the presence of work zone to get more reasonable and convergent results.

$$\mathrm{cWZ\ (pc/h/ln)} = \frac{\mathrm{QDRwz}}{100 - \mathrm{aWZ}} \times 100 \quad (1)$$

Where:

QDRwz = Work zone average 15 minutes queue discharge rate

cWZ = Work zone capacity

aWZ = Percentage drop in pre-breakdown.

While eq. (2) was used to calculate the flow rate (Vp) in pc/h/ln, which was then divided by the average passenger car speed to get the density. The density was then related to LOS using Table below.

$$\mathrm{Vp\ (pc/h/ln)} = \frac{\mathrm{V}}{\mathrm{PHF} \times \mathrm{N} \times \mathrm{fHV} \times \mathrm{fP}} \quad (2)$$

Where:

V = Vehicles volume during the peak hour

PHF = Peak Hour Factor

N = number of lanes

fHV = Heavy vehicle adjustment

fP = Driver population adjustment

Table 2. LOS Based on Density [40]

LOS	Density Range (pc/km/ln)
A	0 – 7
B	> 7 ≤ 11
C	> 11 ≤ 16
D	> 16 ≤ 22
E	> 22 ≤ 28
F	> 28

3.4 Influence of the Mobile Application on Capacity and LOS during Work Zone Activities

In order to estimate the influence of the proposed mobile application, a survey was done, for which the responses were collected from 1025 vehicle users in Bahrain and was dated to 12th March 2019. The survey was done using google forms and aimed toward understanding and analyzing the impact of knowledge of work zone's location on traveler's decisions of routes and the chance of re-routing, as well as their willingness to use mobile application for alternative travel routes. The questionnaire had 9 questions and included questions related to gender, age, and nationality to ensure variety in the population covered. The results obtained from the survey along with other estimations were then used to investigate the potential acceptance of the proposed app and determine the improvement in capacity and LOS during work zone activities.

4. Results

4.1 Capacity of Roadway

Capacity of the roadway is the maximum traffic flow that it can withstand with its available lanes. Road capacity before and during work zone was calculated using equation 1. The capacity before work zone (availability of 3 lanes and acceleration lane) was 2472 pc/h/ln. On the other hand, work zone capacity (availability of 3 lanes and closure of acceleration lane) dropped to 2396 pc/h/ln.

4.2 Level of Service

4.2.1 LOS before work zone

According to MOW concept report [39], the study area operated with none too low congestion and had overall LOS A before construction work.

4.2.2 LOS during work zone

Level of service (LOS) was obtained based on density using Table . The flow rate is calculated using equation (2) while the average free-flow speed was obtained from the field.

- *Peak 1 (6:30 to 7:30 am)*

To calculate flow rate (Vp), peak hour factor was taken 0.98 as per MOW standards, heavy vehicle adjustment and driver population adjustment are obtained from the field as 0.937 and 1 respectively. Substituting in equation 2, and for flow of AM peak 1 (see Table 1), Vp was calculated as 1111 pc/h/ln. The average free-flow speed was 75.5 km/h, which gave the density of 15 pc/km/ln. Therefore, and by referring to Table , LOS is C.

- *Peak 2 (2:00 to 3:00 am)*

Applying the same process and adjustment factors, as AM peak 1, and substituting the values in equation 2, Vp was calculated as 1205 pc/h/ln. The average free-flow speed was 70.8 km/h, which gave the density of 17 pc/km/ln. Therefore, and by referring to Table 2, LOS is D.

- *Peak 3 (4:30 to 5:30 am)*

Similarly, Vp for the PM peak 3 was calculated as 1136 pc/h/ln. The average free-flow speed was 59.6 km/h, which gave the density of 19 pc/km/ln. Therefore, and by referring to Table , LOS is D.

4.3 Survey Results

The survey (see Fig. 2) showed that 97% of the sample uses google maps. However, only 10% of the whole sample keep up with information from official accounts regarding road constructions and traffic jams. The survey also questioned their likely response in case of having prior knowledge about work zones and 96% chose to reroute. Finally, 96% of the sample will rather use a longer route with a low traffic flow, than use a short one with heavy traffic flow with the work zone. Figure 2 illustrates the survey results.

