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Road Crash Injury Severity Prediction Using A Graphical Neural Network Framework

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ABSTRACT

Road traffic accidents remain one of the leading causes of fatalities and severe injuries worldwide, demanding accurate and timely injury severity prediction to improve emergency response and resource allocation. Traditional statistical and machine learning models often fail to capture the complex spatial, temporal, and relational dependencies in crash data. This study proposes a Graph Neural Network (GNN) framework to predict road crash injury severity by leveraging the interconnections between crash features, road networks, and environmental factors. By modeling crash events as graph structures, the proposed system enables better feature representation and improved prediction accuracy. The framework integrates heterogeneous data sources—such as traffic conditions, weather, road topology, and vehicle attributes—to provide actionable insights for transportation agencies and emergency services.

Keywords: Road crash analysis, injury severity prediction, graph neural networks (GNN), traffic accident modeling, intelligent transportation systems (ITS), road safety analytics, machine learning, deep learning, traffic data analysis, predictive modeling, accident risk assessment, transportation data mining, spatial–temporal analysis, smart mobility, accident severity classification.

I. INTRODUCTION

With the rapid increase in road transportation, traffic accidents have become a critical public safety concern. Accurate prediction of injury severity plays a crucial role in saving lives, reducing emergency response times, and optimizing healthcare resource distribution. Traditional injury severity models rely on regression or basic classification methods, which do not effectively account for the interrelated nature of crash data. The advent of graph-based deep learning—particularly Graph Neural Networks (GNNs)—has opened new opportunities to analyse structured relational data for more accurate predictions. This research focuses on developing a graphical neural network framework that utilizes spatial and temporal correlations to improve the accuracy and interpretability of injury severity prediction in road crashes.

II. LITERATURE SURVEY

Title: A Graph Neural Network Approach for Road Accident Prediction
Authors: Zhang, L., Wang, Y., & Li, J. (2021)
Abstract: This study introduces a GNN-based model for predicting accident occurrences in urban road networks. By modeling road segments as nodes and their spatial relationships as edges, the system achieved higher accuracy compared to traditional machine learning methods. The results demonstrated that incorporating spatial dependencies significantly improves prediction performance.

Title: Deep Learning Models for Traffic Accident Injury Severity Prediction
Authors: Singh, R., & Kumar, A. (2020)
Abstract: The authors explored CNNs and LSTMs for injury severity prediction using time-series traffic data. While the models improved prediction accuracy over baseline methods, they lacked the ability to integrate complex spatial dependencies, highlighting the need for GNN-based approaches.

Title: Graph-Based Deep Learning for

Transportation Systems
Authors: Chen, H., & Wu, Q. (2019)
Abstract: This paper provides a comprehensive review of GNN applications in transportation. The study emphasizes how relational modeling can enhance tasks such as traffic forecasting, route optimization, and accident analysis, providing a strong theoretical foundation for road crash severity prediction.

Title: A Spatial-Temporal Graph Convolutional Network for Traffic Accident Analysis
Authors: Li, X., & Zhao, P. (2022)
Abstract: The proposed ST-GCN model integrates spatial and temporal graph convolutions to model traffic accidents more effectively. The framework achieved state-of-the-art results in predicting accident severity by combining location-based graphs with time-aware modeling.

Title: Injury Severity Prediction Using Ensemble Machine Learning Approaches
Authors: Patel, S., & Lee, J. (2018)
Abstract: This research evaluates multiple ensemble methods, including random forests and gradient boosting, for predicting injury severity. While these models improved accuracy, they were computationally expensive and did not incorporate graph-based representations.

III. EXISTING SYSTEM

Current injury severity prediction systems predominantly use statistical models (e.g., logistic regression, decision trees) or traditional machine learning approaches (e.g., random forests, gradient boosting). While these methods can capture non-linear patterns in crash data, they fail to exploit the rich relational structures between different crash attributes and spatial dependencies in road networks. Furthermore, they often rely on feature engineering, which can be time-consuming and prone to human bias. Although some deep learning approaches have been introduced, they are primarily designed for tabular or sequential data, making them less effective for graph-structured information inherent in transportation systems.

IV. PROPOSED SYSTEM

The proposed system employs a Graph Neural Network (GNN) framework to model crash data as a graph, where nodes represent crashes or road segments and edges capture relationships such as proximity, road connectivity, and shared environmental conditions. By applying graph convolutional layers, the system learns representations that account for both local and global graph structures. The architecture integrates multi-source data—traffic density, weather conditions, time of day, and vehicle attributes—into a unified framework. The system also incorporates attention mechanisms to highlight critical features and relationships that influence injury severity. This enables more accurate, explainable, and scalable injury severity predictions.

