ISSN 2348-1196 (print)
International Journal of Computer Science and Information Technology Research ISSN 2348-120X (online)
Vol. 7, Issue 3, pp: (84-94), Month: July - September 2019, Available at: www.researchpublish.com

A Real-Time Embedded System for Speed Limit and Route Adherence Monitoring for Matatu Saccos

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Abstract: **Information technology (IT) has transformed many industries, from education to health care to government, and is now in the early stages of transforming transportation systems. The major issue that faces transportation is a high rate of accidents and this is much more in developing countries. The lack of proper infrastructure for roads and indiscipline among drivers is one of major reasons for these crashes. The major indiscipline cases are over speeding and driving outside permitted routes for Matatu Saccos. This project focuses on public service vehicles (PSV) i.e. Matatus, where the goal of the project is to design and deploy a Real-Time embedded system that will be attached to public vehicles to act as a speed limit and route advisory and monitoring tool for drivers. The proposed System will base on the designed model and will play a major role in reducing risks and high accidents rate, whereas it can increase the driver's ability to adhere to speed limit and routes. This research project explored earlier methods that have been used previously in speed limit adherence. It goes on to synthesize and then reorganized the methods into a conceptual model. This is the model that acknowledges the presence of speed awareness method, route awareness method and a computation method that analyses and gives a deduction of whether the driver is over speeding, violating route or both. The concept identified was then the drive in model design. The model that was designed was to achieve the research objects the main objective being to monitor speed limit adherence and location violations. A prototype based on the model was analyzed and designed then developed. To develop the prototype, enabling technologies from literature review were used to implement. After development, testing and evaluation had to be done on the prototype. To test the prototype, simulation played a very major role. By use of rheostat to vary speeds and a string of saved coordinates that represent a route, speed limit and route adherence were tested. The prototype was found to be able to detect posted speed limits and compare the vehicles speed with them and report whether a violation happened or not. Simulation also showed that the route violation was possible. To evaluate the prototype, two parameters were looked at. A utility and usability test was done on the prototype. Questionnaires were used to collect data pertaining utility and usability and analysis and interpretation done. It was noted that the prototype was able perform the functions it was designed. A SUS approach of usability was used to evaluate how usable the prototype after development. In conclusion a model to monitor speed limit and route adherence, which was a major project objective, was developed. The prototype was developed basing on the model and combines standardized off-shelf parts and technologies for its wholesome assembly. These means that it can be used anywhere in world but we mostly target developing countries. The system uses technologies such as Microcontroller processing board, GPS, GSM, GPRS Shell, and a remote server**.

Keywords: **Speed Limit; GPS; Route Adherence**.

I. INTRODUCTION

Intelligent Transportation Systems (ITS) is still an active research area and has received much attention in recent years in academia, industry and standardization entities. This is so because of its wide impact on people's life as the domains scope provides vital applications and services to improve transportation safety and mobility and also optimizes the usage of available transportation resources and time. ITS applications and services rely on advanced technologies to be deployed. Mainly, these technologies include but not limited to physical sensor technologies that able to convert real world physical quantities and convert them into the digital world. Processing and storage capabilities are also vital in the use of the said technologies to assemble full fledge systems that are used in ITS.

GPS devices are the core enabling perceiving technologies for ITS applications and services. The GPS primarily is able to depict location, speed, heading and even acceleration. Other GPS-based services include in- vehicle satellite navigation, vehicle security system, accident notification and tracking along with monitoring to name few. [1] Most of GPS-based applications depend on real time information collection but there are also possibilities of historical GPS collected data (saved) being able to be used in applications like calculating speed, distance and other aspects [2]. This project aims to build an open model that focuses on speed limit and route adherence. The proposed model consists of two main phases namely user data acquisition and analysis/computation.

The first phase, which is data acquisition, uses GPS device connected on a processing board. GPS device collects the vehicles geographical location (i.e. longitude and latitude), speed and the driving direction at regular intervals of time [2]. The implementation of this phase is based on an integration of multi-sensor capabilities together, in order to increase of the range of possible application. These may then be used for some other applications such as population of the road segments. In the analysis/ computation phase calculations are done to make comparisons with known basis resident in the memory base. This is a knowledge base storing allowable speed limits and routes.

