Improving Traffic Safety Towards Sustainable Built Environment in Dammam City, Saudi Arabia

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Abstract. Traffic safety is vital to the socioeconomic wellbeing and sustainable development of any society. This study assesses factors undermining traffic safety in Dammam city of Saudi Arabia. The study utilized expert-based questionnaire survey, and employed Analytic Hierarchy Process (AHP) in developing an experts’-based traffic safety model. Six factors believed to be triggering road traffic accident were analyzed, and weights (W) were assigned to each factor using Saaty’s 9-point scale of reference. The weights were further normalized through the AHP. The study found traffic lights violations (W=0.37), over speeding (W=0.18), and wrong turns (W=0.17) to be the most critical factors responsible for road traffic accident in the study area. Speed cameras, speed bumps, and speed limits signage were evaluated by experts as means of minimizing road traffic accidents. Speed cameras (W=0.54) and speed bumps (W=0.30) are perceived to enhance road traffic safety over speed limits signage. The study stresses that benefits attached to speed cameras and speed bumps are yet to be fully implemented within the city and outskirts. The study concludes by highlighting how the model can minimize road traffic accidents in the city.

1. Introduction
Improving traffic safety is increasingly important, yet challenging for governments, urban planners and traffic engineers, especially in rapidly urbanizing cities. Traffic safety is here described as a system that prevents road users from being killed or injured and it is a vital component of sustainable transportation system [1]. An improved transportation system is that which succeeded in minimizing traffic accidents, traffic congestion, pollution, and improving public transport infrastructure [1]. However, in low and middle-income countries traffic accidents claim about 1.25 million lives per annum and have a tremendous effect on health and development [1]. In these countries where urbanization has been accompanied by soared motorization (with roughly 54% of the world’s vehicles) and road traffic accidents, youngsters between 15 and 29 of age were killed, and cost governments roughly 3% of GDP [1]. Youngsters are more vulnerable to road traffic accidents due to: inexperience, risk-taking, over speeding, distractions, and drugs and alcohols among others [1]. Similarly, rapid transformations of cities and living standards of people is partly responsible for the dramatic increase in road traffic accidents which accounts for 90% of the world’s mortality rates occurring [1]. Due to human, technological, and environmental factors, road traffic accident has become epidemic worldwide, causing tremendous increase in death and casualties.
In Saudi Arabia, road traffic accident is a serious socioeconomic and public safety challenge. Since the oil boom of the 1980s, there is massive increase in urban growth and associated transportation networks, land uses and infrastructural facilities. High living standard in Saudi Arabia has led to an
increase in car ownership rate to 219 cars for every 1000 people [2]. Thus, this has contributed to road traffic accidents which is the second major health and economic challenges that annually cost Saudi government about 21 billion Saudi riyals [3]. According to Saudi Traffic Authority’s statistics, on average over 4100 people died with 28,000 being injured yearly from road traffic accidents in the country [4]. A study conducted in 2008/2009 revealed that road traffic accidents have killed 6,485 people and injured more than 36,000 in just more than 485,000 traffic accidents in Saudi Arabia [5]. Therefore, road traffic accident will continue to be one of the contending challenges causing many injuries and deaths. The impact of road traffic accident on societies and the built environments has been widely acknowledged. Despite its importance, traffic safety was not included in the Millennium Development Goals (MDGs). However, upon recognizing its importance in improving the wellbeing of the citizens and promoting sustainable built environment, traffic safety is recently included in the Sustainable Development Goals (SDGs) under Goal 3 [1]. The target is to reduce road traffic fatalities by 50% by 2020. However, achieving this noble Goal is impossible without a much clear focus on assessing the factors influencing road traffic accidents. Identifying and understanding these factors offers targeted mediations towards realizing the Goal.

