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DynaTrack: Machine Learning Aided Variable Speed Limit System

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Abstract

In the past decade or so, we have seen traffic congestion become a ginormous issue in the major cities of the world, the main reasons for the above being exponential growth in vehicle purchases, constant unplanned maintenance of the road networks, and so on. And as far as the current situation is concerned, it can be safely said that even though steps have been taken to counter the issue at hand, the improvement made has been close to nothing as the problem persists. The solution to this is being suggested is based on the concept of Variable Speed Limits, which says that the speed limits for the road segments be dependent on the traffic volume and situations on the road segment rather than being constant. The system would use the feed from CCTV cameras to keep a track of the flow variable, which lies within the low traffic limits, the speed limits would be increased accordingly. This would ensure convenience for travelers, reduce travel time, fuel consumption, and greenhouse gas emission, and will also improve economic gains, among other advantages.

Keywords: Speed limits; Traffic density; Variable speed limits; Background subtraction; Traffic management

1. Introduction

The state of Indian road travel has been extensively critiqued for quite some time now, with the rectifying measures producing results close to none. Over the past few years, it has been observed that the major Indian cities of Mumbai, Bengaluru, and New Delhi, have been constantly ranked among the most congested cities in the world, with Mumbai being rated first in the list compiled by TomTom International [1].

Indian drivers have a mindset of not sticking to their lanes and have a tendency to drive in a fashion, which incorporates overtaking and increasing driving speeds. In such a scenario, when different types of vehicles with varying dimensions and characteristics tend to use the same kind of roadway facility, therefore, an improper

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distribution may be noticed from time to time. Thus, whenever a fact in the context of Indian roads is stated or presented, usually an image full of honking vehicles and aggressive drivers pops in the mind.

Traffic congestion is not just a problem that one faces while commuting, but it can have a long-lasting impact on an individual's health and mental well-being also. The enormous amount of vehicular smoke generated can lead to nasal-tract-related problems, excessive use of horns/claxons can lead to hearing problems [2], and driving for uncountable hours in never-ending queues can lead to physical problems, like- axial pain, muscle pain, etc. Thus, one always suffers from an adverse fear and dilemma of – 'getting late', which in turn could have ill effects like- prolonged headache, improper sleep cycles, and mood swings. Hence unsafe driving comes into the picture leading to increased cases of road rage and accidents happening in our neighborhoods.

Traffic jams not only create stress and frustration, but even the environment is affected due to excessive consumption, or rather wastage of fuels. This increases the carbon emissions leading to the issue of global warming. In this way, the story goes never-ending, where one thing leads to another.

Despite great distinguished advancements in various fields, achieved by India, there is still a persistent issue of excessive overcrowding and whatever methods are employed yet, seem to be slow and not effective. But what may not be solved by the implementation of materialistic and physical solutions might just be tackled by the means of simple technical measures. This has been the main motivation behind this study. We have tried to use a technical methodology to solve an issue where changes and improvements in the existing traffic infrastructure have failed to reproduce their worthwhile ensuring that the system generated would be such to ensure low expenditure on execution and easy use and maximum efficiency while curbing the issue of traffic safety and congestion effectively.

The relatively new concept of Variable Speed Limit, in combination with Global Positioning System navigation technology, may provide a viable solution to the aforementioned problem at hand. Tested and being executed in countries of Europe and recently introduced in the US as well, variable speed limit (VSL) was introduced as a measure to counter the traffic and mobility issues [3].

The solution that is being suggested aims to utilize and develop the already existing resources and technologies to create a mobile-based application setup that would not only track the current location of the user but also provides other facilities like generating a new speed limit based on various factors, like traffic flow, weather conditions, visibility, etc.

