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E-Mail :
editor.ijasem@gmail.com
editor@ijasem.org

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OPTIMAL AMBULANCE POSITIONING FOR ROAD ACCIDENTS WITH DEEP EMBEDDED CLUSTERING

[1]Mr.B.Narsingam (Assistant professor)
[2]M.Rishitha (21R91A05G7), [3]N.Manikarnik (21R91A05K0), [4]M.Vasanth (21R91A05F0)

Abstract: Reducing casualties and fatalities from road accidents is a critical global concern. Pre-positioning ambulances instead of dispatching them on demand can significantly decrease response times and provide timely medical assistance. A deep-embedded clustering-based framework is proposed to predict optimal ambulance locations by analyzing patterns and factors influencing road accidents in a geographical region. The framework integrates a novel deep-learning model, Cat2Vec, to preserve these patterns during model building and ensure real-time results. Traditional clustering algorithms such as K-means, Gaussian Mixture Models (GMM), and Agglomerative Clustering are also evaluated for comparison. A novel scoring function is introduced to calculate real-time response times and distances for performance evaluation. The proposed approach achieves superior performance, with a clustering accuracy of 95% using k-fold cross-validation and significantly outperforms traditional methods with a novel distance score. The results demonstrate the effectiveness of the deep-embedded clustering framework in optimizing ambulance positioning, offering a robust solution for enhancing healthcare service response efficiency in accident-prone regions.

Index Terms: *Deep embedded clustering (DEC), Cat2Vec, K-means, ambulance positioning, accident hotspots.*

1. INTRODUCTION

Road accidents remain one of the leading causes of death worldwide, affecting both children and adults. The injuries caused by these fatal accidents result in significant economic and personal losses to individuals, families, and nations. An estimated 1.3 million individuals lose their lives each year due to road accidents, while between 20 and 50 million suffer non-fatal injuries, many of which lead to disabilities [1]. This growing issue has been exacerbated by the rapid increase in the number of automobiles, especially in densely populated urban areas, placing immense pressure on infrastructure. Without decisive precautionary measures, road accidents are projected to become the fifth leading cause of death by 2030. Despite these dire consequences, road safety receives insufficient attention, and systematic approaches to mitigate these statistics remain underdeveloped.

More than 90 percent of global traffic accidents occur in medium to lower-income countries, with Kenya serving as a notable example [2]. In Kenya alone, over a thousand fatalities result from road crashes annually, with an average of 7 fatalities out of 35 casualties reported daily [3]. According to reports from the National Transport Safety Authority (NTSA), 2019 recorded 5186 minor injuries, 6938 major injuries, and 3572 deaths from road accidents [4]. These incidents disproportionately impact individuals aged 15-59, who represent the economically active population, thereby diminishing the country's economic productivity. As a lower-middle-income nation, Kenya has witnessed an increase in regional trade deals, further contributing to the growth of vehicular traffic and the challenges associated with road safety.

Prompt medical attention, accurate data analysis, and timely response are critical to reducing injuries and fatalities caused by road accidents. Delays in ambulance arrival during emergencies significantly affect survival rates. If medical aid fails to reach accident sites within the critical "golden hour," casualties can increase dramatically. Urban areas, characterized by high traffic congestion and unique layouts, present significant challenges in determining optimal locations for emergency responders. The lack of expertise in systematically stationing ambulances further complicates efforts to address this issue effectively.

Strategically pre-positioning ambulances can mitigate these challenges, ensuring faster response times and better medical outcomes. Automated systems to predict accident-prone zones and assign ambulance locations based on real-time data analysis could enable first responders and medical personnel to make timely decisions. Such measures would help save lives, reduce economic losses, and alleviate the burden on urban infrastructure, particularly in lower-income regions like Kenya where the impact of road accidents is disproportionately high.

2. LITERATURE SURVEY

Road traffic accidents are a leading cause of fatalities worldwide, with significant social and economic implications. Addressing this issue requires innovative approaches that leverage advanced computational techniques to predict and mitigate accident risks. Several researchers have explored machine learning, deep learning, and optimization-based methods to improve emergency response systems, predict accident severity, and strategically allocate resources such as ambulances. These methods aim to analyze complex datasets, identify patterns, and provide actionable insights for reducing casualties. The following literature survey examines notable contributions in this domain, focusing on methodologies, proposed frameworks, and their effectiveness in enhancing road safety and emergency response.

Maghfiroh et al. [6] proposed a method to minimize ambulance response times in Dhaka, Bangladesh, by pre-positioning ambulances strategically across the city. Their study utilized optimization techniques to identify optimal locations for ambulance placement, considering the high density of traffic and the geographical layout of the city. By analyzing historical accident data, they developed a framework that significantly improved emergency response efficiency, highlighting the importance of pre-positioning as a practical strategy in urban areas.