Finally decision can be made based on the management policies visa vie the computed outcome. Here, we record the number of times a vehicle violates these speed limits and the corresponding violation time durations. The resulted information is then compared to preset level and limits which are allowable by the system to decide whether the vehicle violated the traffic regulations or not at any given trip or after some period. After experimenting with our model for a number of enough times, we expect that that the model will be linked to another third party system to authorized department.

II. RELATED WORK

This section explores a few research works related to our work. This research considers only solutions that form a part of a whole system for tracking and monitoring a group of vehicles. In general tracking and monitoring systems composed of two main parts, the first part is a GPS device for location and speed acquisition. The second part involves the processing and forms a central application to collect, to process and to visualize useful reports [5]. This section of this paper attempts to classify the considered related work based in different aspects. Each aspect requires intrinsic requirements to build the system. Table I below shows a comparison among different works analyzing the different aspects. The aspects are hereby discussed as follows:

The first aspect differentiates between on- line and offline monitoring systems. Online monitoring systems require that the entire system is available from a remote location via a link; commonly GPRS connection to the cloud of internet. On the other hand, Offline tracking and monitoring systems consolidate the collected data on a local storage unit and communicates with the central application only when the communication link available such as Bluetooth or physical connection. The Offline systems mostly focus on historical data processing and visualizing the generated reports best example being track a vehicle over a digital map). In most cases the offline system data transmission the vehicle and connected it to a PC and/or transfer the data using cables or other technologies such as Bluetooth or Wi-Fi. Therefore basing on the above discussion, some systems can be considered as online, offline or combined (online and offline) solutions.

The second aspect of classifying the tracking and monitoring systems could be the type of device used to collect the data especially the geo-location information. The differentiating thing is between different types of hardware used for build on-Board Unit for the tracking system. There are three common units which are: Commercial units, smart Phone with GPS and wireless links and the customized unit(where authors provide design and implementations in the considered work) [7]. The third aspect depicts the communication channel used by the device to transfer the collected data. Such connections could be any cellular connection or combination of them such as GPRS, SMS.

Last aspect deals with features of the tracking and monitoring. For this particular aspect, a comparison between different tracking and monitoring systems is based on: [2]

1. Visualization of Vehicles onto geographic digital map.
2. Ability to only tell speeds at different instants while on a trip.
3. Alert capability i.e. ability to send alerts to the driver about violations.
4. Geo-fencing capability i.e. Identification of geometric allocation over digital maps that are allowable
5. Geo-Casting Sending Alerts about groups of vehicles on proximity to each other and this plays a major role in accident or alarm situations.

TABLE I: COMPARISON BETWEEN DIFFERENT TRACKING AND MONITORING SYSTEMS

Reference	**Type**	**Smart Unit Type**	**Connection Type**	**Tracking**	**Speed**	**Alerting**	**Geo-fencing**	**Geo-casting**
[2]	Online	Custom Unit	GPRS	Yes	Yes	Yes	No	No
[3]	Online	Custom Unit	GPRS	Yes	Yes	Yes	No	No
[4]	Online	Smart Phone	Cellular	Yes	Yes	No	No	No
[5]	Online	Custom Unit	GPRS	Yes	Yes	No	No	No
[6]	Online	Custom Unit	Wifi	Yes	Yes	No	No	No
[7]	Combined	Custom Unit	GPRS	Yes	Yes	Yes	No	No
[8]	Combined	Custom Unit	SMS	Yes	Yes	No	No	No
[9]	Combined	Commercial Unit	GPRS and SMS	Yes	Yes	Yes	Yes	No
[10]	Combined	Smart Phone	GPRS and SMS	Yes	Yes	Yes	No	No
[11]	Online	Custom Unit	GPRS and SMS	Yes	Yes	Yes	No	Yes

III. METHODOLOGY

This section discusses how the research project was conducted. It looks at the research design and the system analysis and design and proceeds to the implementation.

A. Research Design

The research project was research project was an applied computing research. An investigation of the set of requirement for the GPS modules and the GSM/GPRS modules before they are authorized to be used was done. This investigation was important because by researching on the requirement of the said devices, more aspects of project requirement were identified. Data required for the development of the prototype was acquired at this point also. The researcher reviewed device documents including user manual, specification documents and patents. A survey of related literature was also done including statutory documents governing the use of the devices.