The paper focuses on the issue as discussed, and it shall unfold in phases. The various sections of the paper give a detailed glance at the effort put in the direction of the research conducted. The upcoming section- Literature Review contains some of the work related to traffic management. It outlines some of the key works done in the field. These works lay the ground for the work that has been pursued in the project. In the section- Preliminaries, a discussion of the adopted system of VSL along with the details about the approach have been discussed. Following this, the section- Methodology, provides the implementation details containing the system design, data flow, and graphs depicting a detailed overview of the research. Finally, the later parts of the paper represent the results, and varied impacts which could be achieved through this research and also highlight some of the future scopes that are believed will be a great enhancement. Also, the paper, as usual, includes the references that were utilized as an extensive source of information for conducting the research and study for the project.

2. Literature Review

There is a plethora of control systems and architectures based on widely varying technologies and ideas that have been introduced in recent years to tackle and cope with the issue of traffic management in urban areas and counter the drawbacks of the currently existent traffic light arrangement.

In the "Automated Real-Time Intelligent Traffic Control System for Smart Cities Using Wireless Sensor Networks" [4] authored by Hilmani et al., which makes use of a wireless sensor grid on road network along with other places of interest, a new setup was introduced to better deal with road traffic and determine the quickest path to the journey endpoint. The proposed system used intelligent traffic cameras on the roads to capture the license plate number, which was communicated to the mother system to monitor the vehicles in the area. Even though the latest technology was employed, the system experienced some major drawbacks, which are the immense cost that would be incurred while establishing the infrastructure as well as the inefficiency in detecting vehicles in cases of limited visibility due to both atmospheric reasons and light reflection and glare. These, however, can be overcome by a simpler system of RFID tags and infrared detectors.

Lewandowski et al., in their paper [5], suggested a traffic monitoring system that functions using mobile devices and BT beacons with low power consumption. The system employs detection using mobile instruments, like smartphones, stationed on the curbs to measure the "Received Signal-Strength Indicator" signal strength when receiving packets of data as radio waves by beacons on those on the opposite side of the road. These beacons were placed at varying heights, allowing to identify and differentiate the vehicles on the road. The values generated here are then sent to a central system to measure traffic density and flow characteristics. However, the Bluetooth technology used here posed synchronization troubles and communication obstruction between the beacons and the instruments, especially in situations of high traffic density. This leaves a place for improvement in the system.

Another system to deal with the same issue of traffic was studied and developed by Sharif and Khalil in 2017 [6]. They proposed an affordable solution to the situation, which aimed to better ease the situation by providing traffic updates. Every 500 or so meters down the road, cost-efficient vehicle detectors were installed along the center of the road, and IoT was used to obtain public traffic data immediately. This data is then sent for further data processing. For Big Data analysis, the data is sent in real-time. Several analytical scriptures are used to measure traffic characteristics like density and suggest solutions by employing prediction-based analytics, using state-of-the-art technologies like IoT and Big Data. The information was provided to users through an App, which showed updates on traffic, vehicle strength based on the state of the roads, and such, which makes it user-friendly. However, there does arise an issue of the complexity of setting up the complete apparatus since five or more sensors would be connected to the IoT device as well as each other, and each of these IoT kits would, in turn, be connected to a network to facilitate communication.

There is another system, the idea for which was conceived and worked on by Zaatouri et al. [7-8]. They defined an intelligent system of traffic light control that was adaptive in nature based on the deployment of WSN along the roadways up to an intersection or junction. These WSN nodes are magnetic sensors that form a network topology in the form of a cluster, which would be employed to detect the presence and strength of vehicles on the road and send the received data to the next nearest cluster head. This is repeated to send the data to the base station, where it is run by an algorithm to ascertain the rate of traffic flow in each lane and control the traffic lights grid in real-time. However, a solution similar to this would produce results that are obsolete to a driver who doesn't pay heed to what happens on the road when he drives.

It can be easily observed that the previous research works done in the field of VSL only considered their impacts on singular variables of traffic like mean speed, traffic flow spread, mean headway, etc. The issue while undertaking such approaches is that it is extremely tedious to isolate the effects of other variables that may affect any change incurred. Nonetheless, Papageorgiou recently studied the impact of necessary VSL employing the respective diagrams of flow occupancy [9]. They implemented the method by applying flow-occupancy data before and after the application of the concept of mandatory Variable Speed Limit on European highways. The VSL was based on a flow/speed threshold-dependent control strategy. It was discovered that this reduced the rate of change of the graph under occupancies of critical importance and shifted these to values higher in the FO diagram. The learnings from the research were not irrefutable about the effect of VSL on the volume of the amenity. They also suggested that a VSL-based control plan using the steepness of the occupancy-flow curve, predicted dynamically as a measure of VSL actuation, may produce even more successful and robust VSL approaches/techniques.