Many studies on road traffic accidents have been carried out in some developed and developing countries. These include nationwide studies in Thailand [6], England [7], Singapore [8], Iran [9], and Saudi Arabia among others [3], [10], [11]. A review of the literature shows a relationship between road traffic accidents and seatbelt utilization [11], gender, age [9], [12], education attainment, status [9], age [8], season [13], tire failure, high speed [3], [13], sleeping, loss of control, pedestrian [10], wrong turns, wrong overtaking, traffic lights violations [3], [6], wrong parking, alcohol [3], weather condition [7], road geometries, traffic signs, traffic signals, and rainwater drainage [6]. However, the few national and sub-national studies conducted in Saudi Arabia assesses different road traffic causative factors [10]-[13], without exploring the major and common road traffic causative factors as studied by Ansari et al. [3]. However, Ansari et al. [3] conducted their studies at a national level. Thus, there is a need to study these road traffic accidents causative factors at a local level as each geographical region within the country has its own socioeconomic and demographic background peculiar to it. Similarly, it could help in identifying and understanding areas within a city or region that needs urgent government interventions and assistance in terms of traffic safety enhancement. Therefore, this study considered to build upon the previous studies by employing AHP to evaluate the road traffic accident causative factors using the Saaty’s 9-point scale of preference.

The use of AHP in addressing transport related issues has been conducted by various authors. It has emerged as a multipurpose decision support tool and evaluation technique with extensive application areas. Its applications in transportation planning are quite effective and diverse including projects for the enhancement of the transportation system [14]. Likewise, it was used in road accidents studies (see [6]). Another modern application of AHP is its integration with a GIS in freight terminal location and in transit-oriented development (TOD) [15], [16]. It helps planners in structuring a multifaceted decision making process. Podvezko & Sivilevičius [17] employed AHP in investigating the relationship between transport system factors and traffic accident rate as well as the effect of these factors on road traffic accident generation. The authors found the relationship between vehicles and motorists to be the key component in ensuring road traffic accidents are minimized.

2. Study Area
This study is carried out for an area comprising three major conurbations in the Eastern Province of the Kingdom of Saudi Arabia: Dammam, Khobar, Dhahran and the evolving areas of Aziziyah and the Half Moon located in the south of Khobar. Bigger Dammam encompasses Dammam Metropolitan Area (DMA) and the adjoining cities of Qatif, Safwa and Ras-Tanura. The total area of Dammam is approximately 380,000 ha, accommodating roughly 1.8 million people with substantial proportion of expatriates that increases the number of vehicles in the area [18]. The Kingdom’s economy largely relies on the exploration, extraction and processing of oil and the exportation of petroleum products. The Kingdom’s Eastern Province is mainly the heart of Saudi Arabian oil production. Thus, the economy as well as the physical development of Dammam is largely reliant on the petroleum industry. Figure 1 shows the components of Dammam and its external connections. Therefore, the scope of the study involved Municipal of DMA, Khobar, and Dhahran.
There is incessant increase in the number of cars in the study area. The average car ownership per household in DMA alone is very high, which is 6.1, compared to other metropolitan areas across the world [20]. It is high because in Dammam cars are affordable, available and inexpensive. As shown in Table 1, approximately only 5% of Saudi families do not have private cars, while about 95% of them have at least one car. Compared with non-Saudi families, only 29% do not have private cars, while 71% have at least a car per family. These facts revealed that most residents depend on private mode of transportation for their daily commuting.

**Table 1. Car Ownership in Dammam City (Compiled from [20])**

|                    | Saudi families (%) | Non-Saudi families (%) |
|--------------------|-------------------|------------------------|
| No car             | 4.97              | 28.72                  |
| One car            | 48.21             | 58.86                  |
| Two cars           | 25.28             | 7.78                   |
| Three cars and more| 21.54             | 4.63                   |
| Total              | 100               | 100                    |

3. Study Methodology
Analytic Hierarchy Process (AHP)

This study used AHP mathematical model in ranking the importance of road traffic accidents influencing factors in DMA. The AHP technique supports Multi-criteria Decision Analysis (MCDA) through calculation of ratio scales based on pairwise comparison of the factors under examination. The study’s inputs and outputs are based on the subjective judgments derived from 7 experts through the AHP questionnaire survey. These experts were selected according to their expertise in transportation planning and relevant fields. Priority weights were calculated and further validated by calculating the Consistency Ratio (CR). The rule of thumb in the CR is that, a CR greater than 0.1 is implies unacceptable level of the priority weights calculated, and therefore the pairwise comparisons of the factors should be revised until an acceptable level of the CR is reached. Similarly, a CR less than or equals to 0.1 implies an acceptable level of the calculated priority weights.