After this, the research identified different approaches speed detection and location awareness has been tackled using different technologies. This was instrumental in helping find the best combination that would be robust in helping alert the Matatu drivers in case of speed and location violation. The research then went ahead and suggested a model that would enable a real time speed and location adherence for Matatu Saccos in Kenya. This was very important as it was the main objective of the project. It was after closely reviewing other related model the model for the project was coined by adjusting previous attempts.

After designing a model, the research developed a hardware prototype, based on the new model. This was important so that the research could evaluate if the proposed model would be successfully implemented in a hardware device. The theoretical model would be useful if only it would be implementable into a hardware device. The hardware was built on the Arduino framework and used both C and Arduino C languages for implementation.

Lastly the research project tested the developed prototype. Experiments with the prototype were done on a chosen route having decided speed limits. Simulation was used as a primary testing means.

B. System Analysis and Design

Under this, an analysis of the required system was done where requirement analysis was done and the a design followed.

Requirement Analysis

In order to develop the specific system that will operate in the target environment and meet the specific objectives requirement analysis was conducted. Great amount of information was obtained through observation and interviews on the driver behavior coupled with a review of research literature of research conducted by other researchers in the same and related areas.

Functional Requirement

Functional requirement is a statement of what the system should be able to perform: This embedded system should be able to perform the following.

1. To detect posted Speed limits along roads and inform the driver
2. Alert the driver when he/she violates the speed Limit i.e. driving at speeds greater that the current detected speed limit.
3. To detect whether the Matatu is operating on the specified route by the Sacco it belongs to or not.
4. Alert the driver if he/she is operating outside the pre-specified route by the Sacco.
5. Keep a log of violations and peg a fine on them depending on pre-defined formula. The fine is paid using electronic methods i.e. a deduction from a membership card where some minimum deposit will be deposited.
6. Alert the Sacco Management of serious violation for an urgent action.

Non-Functional Requirement

For this system to meet the all the functional requirements while operating in constrained environment, non-functional requirements need to be met. These non-functional requirements are very critical and core to its performance. They mainly revolve around systems abilities in embedded environment

Embedded Capabilities

The system is designed to be able to operate under the following:

i. Limited memory
ii. Constrained power supply
iii. Low processing power
iv. Meet real time capabilities

The system designed is for detecting posted speed limits and specified routes. It alerts the driver in cases of violation, and logs for fine generation and informs the Sacco Management in case there is a need of an urgent action. The system shall use a GPS module to acquire location in terms of coordinates of a given current position of the vehicle. It will then compare the current location with the stored co-ordinates to determine the speed limit that is supposed to be observed. It then checks whether a violation is happening and alerts.