S.no.	Name of the Models researched	Drawback faced/Inferences	Rectifying Measures
1.	"Automated Real-Time Intelligent Traffic Control System for Smart Cities Using Wireless Sensor Networks" by Hilmani et al.	• High set-up cost • Inefficiency during limited visibility and glare.	• Previously existing amenities and resources were utilized and built on which drastically reduce the cost incurred. • The YoloV3 algorithm with OpenCV and Darknet-53 works better in a low frame rate set-up. This may prove fruitful in increasing the overall efficiency of the system in limited visibility or glare.
2.	"Road traffic monitoring system based on mobile devices and Bluetooth low energy beacons" by Lewandowski et al.	• Sync issues and communication issues.	• Due to its simple architecture and communication network utilized, the system functioned effectively and without sync issues when tested.
3.	" Internet of things—smart traffic management system for smart cities using big data analytics" by Sharif et al.	• The complexity of the system.	• The complexity of the system would depend and will be affected primarily by the complexity of the CCTV, due to which complexity rectification can be easily localized and done efficiently.

4.	"Adaptive Traffic Light Control System Based on WSN: Algorithm Optimization and Hardware Design" by Zaatouri et al.	• Issues with driver compliance due to the ignorance of surrounding traffic situations.	• The system is accessed via a mobile application which can be used to provide talk back and audio alerts to the driver.
5.	"Motorway network traffic control systems" by Kotsialos & Papageorgiou.	• The theoretical study suggested the advantages of VSL methods to improve the efficiency of the system.	• Takeaways from the research used to understand the VSL concept better and increase the efficiency of the system.

3. Preliminaries

The approach adopted to execute the intended concept of VSL has been described in the following section, along with a process flow diagram for both the navigation app and the CCTV vehicle tracker and counter to better visualize the process. In the paper, we will be to developing a mobile application to be used by a commuter to drive their vehicle according to a system-generated speed limit. This system-generated speed limit would be based on the road conditions, which would include the traffic flow for the road segment, the visibility index that day, the humidity and precipitation values, essentially any factor that may affect road travel. These would be processed by a formula to produce the speed limits for the user to travel by [10-12].

4. Methodology

The VSL speed limits will depend on the current traffic conditions of traffic flow, density, and vehicle mobility. This extends out to be the major part of how to monitor the current traffic scenario. For this, it will be asking the user to enable the GPS Service on his/her device, granting the access to monitor his/her location. Using the GPS facility, it would be possible to fetch the current coordinates of the particular user and perform the intended task.

