Open Access Library Journal
2022, Volume 9, e8465
ISSN Online: 2333-9721
ISSN Print: 2333-9705

A Smart Approach for Vehicle Speed Monitoring and Accidents Trend at Black Spot Areas in Tanzania

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How to cite this paper: Runyoro, A.-A.K., Ndume, V.A., Mganilwa, Z. and Kambira, I. (2022) A Smart Approach for Vehicle Speed Monitoring and Accidents Trend at Black Spot Areas in Tanzania. *Open Access Library Journal*, **9**: e8465.
https://doi.org/10.4236/oalib.1108465

Received: February 9, 2022
Accepted: March 25, 2022
Published: March 28, 2022

Abstract

Vehicle speeding is one of the risk factors in road safety and contributes to accidents which lead to deaths and injuries resulting in not only loss of lives but also affecting the economy. This study reports the research conducted with the purpose of monitoring and analyzing the drivers speeding behavior at the black spots. The data were collected using smart cameras installed at Ubena-Zomozi along Highway of T001 in the Coast and Morogoro regions. The collected vehicle data were analyzed using intelligent cameras, ANPR and OCR. The results of monitoring indicated that about 89.17% of car had recommended speed and obeyed the rule; 10.34% had an average tolerable speed while 0.48% were highly over speeding in someplace. It was concluded that many other black spots need to be smartly controlled using installed intelligent camera rather than using gun camera held by police.

Subject Areas

Civil Engineering, Computer Engineering

Keywords

Vehicle Speeding, Road Safety, Driving Behavior, Smart Camera

1. Introduction

Most countries around the globe are working hard to mitigate and if possible to highly reduce the chance for road accidents. Vehicle speeding has been recorded among the causal factors associated with serious road accidents especially in areas

which are earmarked with the purpose of reducing the road accidents due to speed [1]. According to [2], there are only a few bilateral donors, most notably USAID, US and SIDA, Sweden, that have provided funding for road safety activities.

Example Sweden in the year 1997 introduced Vision Zero (VZ) strategy nationwide; it visualized zero deaths as the ultimate road safety goal [3]. The VZ starts with the ethical belief that everyone has the right to move safely in their communities, and that system designers and policymakers share the responsibility to ensure safe systems for travel. Although the VZ policy might be understood as a way to implement specific transport and urban planning measures (e.g., zones with low-speed limits, speed humps, roundabouts, barrier separation of roads), it has also caught the attention of the automotive industry, where companies are trying to increase safety for people both inside and outside of cars through the adoption of technological innovations e.g., detection of driver fatigue or sensors monitoring the situation outside cars [4].

[5] reported that the majority of road traffic accidents that happened in Africa were related to human factor; this implies that human-related factors (like speed driving, overtaking, reckless driving, fatigue, drunk driving, drug, seat belt, sleeping, cell phone usage and, etc.) were playing a significant and accredited role other than environmental and mechanical factors for the occurrences of road traffic accidents in Africa. Speed contributes to at least 30% of fatalities. Each increase in speed by 1 km/h causes a 3% increase in the risk of an accident, the participants of which will sustain bodily injuries, and 5% increase in the risk of a fatal accident. Furthermore, higher travel speeds make the task of driving more difficult, because drivers must perceive, interpret, and respond to relevant stimuli at a faster rate [5].

The reports from [6] claim that Speed management leads to reductions in the number and severity of Road Traffic Injuries (RTI). According to the Global status report on road safety 2015, of the 180 participating countries 90 set maximum urban speed limits of less than or equal to 50 km/h, in line with best practice; only 47 countries, representing 13% of the world's population, meet both legislative criteria for best practice on urban speed management a national maximum urban speed limit of 50 km/h, and local authority power to reduce this limit further to ensure safe speeds locally. A decrease of 1 km/h in mean traffic speed will result in a 5% decrease in the incidence of fatal RTI. Therefore, enforcement of speed limits is essential to make them truly effective. Drinking and driving increase the risk of being involved in the RTI. With a blood alcohol concentration (BAC) exceeding 0.05 g/dL, the RTI risk increases dramatically. Thirty-four countries have good drink-driving laws with a BAC limit of less than or equal to 0.05 g/dL, as well as lower limits of less than or equal to 0.02 g/dL for young and novice drivers.

Other charities that embrace road safety include the International Road Assessment Programme (IRAP) considers more than 90 proven road safety countermeasure treatments to generate affordably and economically sound Safer Road

Investment Plans (SRIP) that will reduce road user risk, improve a road's Star Rating and will save people's lives (IRAP, 2017). It is argued in (Tunisia RAP, 2021) that vulnerable roads user (VRU) are not accounted for correctly in city design architecture.

