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Uncovering Injury Risks in Micromobility: A Comparative Machine Learning Study

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Introduction

As cities increasingly promote sustainable and flexible transport options, **micromobility vehicles**—such as mopeds and pedal cycles—are becoming integrated into urban mobility systems. While these modes offer environmental and congestion-reducing benefits, they introduce new safety challenges.

These challenges arise because micromobility users face physical vulnerability and limited protection in the event of a crash. Compared to occupants of enclosed motor vehicles, micromobility users are more exposed to environmental hazards and direct impact forces. Descriptive statistics from the dataset revealed that micromobility users, though less likely to suffer fatal injuries, were more **frequently involved in collisions** that resulted in serious injuries and slight injuries. The variability of injury counts also suggested more complex or multi-injury scenarios among micromobility incidents, motivating the need for specific analysis.

Objectives

1. **Investigate and compare** the factors influencing serious injury outcomes for micromobility users relative to other road users.

2. Utilize a large-scale **traffic collision dataset** and interpretable machine learning models for this comparative analysis.

3. Develop **mode-specific models** to better understand the distinct injury risk mechanisms present in each user group.

Methodology

Data Source and Segmentation

The analysis focused on the 2023 subset of a comprehensive traffic collision dataset that spans from 2013 to 2023. The dataset included key variables such as transport mode, user demographics (age and gender), accident characteristics (weather, light conditions, number of vehicles involved), and geographical context (urban versus rural areas).

The dataset was segmented into two distinct groups for analysis:
1. **Incidents involving micromobility users**, defined as users of mopeds and pedal cycles.
2. **Incidents involving all other vehicle types**.

Target Variable and Descriptive Analysis

A binary target variable representing the presence of serious injury was constructed by aggregating fatal and severe injury outcomes.

• The high standard deviation for slight injuries in the micromobility group (STD = 7.74) suggests the occurrence of more complex or multi-injury scenarios. These patterns motivated the development of mode-specific models to understand distinct injury risk mechanisms.

Machine Learning Pipeline

For each data subset, a Random Forest classifier was trained within a machine learning pipeline.
1. Imbalance Handling: The Synthetic Minority Over-sampling Technique (SMOTE) was integrated into the pipeline to address the issue of class imbalance.
2. Optimization: GridSearchCV was used with stratified cross-validation to perform hyperparameter optimization, thereby enhancing model generalizability.
3. Evaluation: Model performance was rigorously evaluated using standard classification metrics, including accuracy, F1-score, precision, and recall.

Interpretability Analysis (SHAP)

To enhance interpretability and extract meaningful insights from the trained models, the study applied SHapley Additive exPlanations (SHAP).
• **Mechanism**: SHAP operates by assigning feature importance values based on cooperative game theory principles.
• **Purpose**: This approach allowed the quantification of each predictor's contribution to the model's output for individual predictions.
• **Visualization**: The analysis utilized SHAP summary plots (Figures 3 and 4) which visualize the magnitude and direction of each feature's contribution to individual predictions, thereby offering deeper insight into how specific variables influence the model's classification decisions.
This rigorous interpretability analysis was intended to confirm that injury severity is shaped by **demographic and environmental contexts**, underscoring the limitations of adopting generic, one-size-fits-all road safety strategies.