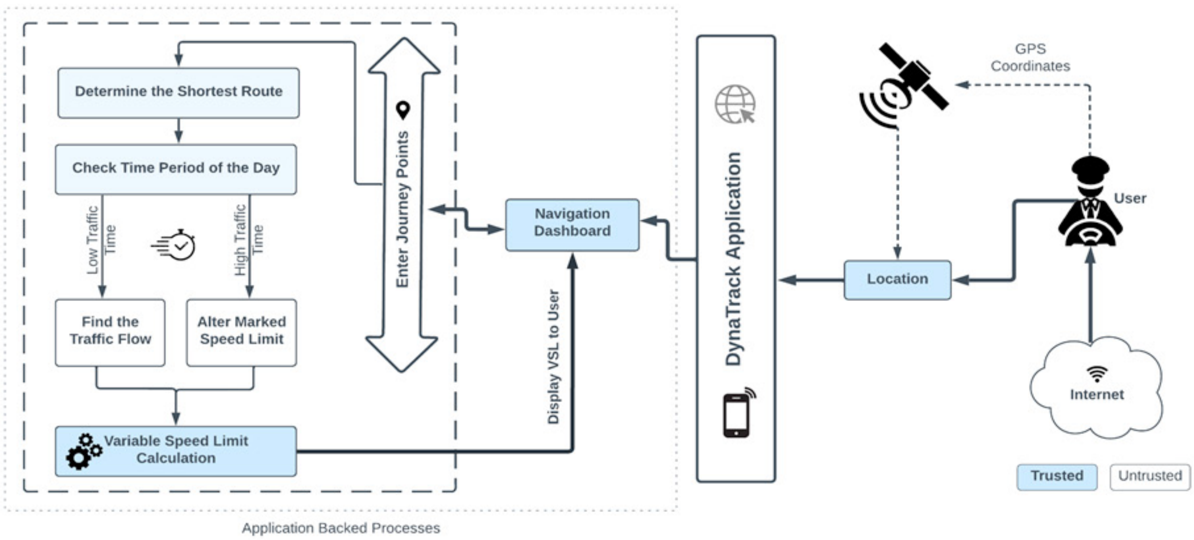

Fig. 1. Process Flow Diagram for DynaTrack Application

Nextly, it is vital to know the current traffic density of the concerned road segment where the user is currently driving. For the fulfillment of this purpose, the existing traffic management system is used. It is a well-known fact that, in most of the road segments through which one travels daily, the government has deployed surveillance cameras.

These cameras that are deployed to ensure traffic safety can prove a valuable component of this research. Analysis of the video feed of these surveillance cameras needs to be performed. The video feed is not just enough. It is a raw component that requires extensive processing to become of any productive use. Hence, a vehicle tracker program is used, which is a system that makes use of surveillance cameras and neural networks to identify different cars from each other and keep track of a large number of vehicles passing a point.[13] This traffic flow is calculated for 15 minutes; the value obtained is multiplied by 4 to produce a rough estimate of the hourly flow.

The traffic counters mentioned above are readily available as programs by companies like itnruVision, Camlytics, Antriksh Technosys and so on which make use of Machine Learning technologies and libraries like OpenCV, various versions of YOLO, Background Subtraction, and such, and can simply be overlaid on the CCTV camera grid that is under use in the city/area under surveillance.

Thus, it will count the number of vehicles in the following zone within a few seconds, and then it will parse this calculated value to the back-end for further processing.

After this is done, the calculated traffic flow will be used to calculate the VSLs. This is done utilizing an equation that can be derived from the variation trends between the traffic flow, speed of traffic flow, and traffic density.[14]