AHP Questionnaire

AHP-based questionnaire was designed and distributed among 7 experts. Considering more than one expert is meant to avoid bias in calculating the experts’ priorities [21], otherwise a judgment from a single expert is enough [22]. The design of the questionnaire was carried out in a way that each individual question was clearly worded to avoid vagueness and checked for expression, objectivity and applicability to the goal being investigated. The respondents were requested based on their expertise to kindly tick the degree of preference of each criterion/factor with respect to road traffic accident generation on a 1 to 9 Saaty’s scale of preference as shown in Table 2. These criteria/factors were derived from literature survey.

Table 2. Interpretation of the Saaty’s scale of measurement (Compiled from [21]).

| Degree of importance | Definition          | Interpretation                                                        |
|----------------------|---------------------|-----------------------------------------------------------------------|
| Scale 1              | Equal importance    | Two element making equal contribution to the goal                     |
| 3                    | Somewhat more important | Moderate importance of element over the other element                 |
| 5                    | Much more important | Essential or strong importance                                        |
| 7                    | Very much important | Very strong importance                                                |
| 9                    | Extremely important | Extreme importance                                                    |
| Scale 2,4,6, and 8   | Intermediate values | These are required when comparison between two adjacent judgment is needed |
| Reciprocals           | If \( v \) is the judgment value when \( i \) is compared to \( j \), then \( 1/v \) is the judgment value when \( j \) is compared to \( i \). |

Figure 2 presents the schematic diagram of the experts-based road traffic safety model for sustainable Dammam city. The concept was developed by Thomas L. Saaty in 1980 using the MCDA principles, which help in decomposing complex and difficulty in decision making into units and subunits. First of all, the problem is structured into a hierarchical structure (Figure 2): goal, criteria, sub-criteria, and alternatives. The second phase comprises pair-wise comparisons of the road traffic accident causative factors and the alternatives on a 9-point scale of preference in a matrix structure. In each group of comparisons, there are \( n (n - 1)/2 \) judgments [21], where \( n \) represents the matrix’s size. Through the comparison, most important factors and alternatives are determined. Comparison is carried out in such a way that 2 criteria are compared at a time within the hierarchy or sub-hierarchy levels. The third phase comprises the use of the weights of the matrix to determine the strength of the AHP methodology, which is the calculation of the consistency ratio (CR).
The experts’ priorities were aggregated and calculated using a Geometric Mean method as shown below:

$$\text{Geometric Means} = ((X_1) (X_2) (X_3)\ldots (X_N))^{1/N},$$

where,

- $X =$ Individual score; and
- $N =$ Sample size (Number of scores). Experts’ preferences helped in performing the pairwise comparison matrix.

**Pairwise Comparisons**

The design of the questionnaire used in this study was based on pairwise comparisons of the road traffic accidents criteria used herein. Pairwise comparison assists in examining the way in which the respondents assigned their priorities to each factor with reciprocal matrices. The experts were requested to give judgment while carrying out each pairwise comparison based on the scales explained in Table 2. However, the pairwise comparisons of all the criteria under consideration are considered as the inputs whereas the priority weights calculated are the outputs; which were validated using a CR. The weights were further normalized and the normalized values of the eigenvector were used as the final outputs. The weights of the factors were generated based on the steps described by [22]. Table 3 presents the average random index values representing the number of the comparison elements.