The same way as it is done around the globe, where Governments are placing efforts to improve road safety; the Government of Tanzania has been taking several measures to reduce the road carnages such as introduction of speed limits, construction of bumps, and organizing road safety week campaigns [7]. Yet, every year the Tanzania National Road Safety Council (TNRSC), Land Transport Regulation Authority (LATRA), Traffic Police and other organizations have been reporting the occurrence of road traffic accident casualties [8]. In Tanzania, speed limits are set by the legislative bodies of national and enforced by police and judicial authorities. Speed limits are indicated on traffic signs reflecting the maximum permitted speed expressed as kilometers per hour (km/h).

The global magnitude of the burden of road accident is very high it is claimed in [2] that 1.25 million people are killed, and around 50 million injured, every year in road traffic crashes which makes it one of the most pressing health emergencies and development issues of our time. It is estimated that 500 children lose their lives because of road crashes every day. It is the leading cause of death among young up to 29 years old, and the eighth leading cause of death globally. The worst case is that about 90% of all road fatalities occur in developing countries. However, a number of countries have seen an unprecedented deterioration in road safety. Tanzania is among them.

Technology enabler has been seen as the solution for reducing road accident. It is noted that while advanced research on driver behavior and characteristics such as dizziness and sleeplessness is important other studies on technology focus on physical monitoring of the drivers. In Tanzania, Police officers are responsible for vehicle speed enforcement. Monitoring of vehicle average speed at the speed limit road sections has been conducted using traditional and modern techniques.

The Traditional techniques are applied on upcountry-passenger buses, whereby the bus drivers are issued with a log book which has to be shown at each check point for the police officer to monitor the bus travelling time and passenger's information. When it is found that the bus has travelled in a short time below the recommended time, it is assumed that the bus was over spending, therefore they get penalized. Also, passenger information is used in case of accident occurrence, the data is used for insurance recovery.

Modern Technology combine all vehicle speed monitoring processes which use machines and technologies. Speed gun devices are used to monitor all vehicles' speed whereby as the vehicle approaches check point the police holding radar speed gun point straight to the vehicle and find out the vehicle speed at that moment; if an offense is found, a penult is charged or driver is taken to the court [9]. According to [10] the use of speed decoders to the public cars (buses)

and long vehicles (lorries), from the installed decoder detailed speeding reports are generated and the driver behavior monitoring is performed. Other modern technology includes use of Average Speed Cameras (ASC) System installed at speed limit road sections which are referred to as black spots. We applied this smart approach at Ubenazomozi and Bwawani along the T001 highway in the Coast and Morogoro Regions respectively; the speed limit at the place is set at 50 km/h.

The main objective of this paper is to study drivers' speeding behavior at the speed limit road sections which are considered as black spots. To battle road crashes, it is important for all road users to obey the rules and regulations governing the use of high ways. Unfortunately, incessant disobedience to traffic rules and regulations on the part of road users has been noted to be one of the major causes of road traffic accident mostly in developing nations and more importantly in the black spot areas [11].

2. Related Work

In the past years, many pieces of research have been developed on driver monitoring system through computer vision concepts. It was presented in [12] that the drivers are distracted and feel drowsy while they are driving on a long route. It is difficult to alert them manually. So with the help of advanced technology, it is easy to alert the driver and detect the distracted and drowsiness driver automatically and efficiently. The same applies to the speeding behavior of the drivers at the blackspots, where drivers can be alerted when overspeeding is noticed. Also [13] presented speed limit camera monitoring/tracking system using Global Positioning System (GPS) and cloud computing with the Software-as-a-Service (SaaS) module which provides useful information about roads. Critical information like driver position is collected by the GPS built-in the device for Android or iOS systems, then this information is sent to a cloud server where it is kept over the Internet. This system provides precise location services of the driver, driving speed, road allowed speed and speed limit camera position all to provide the driver with a street guide to improve speed limit enforcement aiding in road safety and preventing more accidents. Our study is focusing on monitoring over speeding in a pre-defined location by installing smart camera.

3. Materials and Methods

The study area was set along the T001 road. Purposive sampling considered black spots located at Ubenazomozi and Bwawani since the two locations had recorded many accidents compared to other speed limit road sections along the road. The two areas Ubenazomozi and Bwawani were installed with entry and exit gates fixed with intelligent cameras used for monitoring vehicle average speed. ASC system installed with the cameras was collecting and processing the vehicle speed data. The vehicle speed data were analyzed for studying the drivers' speeding behavior at the black spots. Notwithstanding the number of acci-

dents recorded along the T001 road from the year 2019 to 2021 was collected from the traffic police records.