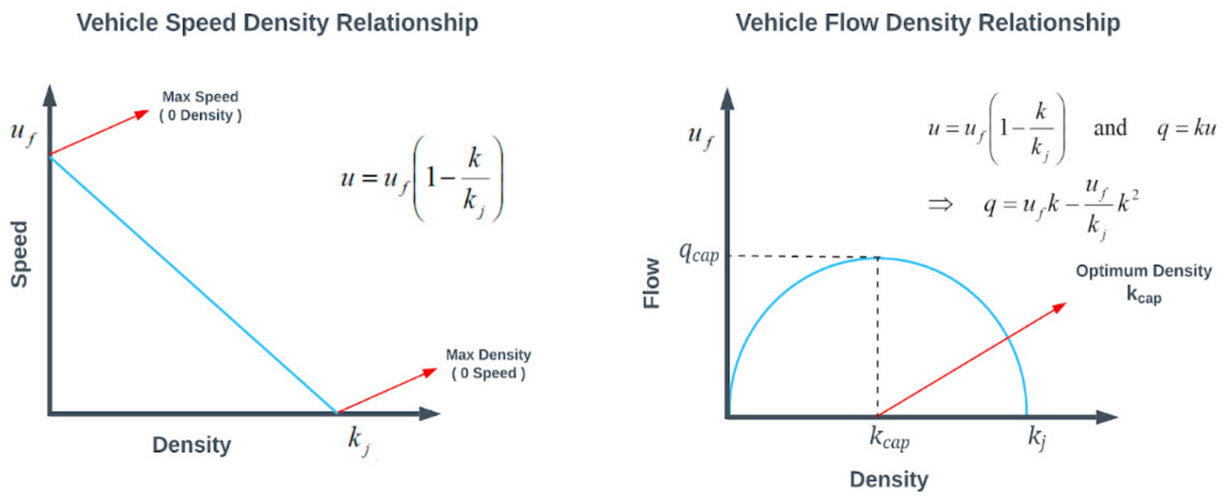

Fig. 2. Graph depicting a relationship- (a) between Speed and Density; (b) between Flow and Density

The various parameters as shown in Fig. 2 can be summarised as:

q = hourly traffic flow rate. Calculated as (15 min flow rate) × 4,
u_f = free-flow velocity, i.e. speed when density is minimum but not zero,
k_j = jam density; i.e. no. of vehicles per km per lane in a jam situation,
u = VSL speed; the desired speed of commute, and,
k = traffic density.

The equation devised based on the above parameters, shall be used to determine the desired VSL value (u),

$$u = \frac{u_f}{2}\left\{1 + \sqrt{1 - \left(\frac{4q}{u_f \, . \, k_j}\right)}\right\} \tag{1}$$

These speed limits can be executed in two ways; either as different VSLs for different equal-sized time periods or the time periods can be of different sizes and classified as per the variation in traffic trends.

For the latter option, the previous historical data might need to be analyzed, either manually or by using Machine Learning methods, to identify traffic variation patterns, an activity that can be performed by methods like the use of Semantic Information on GPS data.[15]

Finally, the calculated speed limits would be displayed to the user through the mobile application. In due course of their journey, the user would be provided with real-time routing instructions, along with traffic directions. So, before the user enters the next road segment, the above process will get into action to display the VSL. The driver then will be alerted to travel at the new calculated speed via a pop-up or an alert message [16].

Figure 1 discusses the process flow diagram for the approach, essentially how the user would interact with the application, be it the start and destination inputs or receiving the output, to achieve the intended benefits. The next diagram (Figure 3) shows the process flow for how the traffic counter may be employed for the desired purposes. It shows how the vehicle flow is found and processed for time periods of low traffic density to calculate the variable speed limit.

