A Critical Review of Road Accident Prediction and Analysis Techniques, Data Sources, Challenges and Opportunities in Future Developments

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Abstract—In today's era, road accidents are highly increasing across world, leads to cause severe injuries and death on every year. It has also imposed with economic loss, financial crisis for the society. Day by day, the road accident occurrence remains as an inevitable factor. Therefore, the accident prediction model is required to develop and deploy for evading such kind of calamities. Researchers have focused on designing a significant impact of model for analyzing the road accident scenarios. It is accomplished with the help of standard techniques, algorithms. Despite many techniques have explored, the victims count is increased. Also, the identification of cause for road accident is quite challenging task since it holds with large dimensional data or depends with one or multiple factors. As traffic accidents caused by various reasons, the rising of automated model becomes the best solution. In such way, enormous techniques have been implemented to reach the best value as well. Over the decade, the research is going on deeper to forecast the accidents that can influence with the risk of traffic rules and facilities. In this survey, different and existing road accident prediction models are analyzed. For better presentation, the road accident and its problem are given. Several learning methodologies are used for the purpose of enhancing the prediction performances that is also to be analyzed. The prediction techniques suggested for identifying the road accidents in the existing research works is analyzed and categorized. Different types of performance metrics used to verify the performance of each prediction model in existing literatures is checked. Future developments are discussed to improve the capability of road accident prediction models.

Keywords—Road Accident; Prediction and Analysis: Literature Works; Machine Learning Model; Deep Learning Nework; Performance Indices; Research Gaps; Future Scope

I. INTRODUCTION

In the world, the major threat is becoming increased by the crash rate of vehicle when it is travelling on the road [1]. Unfortunately, the road accident is an unexpected factor for the passenger or driver although it is quite happened. Owing to this incident, the cost of traffic injuries has been highly maximized across global [2]. The prime cause of road accident is getting involved with multiple factorials and a greater number of people using the bikes, cars and so on [3]. Executing the technological features and adapting of traffic rules might have reduced the accident rate. Nevertheless, the number of victims is still high with beyond expectation level [4]. It may occur based on the situation existed. But the major problems are raised by some mechanical factors, physical and mental illness, fatigue, weather conditions, holes in road and so on [5]. These constraints are the cause of car crashes with the involvement of predefined crash factors as vehicles, human and road infrastructure [6]. Hence, the decision making in road safety measures are the highly complex process, where it involves with higher officials like politicians, public, experts, etc., and along with problems as mobility, environmental and economical [7]. It could be competed with limited available of sources, becomes a quite challenging task [8]. Additionally, the decisive way is not only justifying the safety factors with efficiency, but also focusing on the skeptical factors that to be convinced in hostile manner [9]. Hence, the accident prediction is developed effectively with the better sound indication of system efficacy regarding the casualties and accident [10].

Road accidents are the uncertain things, random events that can occur at any place [11]. Hence, the researchers have been concentrated on finding the deeper knowledge of influencing the major risk factors. Thus, it is there with greatest significance of predicting the traffic accidents, which helps to assess the road safety [12]. Many existing studies have been analyzed and investigated for forecasting the road accidents. Statistical techniques like linear regression have been employed foremost for identifying the road accidents in an early time [13]. But this model still faces with certain countermeasures of data like traffic mix, user behavior, and road quality and so on [14]. Apart from this model, learning methodology has been developed to predict the accidents. Artificial Neural Network (ANN) is one among the intelligent network that incorporating with the flexibility of predicting the accidents. Henceforth, machine learning and deep learning models are immensely involved in accident analysis to provide the impressive outcome of preventing the injuries.

Some of the major contributions are explored for accident prediction as follows:

- ♣ To present the short review of road accident prediction and analysis model using various methodologies and its concept of improving the system performance.

♣ To study the previous deployed papers of road accident forecasting, where it explains with techniques used for prediction with other processing steps.

♣ To categorize the different prediction model and evaluation metric analysis while predicting the road accidents for effective exploration of review work.

♣ To provide the research challenging gap and future work paves for better designing of prediction model.

The organization of the survey paper is explained as: Followed by introduction, the problems of road accident and literature works have been explained in Phase II. Subsequently, the Phase III elaborates the model categorization and performance metrics for analyzing the performance. The challenging issues directs to future work is explained in Phase IV. Finally, the summary of the work has been demonstrated in Phase V.