Drivers speeding dataset consisted of 5 columns such as entry time, exit time, speed, entry plate and exit plate. The important feature that we used for our analysis was speed. The recorded vehicles were uniquely identified using their number plates. Vehicle number plates were extracted from images taken by the cameras as shown in Figure 1; various number plates were recorded. Tanzania number plates' standards are not specific and they are rarely followed, hence there was no uniformity in vehicle number plates which caused some vehicles to be missed out in the data collection. In order to get the correct vehicle number plates, Neural Network (NN) software was trained using several Tanzanian number plate images in order to define the number plate format. Figure 1 shows the identification stage of the plate number. Vehicle image was cropped to focus on the Region of Interest (ROI). The cropped image was processed in the NN in order to define the number plate features. The Automatic Number Plate Recognition (ANPR) technology was applied to extract the number plate image, this image was converted to machine-encoded text using Optical Character Recognition (OCR) technology. License plate recognition (LPR), or Automatic Number Plate Recognition (ANPR) has been one of the useful approaches for vehicle surveillance. It can be applied at the number of public places for fulfilling some purposes like traffic safety enforcement, automatic toll tax collection, car park system and Automatic vehicle parking system [14].

3.1. Description of Tanzania Number Plates

The number plates of Tanzania are date back to 1933 in Tanganyika and to the 1950s in Zanzibar. The image for various number plates is shown in Figure 2. They are the same size as their British counterparts and used the same font until the late 1980s.

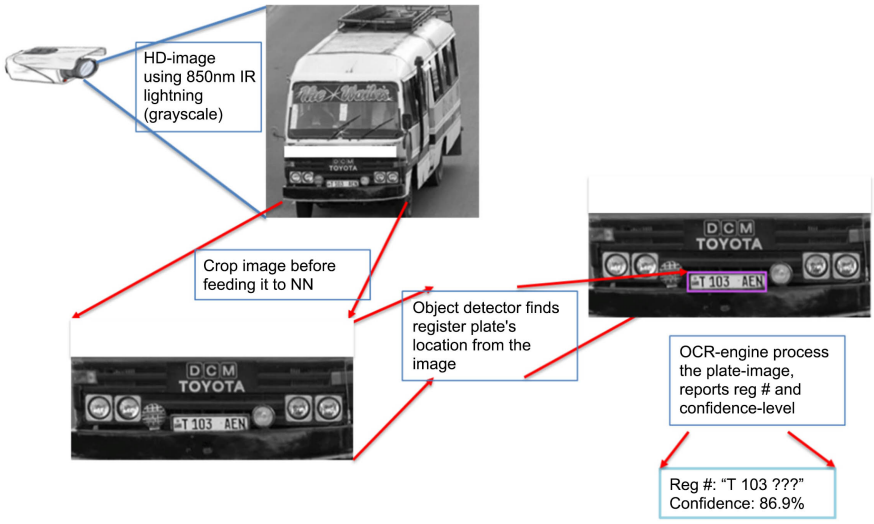


Figure 1. Object detection and identification of the number plate.

Figure 2. Various plate Numbering system in Tanzania.

The number plate detection was accomplished using object detection approach while the extraction of the alpha numerical number was done using optical character recognition. The higher-level algorithm for plate identification is presented in **Figure 3**.

3.2. Algorithm for Speed Data Processing

Vehicle images and time stamps captured at entry and exit points were saved to the ASC servers. Speed management software reads vehicle number plates extracted from the recorded images and saves data to the server. The software uses an intelligent algorithm presented in **Figure 4** to process vehicle speed. This is done by matching the entry and exit data files and calculating the average travelling speed based on the law of motion presented in formula 1. When the average speed is greater than the permitted speed (50 Km/Hr) the data gets recorded. In general, the system provides an Application Programming Interface (API) allowing integration with other application software for the speed enforcement process. The access of the system is through the web interface as presented in **Figure 5**.