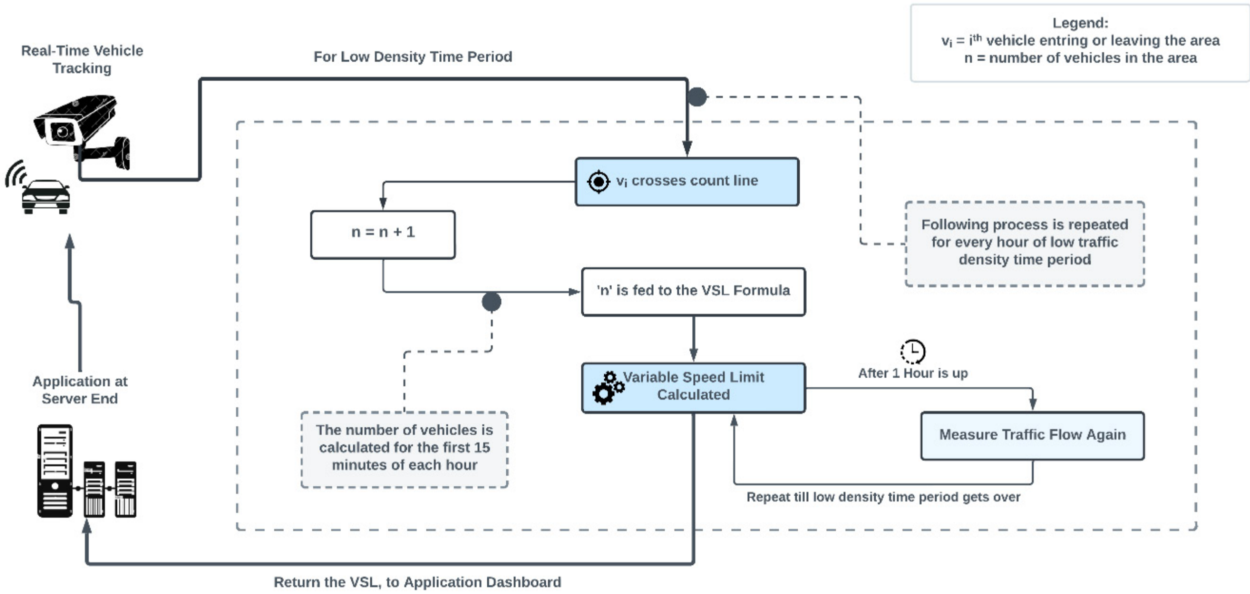

Fig. 3. Process Flow Diagram for Video Analyzer

The video analyzer is employed to be tested during different intervals of the day. For this purpose, the entire day is divided into six durations, each having a difference of 4 hours. Thus, the intervals are- 12 A.M., 4 A.M., 8 A.M., 12 P.M., 4 P.M., and 8 P.M.

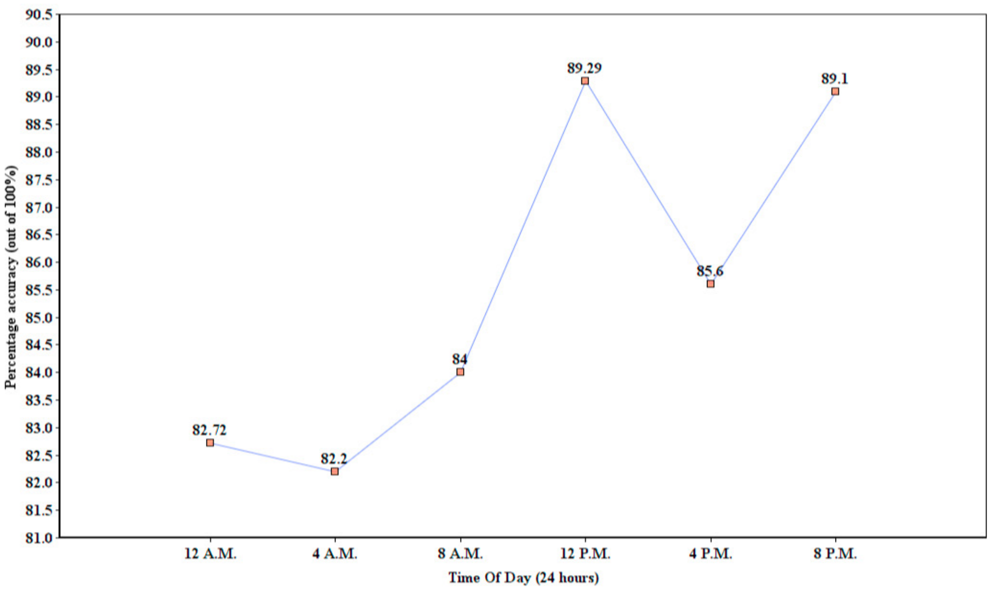

Fig. 4. Percentage Accuracy Upon application of Video Analyzer in Real-Time

For instance, upon application of Video Analyzer at 8 A.M. on 'Kalkaji-Mandir Bi-way Lane' for a duration of 15 minutes, the vehicle count was 91 whereas originally 110 vehicles crossed.
Using the approximation calculation, the video analyzer predicted with a percentage accuracy of :

∴ Percentage accuracy (at 12 A.M.) = 100 - ((Original Count – Estimated Count) / Original Count)
= 100 - ((110 - 91) / 110) = 82.72%.

⇨ Percentage accuracy of model = (82.72 + 82.20 + 84.00 + 89.29 + 85.60 + 89.10) = 512.91/6 = 85.49%

Thus, employing the formula as discussed in equation (1), we have the parameters as k_j = 700 veh/hr per km, u_f = 70 km/hr for road, the marked speed limit for which is 60 km/hr.
Then, if q = 110*4 = 440 veh/km,

$$u = \frac{70}{2}\left\{1 + \sqrt{1 - \left(\frac{4 \cdot 440}{80\,.\,700}\right)}\right\} = 68.4,$$ which is approximately 68 km/hr.