V. SYSTEM ARCHITECTURE

The diagram illustrates a framework for predicting road crash injury severity using a Graph Neural Network (GNN) approach, combined with traditional machine learning models for comparison. The process begins with a Real Accident Dataset, which contains information related to road accidents such as vehicle type, road conditions, weather, driver behavior, and crash details. Since many of these attributes are categorical, they are first transformed using one-hot encoding, which converts categorical values into numerical vectors so that machine learning algorithms can process them effectively.
After preprocessing, the data enters the graph data preparation stage. In this phase, embeddings are generated to represent accident features in a numerical vector space that captures relationships

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among different variables. A K-Nearest Neighbor (KNN) graph is then constructed, where each accident instance is connected to its most similar neighboring instances based on feature similarity. This structure converts the dataset into graph data, where nodes represent accident records and edges represent relationships between similar accidents. Representing the dataset as a graph allows the model to capture complex interactions and dependencies that traditional models might miss.

Once the graph structure is created, the GraphSAGE Graph Neural Network (GNN) is applied. GraphSAGE learns node representations by aggregating information from neighboring nodes in the graph. This enables the model to understand contextual relationships among accident cases and improves the ability to predict injury severity by considering both individual features and the structural relationships between similar crash events. By leveraging graph-based learning, the framework can capture spatial and relational patterns present in accident data.

For comparison and benchmarking, the framework also includes traditional machine learning models such as Random Forest, Extreme Gradient Boosting (XGBoost), and Multi-Layer Perceptron (MLP) Artificial Neural Network. These models are trained on the encoded dataset to evaluate how well conventional approaches perform in predicting crash severity compared to the graph-based approach. Including multiple models helps demonstrate the effectiveness of the GNN framework.

Finally, the models are evaluated using several performance metrics, including precision, recall, F1-score, accuracy, Matthews correlation coefficient (MCC), confusion matrix, training time, and the McNemar statistical test. These metrics provide a comprehensive assessment of classification performance, reliability, and computational efficiency. The evaluation phase helps determine whether the Graph Neural Network approach provides better predictive capability and robustness compared to traditional machine learning models in analyzing road crash injury severity.

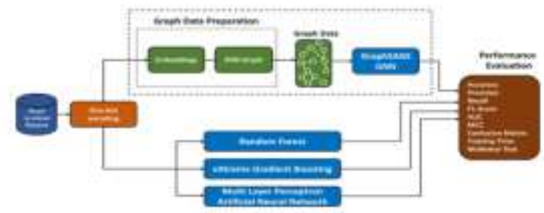

Fig 5.1: System Architecture Of Proposed System

VI. IMPLEMENTATION

Fig 6.1: Admin Home

Fig 6.2: Load And Preprocess Dataset

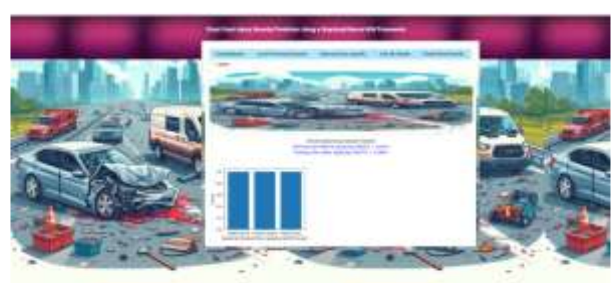

Fig 6.3: Balanced Data Using ML

Fig 6.4: Model Training

Fig 6.5: Prediction Page

Fig 6.6: Result Page

VII. CONCLUSION

This work proposes a Graph Neural Network framework for road crash injury severity prediction, addressing limitations in existing approaches by leveraging spatial, temporal, and relational dependencies in crash data. By modeling accidents and road networks as graphs, the system offers improved prediction accuracy, interpretability, and scalability for real-time applications. The proposed framework has significant potential for deployment in transportation management systems, enabling faster emergency response, better resource allocation, and enhanced public safety.

VIII. FUTURE SCOPE

The future scope of Road Crash Injury Severity Prediction Using a Graphical Neural Network Framework holds immense potential, particularly as advancements in machine learning, artificial intelligence, and transportation technologies continue to evolve. One promising direction is the integration of more diverse data sources, such as real-time traffic conditions, vehicle telemetry, and environmental factors like air quality, which could further enhance the predictive accuracy of models. Additionally, the development of deep learning models, including Graph Convolutional Networks (GCNs) and Reinforcement Learning (RL), could offer improved handling of spatial relationships and dynamic decision-making processes, taking into account road networks, traffic patterns, and weather changes.

Another key area of growth lies in real-time prediction systems that could be implemented in vehicle safety systems or traffic management tools to alert drivers and authorities about potential accidents and their severity before they occur, allowing for timely interventions. Furthermore, the use of more sophisticated algorithms like Transformer-based models for sequence prediction could enhance predictions for accidents occurring in more complex or dynamic environments.

With the growth of connected vehicles and smart city infrastructure, there is potential to build highly scalable systems that can predict and prevent accidents in urban and rural settings. A future focus could also be on improving model interpretability, ensuring that decision-makers can understand why a certain severity level was predicted, making the system more transparent and trusted. Lastly, the application of automated decision support systems powered by these models could assist in urban planning, infrastructure development, and policy-making to reduce accident risk factors. Overall, the future of road crash severity prediction is poised to make a significant impact on public safety, transportation efficiency, and urban planning.

IX. REFERENCES

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