The algorithm starts by detecting a moving object, whereby a camera takes an image of the vehicle and the number plate gets processed. The meterdata of the number plate is extracted and processed to obtain alphanumerical characters, the entry time is also recorded. The system at entry gate passed the information to the exit gate where a similar procedure of plate recognition is performed and data matching to compare vehicle detected at entry and exit gates is performed. When the matching data are found the vehicle speed is calculated, if the speed is above the allowed average speed the data is stored in the server, otherwise, it is ignored. Vehicle speed is calculated using equation 1 since distance between the gates is known then the variable "s" in equation 1below is obtained and the recorded entry and exit times provide data for the variables "t_1" and "t_2" hence the average speed is computed. The speed was classified as follows basic speed 0 - 60

```
    public AlprResults recognize(String imageFile)
    public AlprResults recognize(String imageFile) throws AlprException
    {
        String json = native_recognize(imageFile);
        return new AlprResults(json);
        try {
            String json = native_recognize(imageFile);
            return new AlprResults(json);
        } catch (JSONException e)
        {
         throw new AlprException("Unable to parse ALPR results");
        }
    }
    public AlprResults recognize(byte[] imageBytes)
    public AlprResults recognize(byte[] imageBytes) throws AlprException
    { String json = native_recognize(imageBytes);
        return new AlprResults(json);
        try {
            String json = native_recognize(imageBytes);
            return new AlprResults(json);
        } catch (JSONException e)
        {
            throw new AlprException("Unable to parse ALPR results");
        }
    }
```

```

Plate coordinates
import com.openalpr.jni.json.JSONException;
import com.openalpr.jni.json.JSONObject;
public class AlprCoordinate {
    private final int x;
    private final int y;
    AlprCoordinate(JSONObject coordinateObj)
    AlprCoordinate(JSONObject coordinateObj) throws JSONException
    {
        x = coordinateObj.getInt("x");
        y = coordinateObj.getInt("y");
    }
    public int getX() {
        return x;
    }
    public int getY() {
        return y;
    }
}

```

```
import com.openalpr.jni.json.JSONObject;
public class AlprPlate {
    private final String characters;
    private final float overall_confidence;
    private final boolean matches_template;
    AlprPlate(JSONObject plateObj)
    AlprPlate(JSONObject plateObj) throws JSONException
    {
        characters = plateObj.getString("plate");
        overall_confidence = (float) plateObj.getDouble("confidence");
        matches_template = plateObj.getInt("matches_template") != 0;
    }

    public String getCharacters() {
        return characters;
    }

    public float getOverallConfidence() {
        return overall_confidence;
    }

    public boolean isMatchesTemplate() {
        return matches_template;
    }
}

```

Figure 3. Car detection algorithm for computing vehicle speed.