Assi et al. [7] introduced a novel approach that combined machine learning algorithms with clustering techniques to predict the severity of injuries sustained in road crashes. The study demonstrated the potential of integrating unsupervised learning methods with supervised classification models to improve the accuracy of crash severity prediction. By synergizing clustering methods with advanced machine learning techniques, the research offered a robust protocol for assessing injury severity, which can inform better deployment strategies for emergency response systems.

Granberg and Nguyen [8] explored simulation-based techniques to predict the near-future states of emergency medical service systems. Their study emphasized the dynamic nature of EMS systems and the need for predictive capabilities to improve resource allocation. Using advanced simulation tools, the research provided a mechanism to

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anticipate emergency demand and suggested ways to optimize ambulance pre-positioning to address the predicted needs effectively.

Zheng et al. [9] applied deep learning techniques, specifically a convolutional neural network (CNN), to predict the severity of traffic accidents. The study leveraged the high capability of CNNs to extract spatial and temporal features from accident-related data. The approach demonstrated remarkable accuracy in identifying patterns related to accident severity, proving deep learning as a powerful tool for enhancing predictive analytics in traffic accident management.

Xiong et al. [10] proposed a framework combining support vector machines (SVM) and hidden Markov models (HMM) for vehicle collision prediction. Their hybrid approach successfully captured both spatial and sequential dependencies in traffic data, enabling accurate prediction of collision probabilities. The combination of SVM and HMM offered a reliable solution for predicting accident-prone situations and provided valuable insights for designing preemptive safety measures and ambulance allocation strategies.

Tiwari et al. [11] evaluated the performance of various classification algorithms, including decision tree classifiers, lazy classifiers, and multilayer perceptrons (MLPs), in analyzing traffic accident data. Their results indicated that MLPs outperformed other models in terms of accuracy, demonstrating the advantages of neural networks for capturing complex patterns in accident datasets. The study underscored the relevance of comparing multiple algorithms to identify the best-performing models for traffic incident analysis.

Alkheder et al. [12] employed an artificial neural network (ANN) to predict the severity of traffic accidents. By analyzing historical accident data, their study successfully identified key factors influencing accident severity, such as weather conditions, road type, and vehicle speed. The ANN-based approach proved to be a highly effective method for severity prediction, emphasizing the importance of leveraging advanced neural architectures in traffic safety research.

Hashmienejad and Hasheminejad [13] proposed a novel multi-objective genetic algorithm (MOGA) for predicting traffic accident severity. Their approach combined optimization and machine learning techniques to address the multi-faceted nature of traffic safety analysis. By incorporating multiple objectives, such as minimizing response time and improving prediction accuracy, the study offered a comprehensive framework for managing road safety more effectively.

3. METHODOLOGY

The dataset includes information on traffic accidents that occurred, road segment information, and weather details of Nairobi, Kenya. Performing Exploratory Data Analysis on the dataset of the road surveys, and weather dataset, the paper identifies possible features and attributes affecting the accidents and patterns of risk across the city. To preserve such relationships and patterns of the data we apply a deep learning-based embedding approach called Cat2Vec while converting categorical attributes in the data pre-processing stage. To validate the predicted locations using DEC, the distance from that crash site to the nearest ambulance locations predicted is calculated using a novel Distance Scoring Algorithm. For further evaluation of the algorithm, different clustering metrics have been used and compared with other traditional clustering algorithms.

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Vol 18, Issue 4, 2024

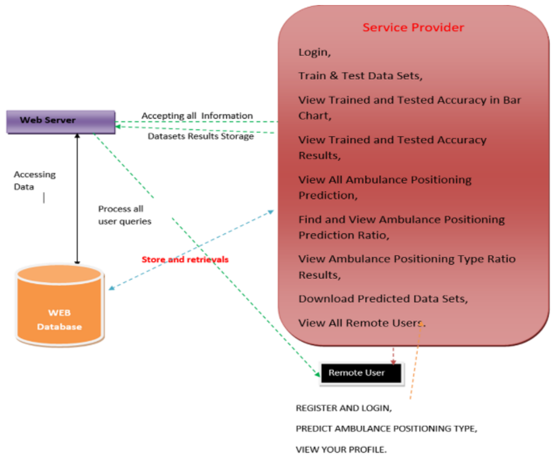

Fig.1 Proposed Architecture

This system utilizes a web server and database to accept and store information related to road accidents and ambulance positioning. It processes user queries, retrieves stored data, and provides various functionalities for remote users. These functionalities include registration, login, prediction of ambulance positioning types, and viewing user profiles. The system also allows the service provider to train and test data sets, view accuracy results, and manage remote users.