Use Case Diagrams

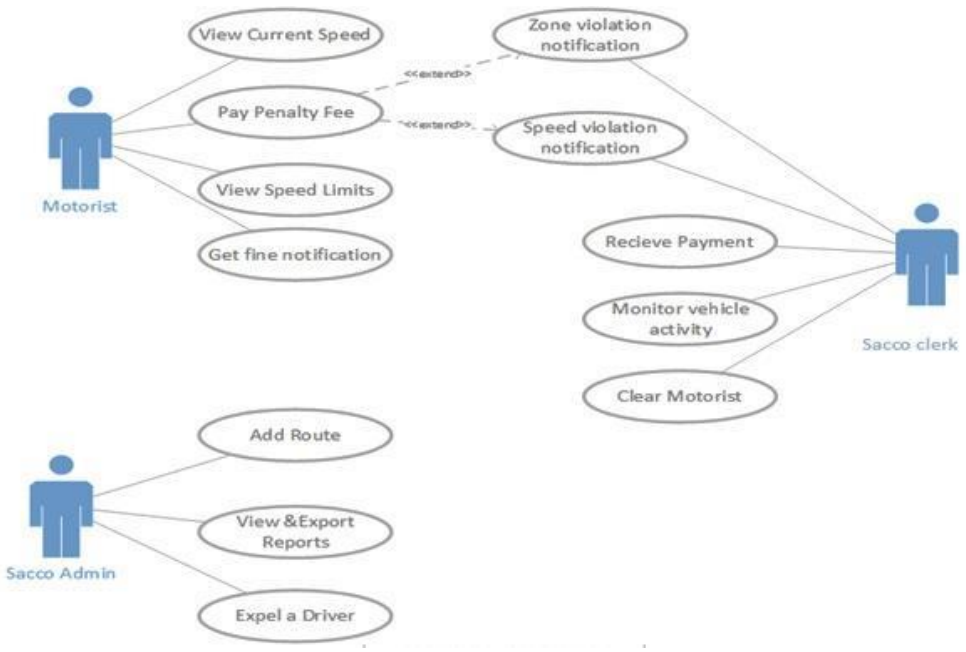

Figure I: Use Case Diagram for the system

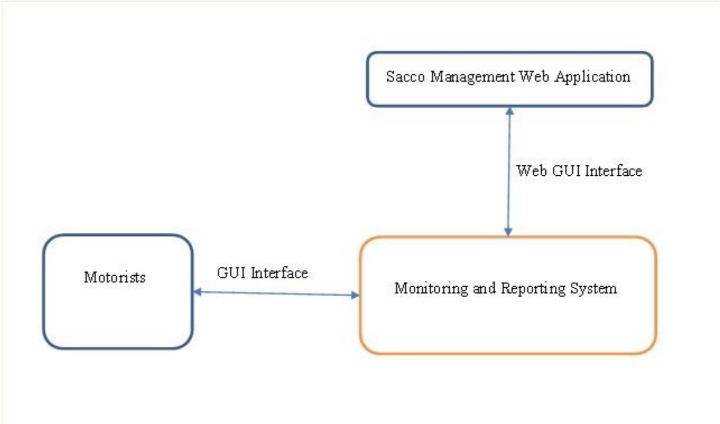

Figure II: Interface design for the System.

IV. ARCHITECTURE AND IMPLEMENTATIONS

This section shows the high level architecture of the prototype (as shown in Figure 1) of the proposed system. Main building blocks are identified which consists the Processing board, the GPS/GSM/GPRS which is mounted and attached to the vehicles. In addition, the Web based application running on the back-end server is introduced. The driver, Sacco management, and Pre-Warning system all interact with the main system. All these are real-time in nature and are depicted by the diagram below.

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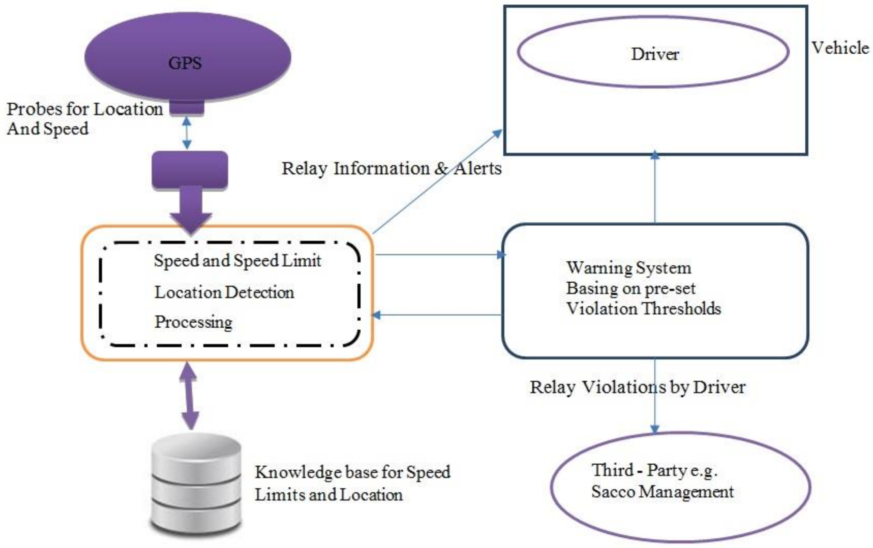


Figure III: Architectural Model of the System.

A. Processing Board

Processing the various aspects of the system is a paramount function in the project. Therefore, this is the main part of the system. It processes signals and gives output. The code for doing the actual work is also stored on the microprocessor. For the purpose of this project Arduino mega 2560 board was used. The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports) and a 16 MHz crystal oscillator.