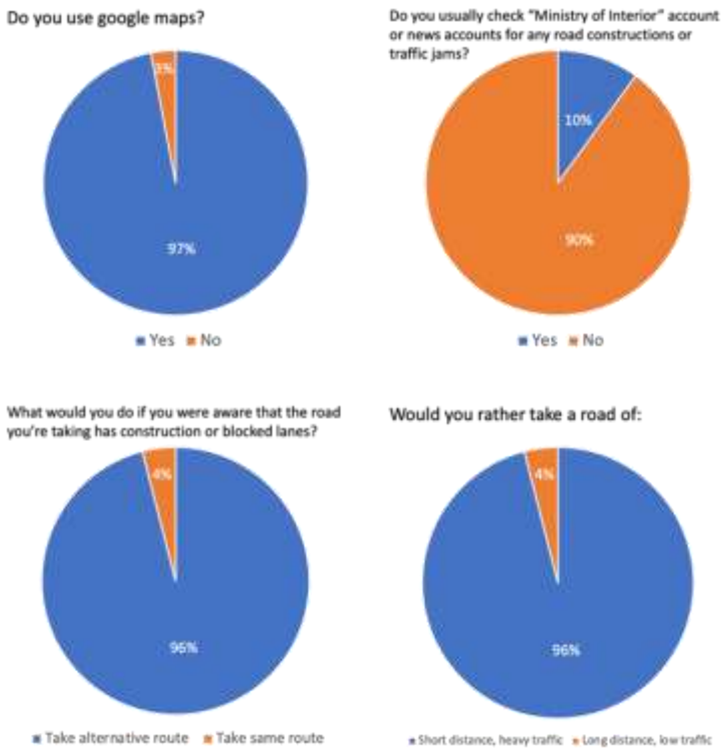

Fig. 2. Survey Results

5. Discussion

5.1 Roadway Capacity

The numbers show a slight drop in the roadway, as it dropped 2472 pc/h/ln to 2396 pc/h/ln. This indicates that work zones presence influences the traffic flow and roadway capacity even if the closure was only associated with the acceleration lane, which is in confirmation to the observations in the previous studies.

5.2 Level of Service

The roadway was facing none to low congestion before the construction. However, due to work zone presence, LOS dropped from A to D. This also gives another indication of how work zones could affect the quality of service on roadways.

5.3 Improving Capacity and LOS on Roadways going constructions by a mobile application

This study suggests the implementation of a mobile application in which authorities will have the ability to update information about different work zones activities around Bahrain. The application is proposed to help the users with their routing decisions in case of availability of work zones. It will alert them when their route has a work zone and give them the choice of using the same route or rerouting with time estimated for each route and the traffic condition to be expected being presented. Having 97% of the survey sample using google maps, gives a positive idea about the possibility of using the proposed application.

Survey results were used to test the effect of implementing a mobile application on capacity and LOS of roadway during road construction. The free-flow speed was assumed to be 80 km/h in accordance with the posted speed, number of lanes was assumed as with work zone availability to be 3, and finally, density was taken as the maximum density available for LOS A which is 7 pc/km/ln. As a result, the maximum number of vehicles per lane was 560 pc/h/ln. Equation 2 was rearranged and used to calculate the maximum volume of vehicles that the road could handle and still have LOS A.

- *Peak 1 (6:30 to 7:30 am)*

The maximum volume for LOS A was calculated using rearranged equation 2 as 1539 veh/hr. Which is 50% of the work zone volume shown in table 1 (i.e. 3061 veh/hr). Therefore, 50% of vehicles need to be rerouted in order to improve LOS from D to A.

- *Peak 2 (2:00 to 3:00 pm)*

The maximum volume for LOS A was calculated to be 1524 veh/hr, which represents 46% of the work zone volume (i.e. 3295 veh/hr). Therefore, 54% of vehicles need to be rerouted in order to improve LOS from D to A.

- *Peak 3 (4:30 to 5:30 pm)*

The maximum volume for LOS A was calculated to be 1503 veh/hr, which is 49% of the work zone volume (i.e. 3057 veh/hr). Therefore, 51% of vehicles need to be rerouted in order to improve LOS from D to A.

Traffic volume modifications indicate that if 50% to 54% of travelers agreed to reroute, LOS will improve back to A. Although survey results stated above are based on sample of Bahrain population opinions and hypothetical scenario, these results showed that 96% of the sample are willing to reroute in case of prior knowledge of work zones and provision of the mobile application suggesting alternative routes. This indicates that LOS could be improved by using a mobile application that offers knowledge about work zones and gives rerouting options.

6. Conclusion

This study reinforces that the availability of work zones on the roadway results in drop in both capacity and LOS. The segment at which the study was conducted shows a slight drop in capacity from 2472 pc/h/ln to 2396 pc/h/ln due to closure of an acceleration lane, and a noticeable drop in LOS from A to D. This drop gives a good indication of a rise in traffic congestion. As a solution, the study proposed a mobile application to improve LOS along the roadway during the presence of work zones. A survey was conducted to measure willingness of people to change their routes based on previous knowledge of work zones occurring on their routes, and 96% of the sample were willing to do so. Calculations were made to test the suggestions, and it showed that rerouting could improve LOS and the percentage of vehicles that need to reroute ranged between 50% to 54% which is way below 96% and this provides a significant margin of error. To conclude, LOS of a roadway during roadway construction could be improved by using an application that keeps people informed about different work zones' locations and gives them rerouting options.

It is recommended for future studies to test different platforms for the development and implementation of the proposed app. The managerial hierarchy, best suited to a digitalized traffic information system, can also be explored.

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