**Table 3. Average random consistency index values (Compiled from [23])**

| Size of matrix | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|----------------|---|---|---|---|---|---|---|---|---|----|
| Random Consistency | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

The Consistency Index (CI) was calculated using the following equation:

$$\text{CI} = \frac{\lambda - n}{n - 1};$$

where, $n =$ number of criteria (i.e. 6); $\lambda =$ average value of the consistency vector.

Moreover, the following equation was used in calculating the CR:
\[ CR = \frac{RI}{CI} \]

Where, \( RI \) = random inconsistency index whose value rest on the number (n) of criterions being compared; for \( n = 6, RI = 1.24 \) ([22]).

4. Results and Discussion

This part presents the study findings in line with the objectives of the study. It analyzes the road traffic accident causative factors in DMA. Each factor was evaluated with respect to its influence in triggering road traffic accident using pairwise comparison matrix. Numbers from 1 to 9 were assigned to each factor/criterion as mentioned earlier herein by the experts to reflect their relative importance. The findings of the study are as in Table 4.

**Table 4. Impact of the alternatives in reducing road traffic accidents**

|                      | STEP 1 |       |       | STEP 2 |       |       | Priority |
|----------------------|--------|-------|-------|--------|-------|-------|----------|
|                      | SC     | SB    | SL    | SC     | SB    | SL    |          |
| SC                   |        |       |       |        |       |       |          |
| Speed cameras        | 1.00   | 2.00  | 3.00  | 0.55   | 0.57  | 0.50  | 0.54     |
| SB                   | 0.50   | 1.00  | 2.00  | 0.27   | 0.29  | 0.33  | 0.30     |
| SL                   | 0.33   | 0.50  | 1.00  | 0.18   | 0.14  | 0.17  | 0.16     |
| Sum                  | 1.83   | 3.50  | 6.00  | 1.00   | 1.00  | 1.00  | 1.00     |

Consistency ratio is 0.01

The influence of speed cameras in reducing road traffic accidents is perceived higher than speed bumps. So, 2 is entered in the first row cell of the second column, and its reciprocal is entered in the transpose position. Therefore, the weighted impact is rated highest as illustrated in the priority column. The same was applied to the rest of the comparisons. Similarly, the pairwise comparisons of the sub-criteria are presented in Table 5.

**Table 5. Judgments matrix on the influences of road traffic accident causative factors for sustainable road transportation system in Dammam city, Saudi Arabia**

|                      | STEP I  |       |       | STEP II |       |       | Priority |
|----------------------|---------|-------|-------|---------|-------|-------|----------|
|                      | C1      | C2    | C3    | C4      | C5    | C6    |          |
|                      |         |       |       |         |       |       |          |
| C1                   | 1.00    | 5.50  | 0.83  | 0.14    | 6.00  | 4.00  | 0.09     |
| Wrong turns          |         |       |       |         |       |       | 0.30     |
| C2                   | 0.39    | 1.00  | 0.24  | 0.36    | 4.50  | 2.83  | 0.04     |
| Wrong overtaking     |         |       |       |         |       |       | 0.27     |
| C3                   | 1.50    | 5.00  | 1.00  | 0.40    | 5.00  | 2.33  | 0.13     |
| Over speeding        |         |       |       |         |       |       | 0.30     |
| C4                   | 7.50    | 5.50  | 4.00  | 1.00    | 5.50  | 6.00  | 0.64     |
| Traffic lights violations |     |       |       |         |       |       | 0.02     |
| C5                   | 0.35    | 0.41  | 0.37  | 0.20    | 1.00  | 1.17  | 0.03     |
| Wrong parking        |         |       |       |         |       |       | 0.05     |
| C6                   | 0.40    | 0.97  | 1.13  | 0.19    | 1.83  | 1.00  | 0.04     |
| Distraction          |         |       |       |         |       |       | 0.05     |
| Sum                  | 11.14   | 18.38 | 7.57  | 2.29    | 23.83 | 17.33 | 1.00     |
|                      |         |       |       |         |       |       | 1.00     |