Fig. 2: The Arduino Mega 2560

C. GPS with GSM/ GPRS module.

This is one of the primary parts of the system. AdafruitFona - Mini Cellular GSM Breakout uFL Version was chosen for the prototype development by the researcher. This device has the capabilities desired for the project. The following are what came out as very important as assessed by the researcher.

Figure IV: GPS-10710 Shield Module

- GPS – This is the Global Positioning System capability which allows the vehicle to be located anywhere on the face of earth.[8]

- GSM – This is the (*Global System for Mobile* communication) is a digital mobile network that is widely used by mobile phone users in Europe and other parts of the world. It would be key in the sending of text messages between the device and the managers.

- GPRS – This is *General Packet Radio Services* (GPRS) is a packet-based wireless communication service that promises data rates from 56 up to 114 Kbps and continuous connection to the Internet for mobile phone and computer users. The AdafruitFona Board has that capability which will be important in the system for transferring packets of data

D. Web Based Application

This was any third party system that is interfaced to the hardware device via violation base. In this case, it was a basic Web based system. To implement it: GSM/GPRS capability was used to connect to a remote server which interpreted the fault base. This then determined what fines (as a punitive measure) that would be imposed on motorists who were violating either speed limits or permitted route. A dashboard was developed to capture some of the parameters.

V. RESULTS

In order to test the system prototype, we used simulation. A route was chosen (Between Uthiru and Westlands); two suburbs near Nairobi City. Along the route, imaginary speed limits were marked i.e. 50Km/h for the first zone A, 80 Km/h for the second zone B and 30 Km/h for the third zone C. GPS device was used with arduino and the coordinates of the route saved on a micro SD card. This stored coordinates were then instrumental in simulation. Testing was important in this research because it was instrumental in enabling the research to answer its research questions and also verify that it had correctly achieved its objective. The aims of these tests were;

1. Verifying if the model was convenient enough to identify different speed limits along a route and the current vehicular speed then do computations to detect violations.

2. Verifying if the model was convenient enough to identify different allowable locations then do computations to detect violations i.e. a vehicle is not in its allowable region of operations.

3. Verifying if the model was convenient enough to log driver's speeds and determine how frequent the drivers violates or adheres to speed limits and routes i.e. Driver behavioral Profiling.

4. Verifying that the built prototype could be integrated to a third party system, meant to improve usability extension mainly giving driver profile reports.

In an aim to achieve the above four aims, the research divided its testing into two tests that catered for various parameters. Simulation tests and experiments, which addressed various aspects of the research project questions and objectives, were carried out. For each of simulation and Experiment item, purpose, objective and the methodology were explained in this chapter. After the simulations and experiments, results are discussed briefly and also an analysis and conclusion. The results and analysis was meant to determine if the testing objectives were met.

A. Simulation Tests

Simulation played an important role of testing. Aspects tested in this manner included speed limit and location. The Speed limits used in the simulation projects were 80Km/h, 50Km/h and 30Km/h. These speeds would be achieved by varying a potentiometer connected on an arduino board. The potentiometer would represent the speeds between 0Km/h and 180Km/h. Location would be simulated from stored GPS coordinates resident on a micro SD card.

B. Speed Simulations

The main purpose of this experiment was to see if the chosen framework would be able to

i. Integrate speed limits in relationship to location. This drove at solving the main research problem. These objectives were to be achieved in the test;

ii. Read GPS coordinates of a given route.

iii. Determine various speed limits on the route

iv. Generate speed values from a Speed potentiometer

v. Save the values from the potentiometer to a file

vi. Verify if the control unit was able to correctly identify when the speeds were exceeded or not for a particular speed zone.

To achieve these objectives, the below steps were followed:

1. Speed data was simulated by varying a Speed potentiometer for a range of 0 to 180. The potentiometer values were cleaned by the mapping of all its values to a range of 0 to180. The 0-180 range corresponded to the speed odometer readings on the PSV's dashboard along any given road. (0-180 Km/h)

2. Stored GPS data was read from a micro SD card and used in temporary files as .CSV files

3. The generated speed data was saved in different file formats. The formats used were .TXT and .CSV

4. Data was fetched from these files (GPS and Speed), mimicking the data that can be got from GPS device data file into the control unit as per the Conceptual framework. The data from the GPS is Location and Speed.