Hence, we can draw a parallel between the static/fixed limit compared to the computed VSL value.

5. Results and Discussion

When the idea for the system was first conceived, it was mainly aimed at increasing the speed limits for a road segment when the traffic conditions depicted situations of light traffic density and traffic flow. This would have helped improve the efficiency of the transportation industry, which mainly functions during the nighttime (i.e., a period of low traffic density), by cutting the travel time for the delivery journeys. This would have, in turn, reduced the overall cost of industrial processes.

However, a brief study of the actual concept of VSL showed that it has many other benefits as well, which are:-

- **Smoother Traffic Flow:**
  The VSL system actively manages the traffic speed based on the traffic situations to improve the safety of commuters and the traffic flow. Some other advantages that may be related to the same are shortened traffic queues, reduced congestion, and stop-go traffic, smoother traffic flow, quicker dispersal of traffic during incidents like pile-ups, and overall fewer crashes.

- **Safer work-zone speeds:**
  While it's known that night-time construction procedures can effectively reduce congestion and shorten queues, the lower volumes of traffic can make people go at speeds faster than can be safe. VSL systems would reduce the speed limits so that the vehicles can approach such areas at controlled speeds, and the safety of the travelers can be ensured.

- **Combination with Weather Information Systems:**
  The weather conditions can have a major impact on on-road travel. And that's where the beauty of VSL systems lies. They can be used in combination with the Road Weather Information Systems to get a general idea about the weather conditions that might be observed on that day and can set the speed limit parameters accordingly, effectively tackling the unruly situations that may arise due to them.

Apart from these, the system being suggested also has some major and minor advantages over the previous versions and models. For example, Dynatrack is designed as a direct-interaction system, meaning that the user can directly use the app to "communicate" with the system which allows the user to be intimidated beforehand about the situations and speed limit for the upcoming road segments. Also, the system is relatively lightweight and hence the stress caused to the system during processing would be reduced.

Having discussed this, however advantageous a system may be, its effectiveness and benefits can be completely negated by the challenges that may be encountered in its execution. And the same is true for the VSL system that has been developed, which comes with its fair share of difficulties that might be faced during its execution. Some of these are:-

- **Enforcement of VSL:**
  Nearly everywhere the VSL speed limits were executed, there arose the issue that the local law enforcement was unaware of the changes being done by the system, which led to general confusion and disagreement between the commuters and traffic enforcement agencies. This may, however, be countered by making sure that the authorities are aware of the speed limits that are being set by the system.

- **Driver Compliance:**
  The degree of success of any system is dependent on how well the users or the people affected by the system follow them. The major issue that would arise when such a system is applied in Indian Transport Networks, is going to be that the general public would need to be made aware of the system and its functioning. Also, it would be vital that the commuter strictly follow the system rules to the point.

- **Failure of hardware and/or software:**
  Minnesota is one of the locations where the concept of VSL has been in application for quite some time now. It was observed that there was a life shorter than the expected one for their VSL signboards. Similarly, Nevada has also been experimenting with the concept and has been facing issues where the speed limits being displayed in the same were different when they should have been the same. They have also seen their signboards or indicators going blank, not displaying the speed limits. Also, it has been observed that there is a constant need to keep changing the technologies in use to ensure the high efficiency of the system.

- **Data lag:**
  Though the results may depend on the algorithm or system or the source of data being employed, it is often observed that there is a delay in the processing of data due to which the sign system is unable to display the speed limits being calculated, causing an issue untimely posting/removal of the suggested speed limits.

- **Going back to marked speed limits:**
  This is another one of the main issues being faced with the VSL systems is the fact that the engineers often become so engrossed in the development process that they seem to forget a core point, i.e. the speed limits need to be returned to normal values soon as the conditions drop back to their typical values. The better and quicker a VSL system can transition a driver to the marked/authority-set speed limits, the better and more efficient it is considered.