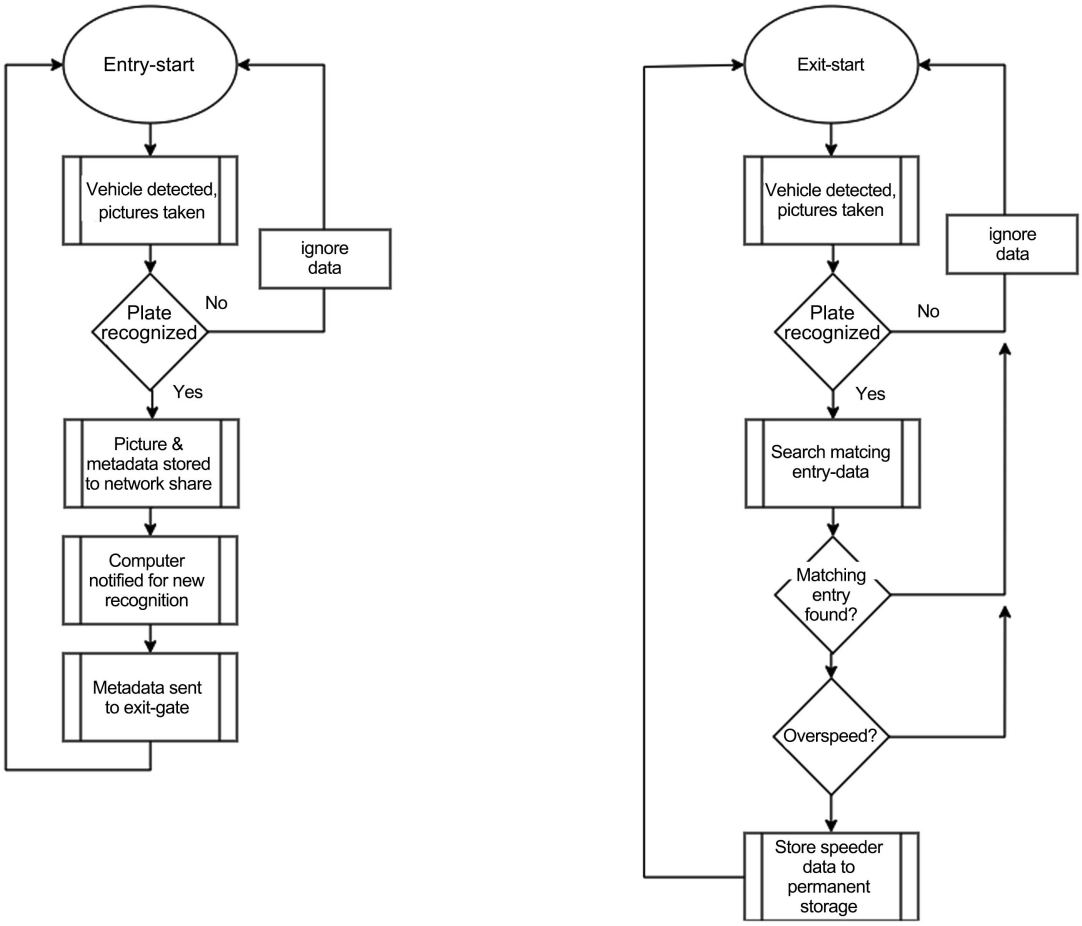


Figure 4. Flowchart for Plate number Metadata Information capturing and speed calculation.

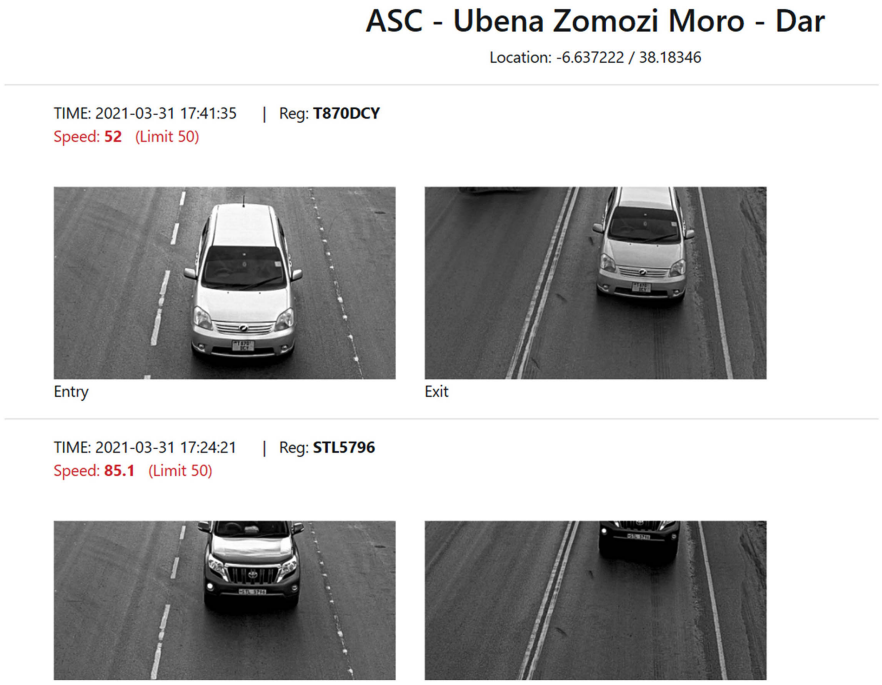


Figure 5. Web interface showing recorded vehicle image and its average speed.

km/hr, average speed 61 - 80, high speed 81 - 120, supper speed over 120. Either to relate speed with time the time zone was classified as follows from 19 hrs to 5 am was considered night, from 5 hrs to 11 am was considered Morning hrs., from 12 hrs to 15 hrs. was considered noon and from 15 to 18 was considered evening hrs.

$$V(av) = \frac{S}{t_2 - t_1} \quad (1)$$

where

v_{av}	Vehicle Average Speed
S	Total Distance
$t_2 - t_1$	Total travelled time

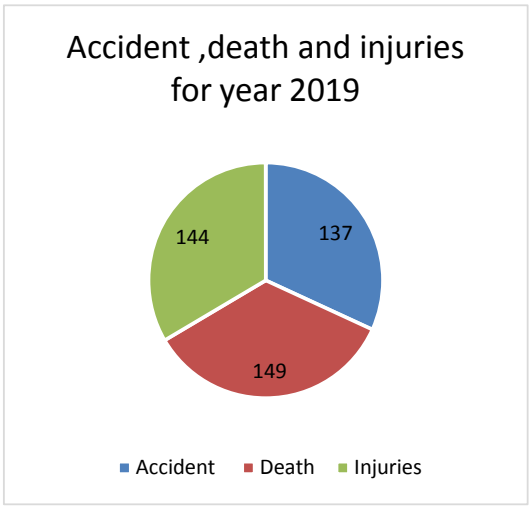
The cameras installed at entry and exit gates were able to capture the vehicle image together with its unique identification data being the number plate. For each record, the time stamp was placed in the format of 2019-11-13T12:45:27.049000+03:00. Figure 5 shows the vehicle images captured at entry and exit gates, time, vehicle registration/number plate and the average speed. An algorithm for speed data processing was therefore able to concatenate the entry and exit time strings to compute the time taken.