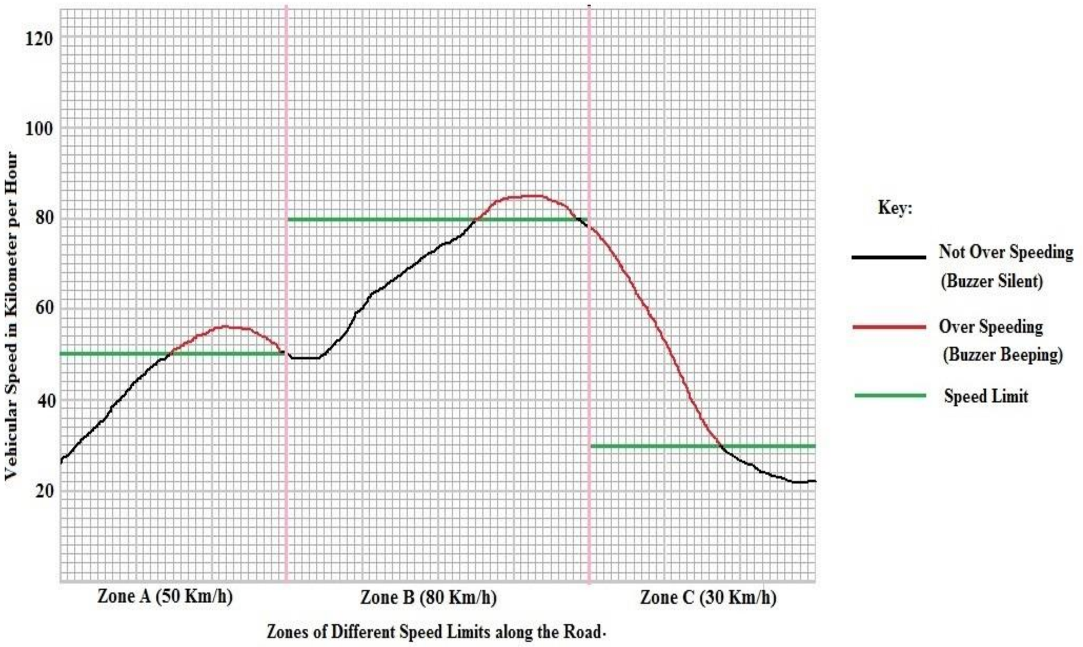
5. The main way to report at the control was by use of a buzzer and two LEDs. The buzzer would beep continuously whenever there was over speeding while a Green LED will be on whenever the vehicle is on allowable route. Red LED would be on whenever the vehicle was in a route that is not allowed for that particular vehicle. Additionally the LCD display connected on the control unit would be reporting those two parameters i.e. Speed limit and route violation

C. Results, Analysis and Conclusion

The tables below show some of the results that were got in the simulation. The speeds were recorded for the chosen distance. The graph also shows results of the simulation below.

Zone	**Distance (Km)**	**Vehicular Speed (Km/h)**	**ON Buzzer Status**
A (50 Km/h)	0	26	**N**
	0.5	34	**N**
	1	44	**N**
	1.5	50	**N**
	2	56	**Y**
	2.5	56	**Y**
B (80 Km/h)	3	50	**N**
	3.5	50	**N**
	4	50	**N**
`	4.5	68	**N**
	5	74	**N**
	5.5	80	**N**
	6	84	**Y**
	6.5	84	**Y**
C (30 Km/h)	7	78	**N**
	7.5	68	**Y**
	8	52	**Y**
	8.5	36	**Y**
	9	26	**N**
	9.5	23	**N**
	10	22	**N**

The results showed that in all the 15 speed experiments done, the device correctly identified if the limits were exceeded or not. The Reason why all the experiments correctly classified the instance is the Control unit was a rule based system. The speed data generated was also correctly logged. This was important to note since it was one of the research aims. Due to this, the research concluded that the device could correctly verify if the limits were exceeded or not. It also concluded that the device would correctly save all the speed instances generated in future.