II. PROBLEM FORMULATION AND LITERATURE ANALYSIS OF TRAFFIC ROAD PREDICTION AND ANALYSIS

A. Road Accident and its Problem

Road accident plays a pivotal role in integrating, managing and planning the traffic [15]. On the other hand, the traffic accident is caused by non-linear particles like car, climate, people and road. Therefore, the injuries and fatalities could be resulted as major problem in India. To overcome such accidental issues, an effective prediction model is advised to manage the traffic without any crashes of vehicles, particularly in metropolitan city, national state [16]. Some common problems are explained as follows.

♣ During the season of May-June and December-January, the weather condition gets worsen that make the person to drive the vehicle improperly; finally, it leads to cause crashes.

♣ Accident may also degrade the road safety [17], which makes the people difficult even walking or cycling on the road.

♣ Another problem is driving the vehicles during the peak time of week days. Thus, the accident remains consistently over this time period. Severe injuries are also occurred due to accidents.

Hence, the focus is to identify the accident for improving the securities with the potential of addressing the specific road accident problems.

B. Literature Works

In 2018, Garca et al. [18] have explored the method for accomplishing the accident risk forecasting, which could be further used for making the decision to manage the infrastructure. This was allowed to handle the available set of data and at last examined with the Artificial Neural Networks

(ANNs). In this systematic ANNs, the optimization method was done to estimate the optimum structure of the network to enhance the performance. For experimentation, the data was acquired at Swiss roads from the year of 2009 to 2012. Therefore, the ANN model was employed to predict the accidents with the occurrence of appropriate outcome. On the contrary, the proposed system has achieved the less error value of predicting the accidents.

In 2018, Parvareh et al. [19] have explored the better model of finding the traffic conditions over the region of Kurdistan, Iran. This has been conducted with the characterization and prediction of road accidents based on time series analysis. The injuries were made during accidents, has been distinguished by pedestrians, car vehicles and motorcyclists. Hence, the data acquired from the "Autoregressive Integrated Moving Average (ARIMA) and Seasonal ARIMA (SARIMA)" during the year of 2009 to 2015. Finally, the analysis has been made to carry out the extensive results.

In 2019, Ryder et al. [20] have addressed the existing gaps of road accident prediction model, which was gathered the data from the region of Switzerland. Data fetched from CAN bus of such vehicles that were indicated with the mutual relationship of vehicle fleet and crash rate of accident location. Subsequently, the spatial regression evaluation has been made with CDEs as well as trip frequency. Hence, it has been highlighted with emerging spots to easily forecast the accidents. In 2020, Al-Omari et al. [21] have developed the method of GIS and fuzzy logic. The data utilized for accident types for analyzing the model. Consequently, the major hotspots were identified by "Fuzzy Overlay Method (FOM) and Weighted Overlay Method (WOM)". The outcome has been rendered by "Analytic Hierarchy Process (AHP)" with Point Destiny (PD). The final outcome of the model has been provided with road sections with proper values.

In 2020, Yassin and Pooja [22] have proposed the hybrid approach of K-means and Random Forest (RF) for prediction. Here, the k-means algorithm has used for extracting the features of raw data. Further, this resultant feature was subjected into the RF model to provide the predicted result. Therefore, the experimental findings have demonstrated that the model attained the superior results. In 2022, Wakatsuki et al. [23] have employed the CNN model for prediction. On the analysis, the previous study has contained the traffic data details like volume, traffic, speed and so on. Along with this, the time related data and weather data has included. Thus, the chosen information has been represented for easily train the model. After the validation, the proposed work has provided the effective results. In 2023, Raja et al. [24] have presented with six different neural network models for performing the prediction of road accidents. While implementing such techniques, the GUI has been generated in Python platform. In the overall model, the RNN has achieved the high accuracy value that could avoid the accidents.

In 2024, Wei [25] have concentrated on the Internet of Vehicles (IoV)-aided approach for tackling the road safety measures. For improving the safety, certain attributes were taken as weather condition, road traffic and external factors.

This kind of attributes has processed in the convolution deep learning network model with spatial and temporal features. Thus, the significant results were obtained to enhance the system performance. In 2018, Ihueze and Onwurah [26] have developed the ARIMA along with its explanatory process (ARIMAX). The results have showcased the better performance of forecasting the road accidents in terms of less error rate. On compared with other Bayesian models, the findings have declared the supremacy of predicting the accidents.