4. Results and Discussion

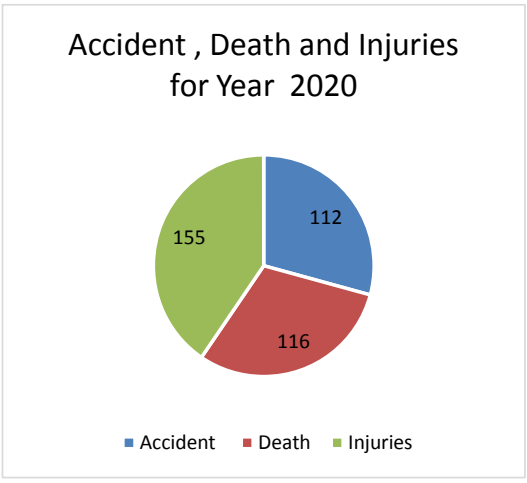
The study was conducted at highway road known as T001 and named Akiba-Uwawa. The zero point of this road is found at PPF junction in Dar Es Salaam and end point is at Uwawa in Tunduma border in Mbeya. The T001 road has a total of 922.87 Km and it has the most accident occurrence.

The events in the last three years show that a total of 351 accidents was recorded at T001. of which 137 occurred in 2019, 112 occurred in 2020 and 102 occurred in 2021. Total death was recorded at 353 of which 149 occurred in 2019, 116 occurred in 2020 and 88 occurred in 2021. Total injuries were recorded as 488 of which 144 occurred in 2019, 155 occurred in 2020 and 189 occurred in 2021. The details of the accident, injuries and death are presented in Figure 6. The current reports of accident and injuries up to September 2021 show that there were 102 accidents, 88 deaths and 189 injuries. The results show a decreasing trend of deaths due to accidents as presented in Figure 6. Whereby there were 149 deaths in the year 2019, 116 deaths in the year 2020 and 88 deaths in the year 2021. This gives a positive indicator of the efforts made in vehicle speed monitoring and enforcement.

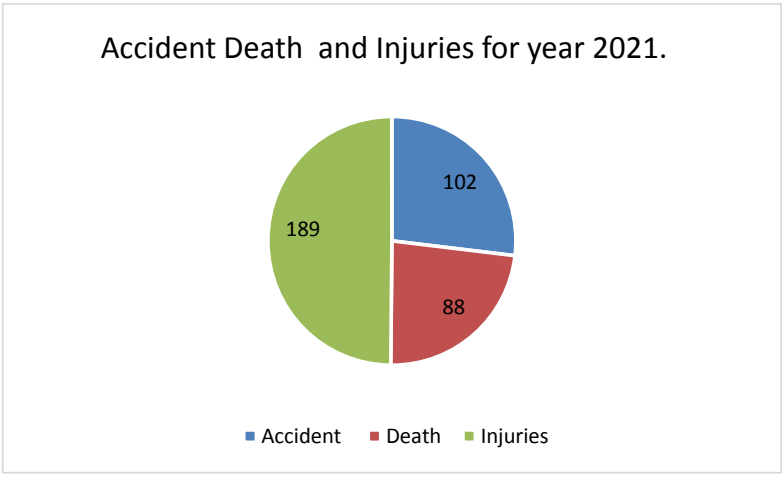
Figure 7 indicates the distribution of road accidents national wise compared with the same in the coast region for the past five years. When compared with national distribution the accident due to speed in Pwani region indicated almost the same trends of the RTA.



(a)



(b)



(c)

Figure 6. Accident, injuries and death for years 2019, 2020 and 2021. (a): Accident, injury and death in 2019; (b): Accident, injuries and death for the year 2020; (c): Accident, injuries and death for the year 2021.