A simulation of a driver who adhered to Speeds

Zone	Distance (Km)	Vehicular Speed (Km/h)	ON Buzzer Status
A (50 Km/h)	0	40	**N**
	0.5	36	**N**
	1	32	**N**
	1.5	32	**N**
	2	36	**N**
	2.5	38	**N**
B (80 Km/h)	3	42	**N**
	3.5	50	**N**
	4	56	**N**
`	4.5	60	**N**
	5	62	**N**
	5.5	58	**N**
	6	52	**N**
	6.5	40	**N**
C (30 Km/h)	7	30	**N**
	7.5	22	**N**
	8	17	**N**
	8.5	14	**N**
	9	14	**N**
	9.5	16	**N**
	10	20	**N**

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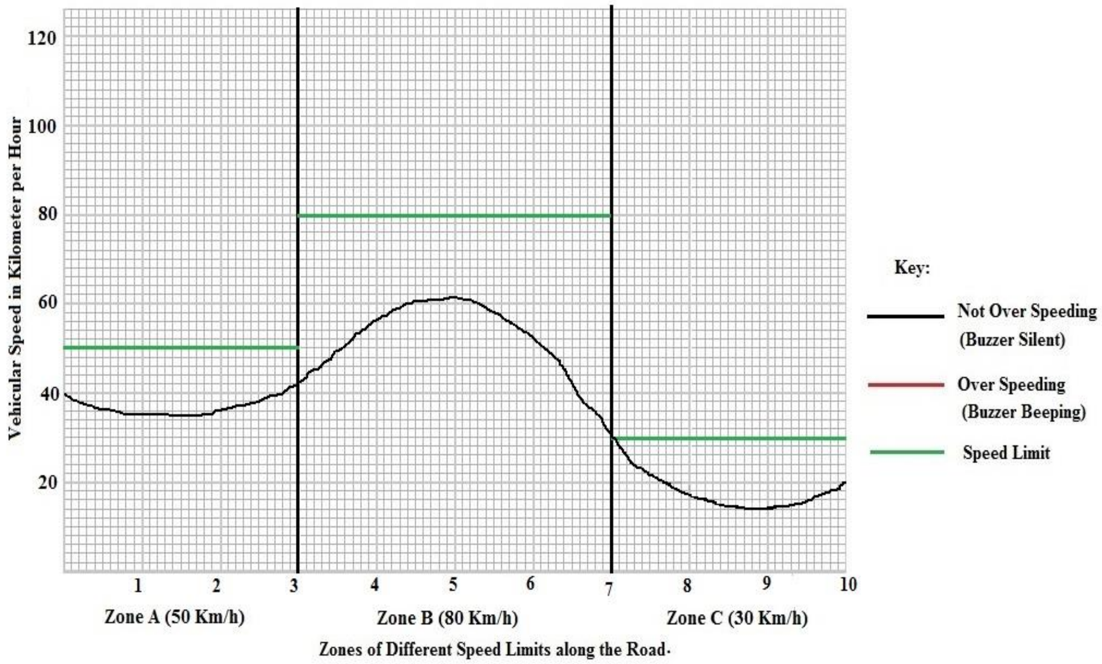

VI. CONCLUSIONS

With the increase in a need for public transportation management systems (PTMS) using GPS technologies which aim at saving human life by monitoring the driver behavior This paper plays an important role in that regard. It introduces a system composition structure and explains the system software and hardware design which in turn will reduce number of times when the driver violate traffic regulations. Experiments with the prototype show that our system is practicable and reliable in identifying speed limits along the road and informs the driver whether they are over speeding or not. The prototype also recognizes the current location where the vehicle is and reports if there is a route violation or not. Generally, the system ensures adherence to the two aspects (speed limit and route). It does this by reporting the logs to a third party system which is actually web based. This creates a great amount of accountability and discipline enforcement by the management [9]

When compared to other Transport management systems based on GPRS and GPS technology, it is greatly reduced the operating price and it provides extra capabilities including driver profiling and violation ticketing. In our system, the GPS plays a major role during monitoring, identification of the maximum allowed speed for each road segment along with the travelled route. Ongoing work is to enable the system for supporting proper interaction with the users using other technologies including GSM and Bluetooth and Wi-Fi [13]

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