Consistency ratio is 0.10

Where, C1 = wrong turns, C2 = wrong overtaking, C3 = over speeding, C4 = traffic lights violations,
The priorities assigned by the experts using pairwise comparisons of the sub-criteria along with the sub-criteria weightings (Table 5) were used in calculating the CR. Thus as CR = 0.10, it expresses that, there is an accurate amount of consistency in the pairwise comparisons and therefore, the weights 0.17, 0.14, 0.18, 0.37, 0.05, and 0.08 can further be assigned to wrong turns, wrong overtaking, over speeding, traffic lights violations, wrong parking, and distractions respectively. The findings of the present study are in line with those reported in similar studies. In Riyadh city for example, a study reported that 52.5% of fatal collisions and roughly 45.9% of injury collisions are caused by traffic lights violations and over speeding [10]. Similarly, Ansari, et al. [3] revealed that more than 50 percent of road accidents in Saudi Arabia are because of over speeding (which is about 3.5 more times than in the US), sudden brakes/stops, and distractions: speaking on phones, text messaging, et cetera while driving. Twenty years ago, Saudi Arabia has documented 4 million road traffic accidents that led to 86,000 deaths and 611,000 casualties, 7 percent of which led to permanent disabilities [24]. A lot of advancement with regards to technology services, infrastructure, trade and industry to transform Dammam to an international standing city is witnessed. However, the magnitudes of road traffic accident predicaments as well as the extent of human and economic damages caused are gloomy. It is therefore necessary for the decision makers to understand the basic road traffic accidents causative factors within and in the outskirts of the city to enable them take sustainable strategies in curtailing the frequencies and fatalities of road traffic accidents in the study area

5. Conclusion
This paper highlights the impacts of road traffic accident causative factors in Dammam city. Although many factors are responsible to the overall severity of road traffic accidents, this study concentrated mainly on the human causative factors: wrong turning, wrong overtaking, over speeding, traffic lights violations, wrong parking, and distractions as the major factors contributing to road traffic accidents in Dammam city. Significant findings include that traffic lights violations (37%), over speeding (18%), and wrong turns (17%) are the most critical factors responsible for road traffic accidents in the area, according to experts. The experts also rated speed cameras (54%) and speed bumps (30%) as sustainable strategies for enhancing road traffic safety, while the use of speed limits signage is less preferred. Key lessons from these findings include the need to install more speed cameras and speed bumps at major and minor junctions, roundabouts, and pedestrian crossing among others within and in the outskirts of the city including rural areas. This will help in promoting healthy lives and well-being of all residents and to reduce road traffic fatalities by 50% by 2020. Therefore, there is an urgent need for government interventions to implement traffic safety strategies in the city, more especially speed cameras and bumps. Though there is a dilemma of balancing contending challenges with regards to urban transportation initiative [25]. This is because the citizens are used to traveling in their private cars and therefore may not instantly accept public transportation that might assist in minimizing road traffic accidents, energy consumption and pollution.

6. References
[1] World Health Organization 2015. Global status report on road safety 2015. World Health Organization.
[2] Gately, D., Al-Yousef, N., & Al-Sheikh, H. M. H. 2013. The rapid growth of OPEC’s domestic oil consumption. Energy Policy, 62, 844–859. doi:10.1016/j.enpol.2013.07.044
[3] Ansari, S., Akhdar, F., Mandoorah, M., & Moutaery, K. 2000. Causes and effects of road traffic accidents in Saudi Arabia. Public health, 114(1), 37-39.
[4] General Directorate of Traffic, (2003). Annual Traffic Report. Ministry of Interior, Riyadh.
[5] Green Prophet, 2010. Saudi Arabia Has the Highest Road Accident Death Toll in the World. <http://www.greenprophet.com/2010/03/saudi-arabia-death-toll-driving/> Accessed 02.11.2017
[6] Temrungsie, W., Raksuntron, W., Namee, N., Chayanan, S., & Witchayangkoon, B. 2015. AHP-based prioritization on road accidents factors: A case study of Thailand. International Transaction Journal of Engineering, Management, Applied Sciences & Technologies, 6, 135-144
[7] Edwards, J. B. 1999. The relationship between road accident severity and recorded weather. *Journal of Safety Research, 29*(4), 249-262.