a) Data aquisition module:

The data acquisition module gathers real-time information from multiple sources to improve ambulance positioning for road accidents. Traffic Sensors collect data on vehicle movements and congestion patterns, while Weather Data integrates real-time conditions affecting road safety. This module ensures comprehensive and up-to-date inputs for accurate analysis and decision-making.

b) Clustering algorithm module:

The clustering algorithm module optimizes ambulance deployment by analyzing real-time data. Data Collection gathers information on traffic conditions, accident hotspots, and ambulance availability. Optimal Positioning identifies strategic locations for ambulances to reduce response times, ensuring efficient emergency services.

c) Predictive modeling module:

The predictive modeling module forecasts accident occurrences to improve ambulance readiness. Accident Hotspots are identified using historical data to predict likely crash locations. Ambulance Demand predictions help allocate resources effectively, ensuring timely responses and efficient coverage.

d) Optimization module:

The optimization module enhances ambulance allocation to minimize response times and maximize coverage. Resource Allocation uses algorithms like genetic algorithms and simulated annealing for precise positioning. Dynamic Adjustments integrate real-time data and predictions for continuous optimization of ambulance placements.

e) Communication module:

The communication module ensures seamless real-time coordination among stakeholders during emergencies. Data Transmission facilitates sharing of critical information, such as accident locations and ambulance availability, between dispatch centers, emergency services, and ambulances. This ensures faster decision-making and response.

4. EXPERIMENTAL RESULTS

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Fig.2 Login page

Fig.3 Service Provider

Fig.4 Chart Bar

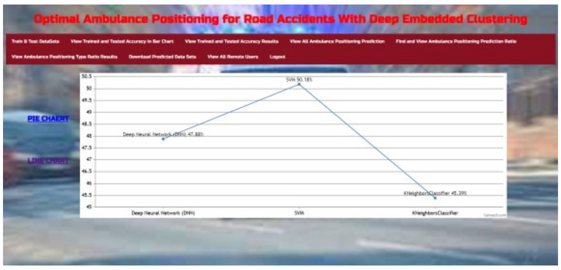

Fig.5 Accuracy Results

Fig.6 View All Ambulance Positioning Prediction

Fig.7 Prediction Ratio

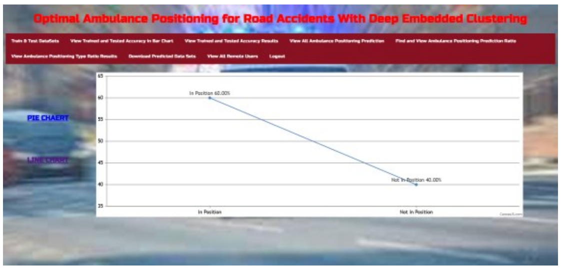

Fig.8 View Ambulance Positioning Type Ratio Results

Fig.9 View all Remote Users

Fig.10 Predict Ambulance Positioning Type

5. CONCLUSION

In conclusion, the developed models for predicting optimal ambulance positions in Nairobi city demonstrate the significant potential of deep

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learning and clustering algorithms in traffic safety management. By utilizing the Cat2Vec model for encoding categorical data, the study successfully identified optimal ambulance locations through a clustering-based approach using Deep Embedded Clustering (DEC-AE). The DEC-AE model outperformed traditional clustering algorithms, such as K-Means, GMM, and Agglomerative clustering, achieving an impressive accuracy of 95% in k-fold cross-validation. Furthermore, the Distance score of 7.581 highlights the effectiveness of the DEC-AE model in minimizing the distance between predicted ambulance positions and accident hotspots. The evaluation metrics, including the Silhouette score and Davies Bouldin Score, confirm the superior clustering performance of the DEC-AE model, ensuring more precise ambulance positioning. This study offers valuable insights into improving emergency response times and provides actionable recommendations for decision-makers to optimize ambulance deployment and enhance road safety initiatives. Ultimately, the findings contribute to the ongoing efforts in reducing fatalities and injuries caused by road accidents.

The ***future scope*** of ambulance positioning systems lies in integrating real-time data from traffic, weather, and accidents to dynamically adjust ambulance locations. Leveraging reinforcement learning for dynamic fleet management, geospatial neural networks for accident-prone area prediction, and smart city infrastructure integration will further enhance efficiency. Ensuring safety, fairness, and addressing privacy concerns will be essential. The combination of deep learning, edge computing, and IoT will lead to optimized emergency response, improving both resource allocation and patient care outcomes.

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