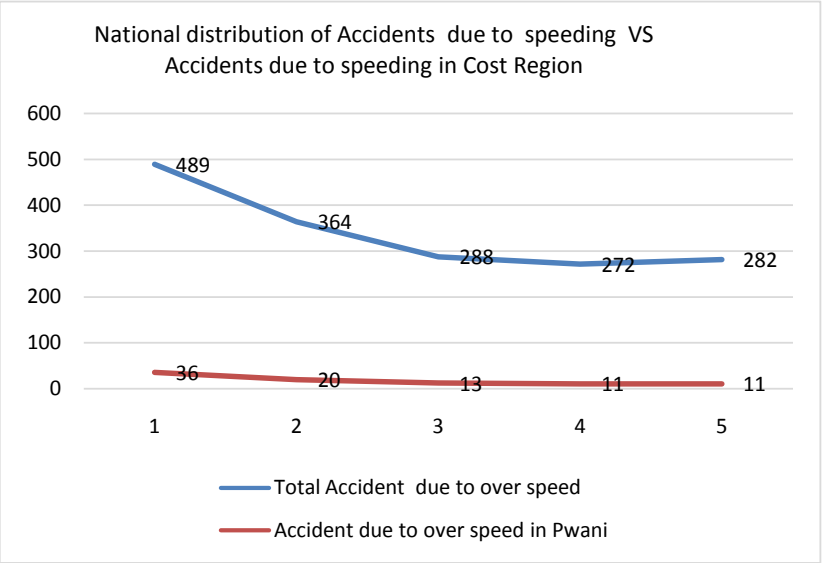


Figure 7. National distribution of accidents due to speeding country wide vs accident due to speeding in Coast Region (Pwani).

Speeding is among the critical causative of the RTA in Tanzania. While car defect is characterized as mechanical property on driving. Speeding is classified as human (driver) behavior that can be controlled by well-known procedures and manmade tools. **Figure 8** indicate that in the last five years and in every year speeding caused more road accidents compared to those caused by car defect.

4.1. Deployment of the System

Deployment of the smart approach for speed monitoring at the two pilot road sections showed positive results and proved the concept of vehicle speed monitoring automation and elimination of human-related challenges in monitoring and control of speeding at the speed limit road sections. The ASC system offers prompt violation reports as presented in **Figure 5**, the reports can be used for immediate actions and provide forensic evidence which facilitates prosecutions. The system gives out the speeding vehicle reports presented in web interface as shown in **Figure 5**, this can be accessed through any device connected to the internet. The enforcers such as traffic police can get the reports in real-time while on the road continuing with other patrol responsibilities.

4.2. Data from the Deployed System

Since startup of the system in 2019 to the year 2021 more than 200,000-speed violators were recorded. **Figure 9** presents the recorded over speeders in relation to the time distribution of Morning, Noon, Evening and Night.

The data indicate that many cars pass at a higher speed during the night. This accounts for 42.43%. The rest of time has almost average speed. About 16.45% of cars traveled during noontime, 15.24% traveled in the evening and 20.88% traveled in morning hours. When grouped together; Almost 52.58% of the total car travelled in a day time and the rest 47.43% travelled at night.

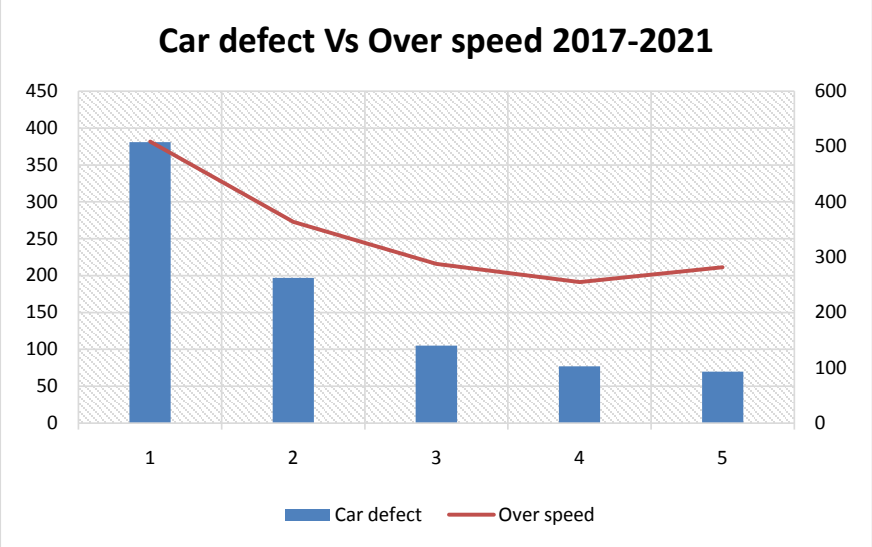


Figure 8. Road accident due to speeding vs car defect.