- **Lack of funds/grants for VSL systems:**
  Since the work done in the field of VSL and smart traffic management seems mostly theoretical and hasn't been sufficiently and greatly experimented with, the general awareness of the concerned authorities about the topics remains pretty limited. To ensure efficient execution of these systems, the officials would need to be made familiar with the concepts and technologies being used, their advantages, and how they vastly outweigh the cost incurred if the execution of such systems needs to be made successful in the country.

The suggested system also tackles these drawbacks, proving it advantageous over the other models. Since the system would involve maintaining a database of the variable speed limit values, the authorities can be notified of the changes using the same. Also, since the vehicle counter is operated in intervals, the load on the supporting infrastructure like the digital sign boards is drastically decreased, reducing the strain and hence the chance of failure of these. Some previous VSL systems also faced the issue of data lag.

In Dynatrack however, since the formula and procedure for calculation of VSLs are very straightforward and non-complex, this issue is also taken care of. The last issue was regarding funding and grants. However, the system that we are proposing builds on the already existing resource of the High-Speed CCTV camera Grid and database, the only major cost incurred would be in developing the application and installation/maintenance of digital signboards as and when needed.

Finally, we can discuss the future scope of the system discussed in the paper and hence VSL technology as a whole. Even though the technology shows great promise and potential to greatly transform the road and transport industry as it is, it is the ability of the VSL systems, which allows it to be coupled with various other models and technologies, that can prove to be the real game-changer. It can vastly increase the efficiency of the system, providing enhanced features and functionalities and an overall improved and smoother user experience. So of these systems that can be integrated with VSL systems are:-

- Smart Traffic and traffic light management systems.
- Location-based recommender systems may assist in cases related to information overload [17].
- The traffic authorities can enforce a multi-lane system as used for highways. The individual lanes can be separately monitored, the commute on them being limited or completely closed if the traffic flow seems to be obstructed in that lane or if there is a situation of pileup or other such incidents.
- The variable speed limit systems may even be directly coupled with the autonomous vehicle systems, which can make the task of monitoring and tracking them somewhat easier.

Though these systems, which are just a few of many others, are purely a suggestive component of the VSL system, if executed, they can prove to be extremely fruitful if applied, and the roadblocks of user compliance and other such issues are overcome.[18]

The focus was on designing a VSL-based system and overcoming the limitations of existing methods, which relates to their inability to adapt to modern traffic situations. The researchers devised a model which could achieve an accuracy of about 86% as discussed in the previous section. The proposed work, if implemented in real traffic scenarios, can prove to be a bane for many people rushing out to reach their workplace on time, for those looking to save every inch of time they have, and for those who always want to get rid of the headache of driving on roads. Hence, it may guarantee a hassle-free driving experience.

6. Conclusion

In this paper, at first, we discussed the scenario of the current traffic clogging and the need for an efficient solution, to tackle the same. The concept of Variable Speed Limits was thus introduced, and all relative parameters on which it relies were discussed. A study of the past works provided a base for simulation-based VSL system modeling to investigate the potential benefits.

In later sections, the process of determining VSL was addressed, which included GPS tracking of the user's vehicle, obtaining the absolute road speed limit, analyzing the current road conditions, and thereafter perceiving the current road density via road safety cameras. We also talked about pushing the alerts/notifications to the driver.

Next, we discussed some statistical data regarding the performance of the system and discussed various its advantages and how it would tackle the drawbacks of its predecessors. These included efficiency of economy and resources, reduced lag in processing, reduced load on technical infrastructure, and so on.

Further, it can be discussed that fuel consumption will substantially be reduced, as are CO_2 and NO_x emissions, which shows an environmentally friendly aspect of the proposed VSL system.

This paper leaves scope for further research by implementing some new ways to improve the efficiency of the techniques and studying the loopholes in these techniques and finding solutions for that. The concept of Dynatrack was conceived with the idea of simplicity, ease-of-use-&-implementation, versatility, and the chances of seamless integration with other models in mind, and an attempt has been made while keeping in mind the same.

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