Results

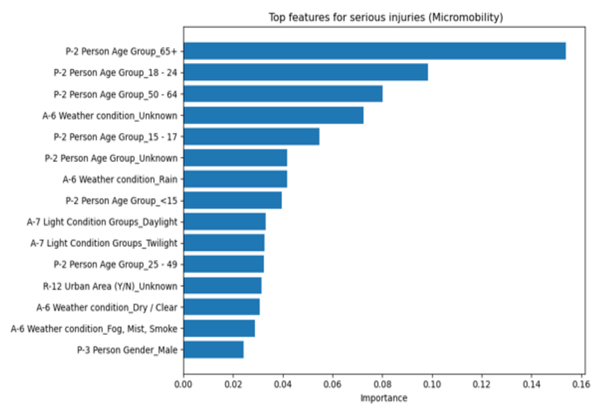

Figure 1: *Feature Importance Chart for micromobility*

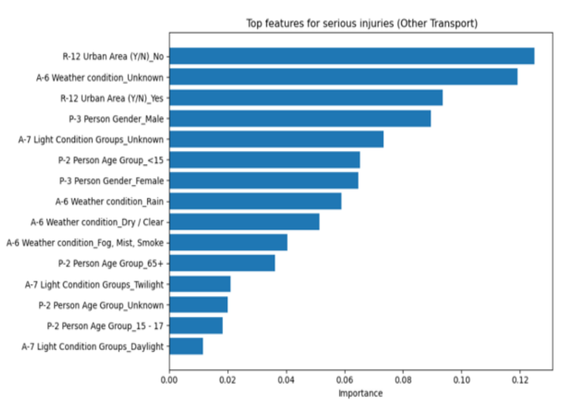

Figure 2: *Feature Importance Chart for other vehicles*

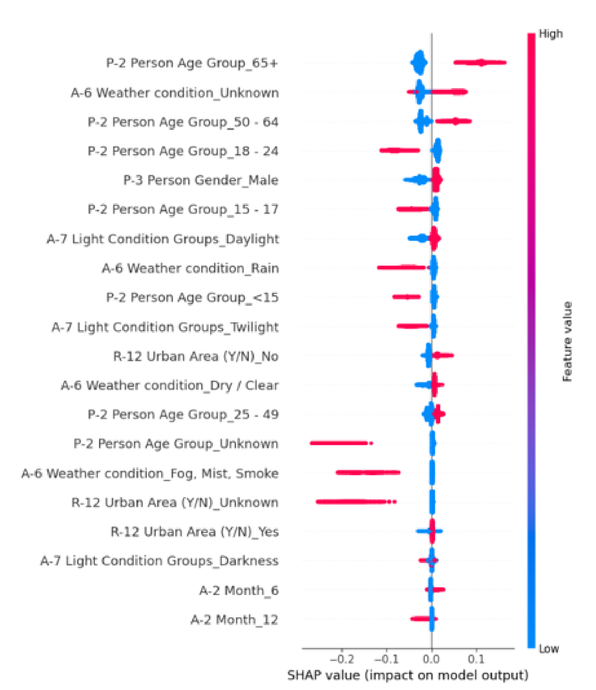

Figure 3: *SHAP Summary Plot for micromobility*

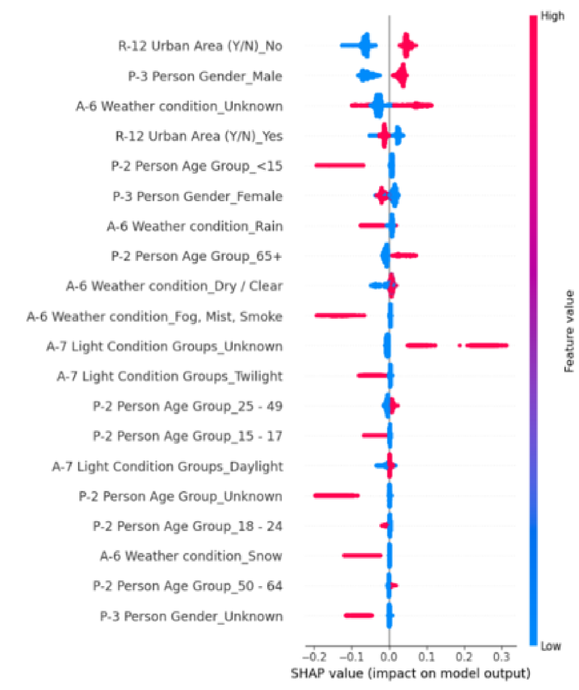

Figure 4: *SHAP Summary Plot for other vehicles*

Model Performance

The Random Forest models provided moderate predictive performance, supporting the subsequent interpretability analysis:
• Micromobility Model: F1-score of 0.64 (63.3% accuracy).
• Other Vehicle Model: F1-score of 0.67 (64.7% accuracy).

These findings underscore that injury severity is shaped by unique demographic and environmental contexts, necessitating mode-specific safety strategies.

Conclusions

The study provides evidence for the heterogeneous nature of injury severity determinants across transport modes. The results reveal distinct injury risk profiles between micromobility users and traditional vehicle occupants.

Key Findings and Implications:

• **Vulnerability and Risk Profiles**: The elevated serious and slight injury rates among micromobility users, despite lower fatality rates, highlight their increased vulnerability associated with limited physical protection.
• **Risk Drivers**: Micromobility users face greater risks stemming from environmental exposure and demographic vulnerability (e.g., age). In contrast, other vehicle users are more impacted by contextual and spatial factors (e.g., urban setting).
• **Policy Needs**: The interpretability analysis confirms that injury severity is shaped by demographic and environmental contexts, which emphasizes the limitations of generic, one-size-fits-all road safety strategies.
• **Mode-Specific Interventions:**
  ◦ For micromobility users, the strong influence of age suggests a need for targeted interventions aimed at age-specific risks, such as training programs for young riders and adaptive infrastructure for older adults.
  ◦ For other vehicle users, the dominant role of urban context and gender underscores the importance of location-sensitive planning and gender-informed policy design.

In conclusion, these findings support the development of **mode-specific safety strategies**, including tailored infrastructure adjustments, educational campaigns, and policy reforms. Integrating such evidence into safety planning is essential for ensuring equitable and effective protection across all user categories as micromobility adoption grows. Future work should explore behavioral variables and longitudinal injury patterns to further refine these insights.

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