In 2021, Tian and Zhang [27] have utilized the k-means approach for solving the prediction issue. This work has concentrated on clustering approach used for analyzing the feature space of the model. Finally, after the simulation, the outstanding results were obtained to easily and effectively evade the road accidents with an attainment of high accuracy. In 2020, Singh *et al.* [28] have employed the "Deep Neural Networks (DNN)" for accident prediction. Since this model has encompassed with two more hidden layers, it has trained well and used for testing purpose. The data has been totally collected as 2680 records for prediction. Finally, the higher results have paved the way for identifying the accident spots significantly. In 2021, Jha *et al.* [29] have applied the six various types of learning models for accident prediction. The performance of the system has been examined with five and ten-fold cross. This work has investigated with possible factors to deliver the numerical results. Overall, the SVM model has produced the impressive results of prediction accuracy.

In 2023, Baek and Chung [30] have demonstrated the attention-aided LSTM network for risk prediction. Initially, the raw data was getting pre-processed, and then the correlation among the variable has been computed. Correlation and regression coefficient were used in the model of attention-based LSTM. Subsequently, the loss function has been evaluated. Therefore, the less error value was acquired to improve the prediction performance. In 2021, Sangare *et al.* [31] have explained the Gaussian model along with SVM for prediction. Hence, the experimental outcome has delivered the maximum true value while predicting the accidents.

In 2021, Yu *et al.* [32] have built the "Deep Spatio-Temporal Graph Convolutional Network (DSTGCN)" for accident forecasting. It has encompassed with three modules; the first module was used for extracting the spatial information, whereas the second module utilized the convolution for capturing the spatial and temporal features. Then, the final module was aimed to get the semantic feature information. Simulation results have revealed the efficacy of proposed system. In 2022, Tian and Zhang [33] have solved the issue of prediction in urban regions; this was further tended to acquire the high prediction accuracy value as 94%.

In 2023, Azhar *et al.* [34] have explained the deep learning network for predicting the accidents using the tweet messages. The outcome has provided with higher detection accuracy rather than traditional approaches. In 2022, Charandabi *et al.* [35] have presented the self-organizing map model for predicting the road accidents. This system has been estimated with 22 various predictor features included with weather,

temporal and geographical attributes. Finally, the efficacy of the model has done with divergent metrics and compared with baseline methods. Thus, the proposed work has provided the outstanding results of finding the accident spot.

III. VARIOUS PREDICTION MODEL AND PERFORMANCE METRICS USED FOR ROAD ACCIDENT FORECASTING

A. Prediction Model: Categorization

In order to predict the road accidents, various prediction models have been deployed and implemented. Being with the foremost process, the required set of data has been collected and given to the aforementioned models. Since the prediction uses machine and deep learning model, it needs two major phases as training and testing. The model has trained effectively with the feature specification to deliver the expected outcome. Learning methods like autoregressive model [19] [23], clustering method as k-means algorithm [22] [27], machine learning model as ANN [18] [34], RF [22], SVM [29] [31] and most effective deep learning technique as DNN [28], LSTM [24] [30] [34]. All these models have been employed with various steps in order to predict the road accident.

Regression model: It belongs to the supervised learning approach mainly used for predicting the target with sequential data values, can be applied for various purposed. The ultimate aim of this algorithm is to render the better relationship among the target variables and input features. Hence for the literature analysis, the road prediction has been deployed with some autoregressive models as mentioned in the review paper [19] [26].

Machine learning: It is an algorithm employed for making the prediction with the help of given input data source. The learning classifiers are processed as like the human brain neural activities. Thus, most of the networks have been structured with multiple layers with an appealing of neuron connection between them. Such classifiers are explained as follows:

- ANN [18] [34]: This model is processed with the three major layers as input, hidden and output layer. Once the input is given at the input layer, it is then fed into the hidden layer, where the major operation is taken place in terms of weight and bias term.

- SVM [29]: It is performed with the hyper-planes, in which it classifies the two outputs as either normal or abnormal.

Deep learning: It is an advanced or sub-set type of machine learning model, where it allows the network to build itself to retrieve the essential features while training the network. This feature has been learnt to pave the way for attaining the desired classified result. Hence, some models are used to forecast the accident.

- DNN [28]: It is structured with three most layers for rendering the effective outcome. Between the input and output layers, multiple layers are

included where the features have been learnt weight and bias factor.