[8] Wong, E., Leong, M. K., Anantharaman, V., Raman, L., Wee, K. P., & Chao, T. C. 2002. Road traffic accident mortality in Singapore. *The Journal of emergency medicine, 22*(2), 139-146.

[9] Montazeri, A. 2004. Road-traffic-related mortality in Iran: a descriptive study. *Public health, 118*(2), 110-113.

[10] Al-Ghamdi, A. S. 2003. Analysis of traffic accidents at urban intersections in Riyadh. *Accident Analysis & Prevention, 35*(5), 717-724.

[11] Shanks, N. J., Ansari, M., & Al-Kalai, D. 1994. Road traffic accidents in Saudi Arabia. *Public health, 108*(1), 27-34.

[12] Bendak, S. 2005. Seat belt utilization in Saudi Arabia and its impact on road accident injuries. *Accident Analysis & Prevention, 37*(2), 367-371.

[13] Al-Zahrani, A. H., Jamjoom, M. M. O., & Al-Bar, H. O. 1994. Traffic Accident Characteristics in Jeddah, Saudi Arabia. *Engineering Sciences, 6*(1).

[14] Banai, R. 2000. Public Transportation Decision-Making: A Case Analysis of the Memphis Light Rail Corridor and Route Selection with Analytic Hierarchy Process. *Journal of Public Transportation, Vol. 9, No. 2, 2006*.

[15] Banai, R. 2000. Transit station area land use/site assessment with multiple criteria: An integrated GIS-expert system prototype. *Journal of Public Transportation 3*(1): 95–110.

[16] Dantas, Sergio, and Yaeko. 2001. Integrating GIS and AHP for bus route definition. *Proceedings Symposium on ASIA GIS, Tokyo, Japan*

[17] Podvezko, V.; Sivilevičius, H. 2013. The use of AHP and rank correlation methods for determining the significance of the interaction between the elements of a transport system having a strong influence on traffic safety. *Transport 28*(4): 389–403.

[18] Abou-Korin, A.A. and Al-Shihri, F.S., 2015. Rapid Urbanization and Sustainability in Saudi Arabia: The Case of Dammam Metropolitan Area. *Journal of Sustainable Development, 8*(9), p.52.

[19] General Administration of Urban Planning 2017. Construction and Project Agency, Amana, Eastern Province, Saudi Arabia.

[20] Al-Sheriff, M. 2010. The problem of public transport within the cities of Saudi Arabia. *Alegt Journal, No. 5999, online, retrieved 15 March 2010, from http://www.aleqt.com/2010/03/15/article_363931.html. Accessed 03.03.2017.

[21] Ishizaka, A. and Labib, A. 2011. Review of the Main Developments in the Analytic Hierarchy Process. *Expert Systems with Applications, 38*(11), 14336-14345.

[22] Saaty, T. L. and Sagir, M. 2009. Extending the Measurement of Tangibles to Intangibles. *International Journal of Information Technology and Decision Making, 8*(01), 7-27.

[23] Lawal, D. U., Matori, A. N., Yusof, K. W., Hashim, A. M., Aminu, M., Balogun, A. L., & Molokht, M. R. M. 2014. Group-based Decision Support for Flood Hazard Forecasting: A Geospatial Technology-based Group Analytic Hierarchy Process Approach. *Research Journal of Applied Sciences, Engineering and Technology, 7*(23), 4838-4850.

[24] Arab News, 2013. Road accidents cost KSA SR 87 billion annually. http://www.arabnews.com/saudi-arabia/road-accidents-cost-ksa-sr-87-bn-annually Accessed 03.11.2017.

[25] Abubakar, I. R. & Aina, Y. A. 2016. Achieving sustainable cities in Saudi Arabia: Juggling the competing urbanization challenges. In *Population Growth and Rapid Urbanization in the Developing World. Hershey, PA: IGI Global*. 