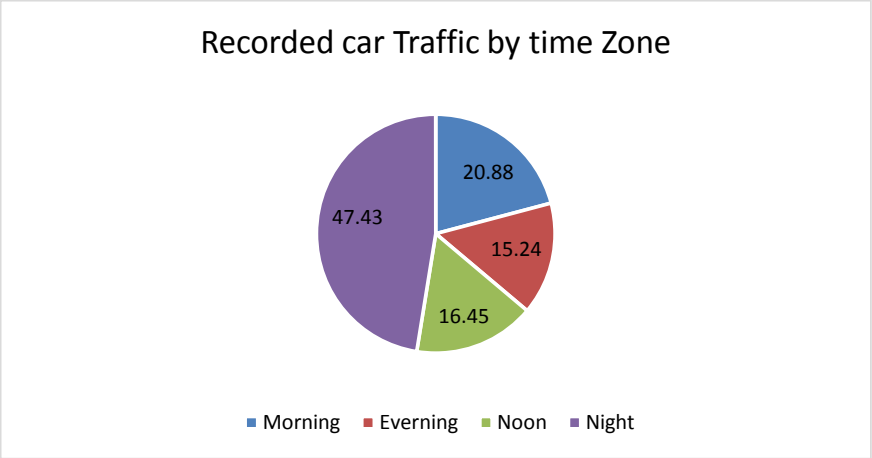


Figure 9. Traffic flow based on time zone.

After configuration and installation of the ASC system at the two black spot areas, it was found that almost 89.17% of drivers obeyed the road traffic speed limit passed with the basic tolerable speed of 51 - 59 km/h. About 10.34% passed with an average speed of 60 - 80 km/h which is not tolerable and might cause impact in case of accident and a few drivers of about 0.48 passed with very high speed above 80 km/h. It was found that about 10.82% violated the rules at the black spot (**Figure 10**).

4.3. General Discussion

The smart approach implemented in this research has capability to offer an improved solution in monitoring speed at black spot areas of the road sections. If this approach can be implemented in most road sections with higher risks, especially in areas with high accidents records (black spots) it is expected to improve transparency and accountability and therefore strengthen road safety. The

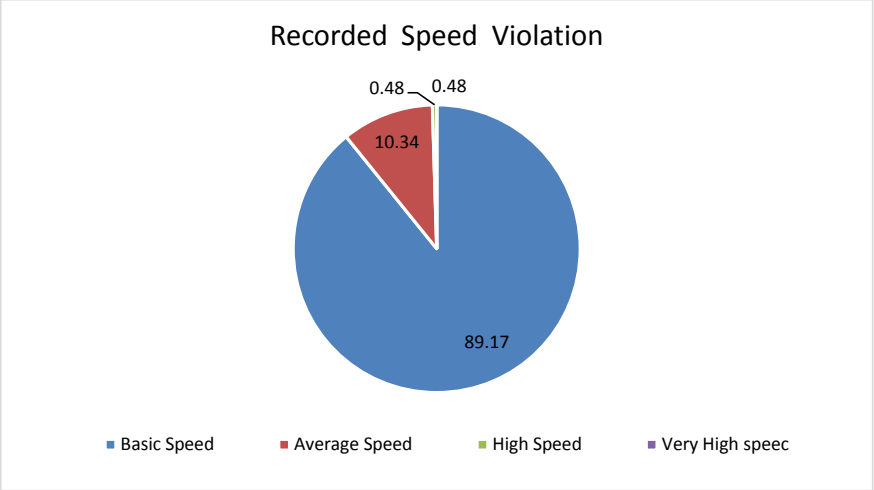


Figure 10. Speed Violation at the black spots.

system performance is mainly depending on vehicle number plates for unique identification of the vehicles; therefore, enhancing performance of the system requires enhancement of the number plate.

It is argued that it is not only higher speed that causes accident but also driver fatigue and drowsiness is a major cause behind a large number of road accidents.

5. Conclusions and Recommendation

Smart use of transport networks gives a high contribution to reducing road accidents. Application of Intelligent Transport Systems (ITS) such as ASC system is unavoidable, as it provides a chance for the country to benefit from application of information and communication technologies in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport. The existing efforts to lower accidents should be supplemented by more sophisticated ways which enable achievement of the best results. We recommend ASC system roll out across the country so that prompt actions can be taken for the misbehaving road users hence creating safer roads. It is concluded the system has given positive performance.

Therefore, it is recommended that together with penalty given to such drivers also they should be advised to attend road safety training which will help them to change the bad behavior hence improving road safety. Future research may be carried out to study and compare the accident statistics before and after the ASC system deployment. More study on intelligent assistive systems that monitor a driver's level of fatigue, drowsiness and alert the driver in case of vigilance can play an important role in the prevention of such accidents.

Conflicts of Interest

The authors declare no conflicts of interest.

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