- LSTM [24] [30] [34]: It is an advanced version of RNN process. This network is built with the input, forget and output gate. This gate mechanism is helpful for removing the past state information.
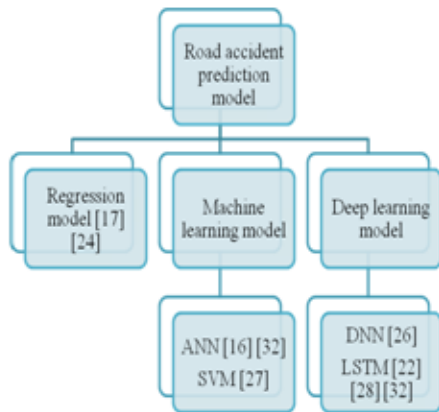

Fig. 1 Prediction model categorization for finding the road accidents.

Fig 1. Depiction of prediction model categorization for road accident analysis

B. Evaluation Measures

Multiple indices are taken to provide the appropriate results. True and false measures are considered for ensuring the system efficiency. Measures like Symmetric Mean Absolute Percentage Error (SMAPE), Sum of Squared Error (SSE), Akaike Information (AIC), Bayesian Information Criterion (BIC), Pearson Correlation Coefficient (PCC), and MAPE are assumed. Moreover, the common prediction performance is evaluated with true rates as precision, recall, f1-score and accuracy. These metrics are used in the literature papers, renders with desired results to prove the system efficacy. Hence, such metric analysis has been given in the Table I.

TABLE I.   PERFORMANCE MEASURES ASSUMED FOR VALIDATING THE ROAD ACCIDENT PREDICTION MODEL

Citations	Accuracy	Precision	Recall	RMSE	F1-Score	Miscellaneous measures
[18]	-	-	-	-	-	SMAPE, SSE
[19]	-	-	-	-	-	AIC, BIC
[20]	-	-	-	-	-	Jerk rate, trip frequency
[21]	-	-	-	-	-	Risk degree
[22]	✓	✓	✓	-	✓	SSE
[23]	-	✓	✓	-	✓	-
[24]	✓	✓	✓	✓	✓	Kappa coefficient, AME
[25]	✓	✓	✓	-	✓	-
[26]	-	-	-	✓	-	BIC, MAPE
[27]	✓	-	-	-	-	Congestion time
[28]	-	-	-	-	-	BIC, AIC
[29]	✓	-	-	-	-	-
[30]	-	-	-	✓	-	-
[31]	-	✓	✓	-	✓	-
[32]	-	✓	✓	✓	✓	PCC
[33]	✓	-	-	-	-	-
[34]	-	✓	✓	-	✓	-
[35]	✓	-	-	-	-	-

IV. CHALLENGING GAPS AND FUTURE RESEARCH FOR ROAD ACCIDENT ANALYSIS

In today's world scenario, the vehicle involvement becomes huge in transportation sector [36]. Traffic accidents are the inevitable one that can occur at anytime and anywhere. The road accidents are normally caused by external factors as weather, road quality and internal factors as mental and physical status of driver, illness and so on. Henceforth, the road accident prediction is requisite for managing the transportation system and avoiding the major injuries. Though some of the models are being more robust, still it has the room for further enhancement. Some challenges with the direction of future work are listed as below:

- ❖ The general prediction system can acquire the output of occurrence of accidents. Yet it fails to deduce the prediction error while analyzing the model. Hence, it could be further upgraded into consideration of other constraints like driver

experience, age, vehicle factors. Thus, the model will be extended to resolve the over-dispersion scenario of prediction.

❖ Due to the automation of the vehicle, it could be able to drastically make changes in the structure for incurring the accidents. Hence, it will be a serious issue in the upcoming development.

❖ Some of model has utilized the clustering mechanism for forecasting the accidents, but it is not able to collect the specific set of data related to the road details [37]. Another standard datasource could be strengthened for performance improvement.

❖ While using the learning approach, the data size becomes inadequate and it is also limited with data resources [38]. According to this, the best accuracy value is not able to acquire for predicting the accidents.

❖ In order to scale-up the data quality, the real-time data set will be considered mostly belongs to the metropolitan area, for example, it holds the information of categorical and sequential.

❖ The data will be gathered about the unknown vehicles used effectively in the case of hit-and-run road accidents.

On accounting such counterfeits, the prediction model will be designed efficiently to focus on majorly evading the accidents and injuries.

V. SUMMARY

This review work has explored the short literature analysis of road accident prediction model. The existing models have demonstrated over the past years with its advantages. Subsequently, the causes of road accident have also discussed. Based on the survey, multiple prediction models were noted and make it into a better categorization. For proving the system efficacy, the prediction system has been validated with true rate, false rate and error, etc. This could be helpful to provide the supremacy of the systems. Finally, the challenging gaps were discussed to pave the way for developing the automated prediction model in near future.

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