# Enhancing Risky Driving Behavior Classification and Using Conditional GANs (cGANs): A Data Augmentation Approach

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## Introduction

Road traffic crashes remain a major **global safety issue** (*WHO*)
Risky behaviours such as **speeding** and **harsh braking** increase crash risk

Machine learning can classify risky behaviour, but:
- **Naturalistic driving data are highly imbalanced**
- Normal driving dominates
- High-risk events are rare

→ Leads to **biased predictions** and poor detection of critical cases

- **cGANs** generate synthetic **minority-class samples**
- Improve detection of **rare high-risk events**

## Objectives

- Evaluate **cGAN augmentation** for class imbalance
- Assess **performance vs. overfitting**
- Examine impact on **interpretability (SHAP)**

⍰ Support **safe use of synthetic data**

## Data Collection

**Dataset:** Naturalistic driving data (**i-DREAMS)**
**Countries:** Belgium (43 drivers) & United Kingdom (26 drivers)
Duration: **4-month monitoring period**
Total: **265,000+ minutes of driving**

**Data Acquisition:**
Vehicles equipped with **OBD-II systems & Mobile sensors**
Recorded variables: Speed, Headway, Braking

**Data Structure:**
Driving segmented into **30-second intervals**
Classified into: Normal, Dangerous, Avoidable Accident

## Methodology

**Data Preparation:**
i. Removed **missing values**
ii. Applied **Min–Max normalization**
iii. Problem: **Binary classification (**Normal vs. **Avoidable Accident)**

**Data Augmentation (cGAN):**
i. Generated **synthetic high-risk samples**
ii. Generator: Noise + **risk label** → **synthetic data**
iii. Discriminator: Evaluates **authenticity + class consistency**

**Model Development:**
- **80/20 train–validation split**
- **Stratified 5-fold cross-validation**

**Models Evaluated**
- XGBoost–Random Forest (**hybrid ensemble**)
- RNN + AdaBoost (**temporal patterns**)
- GAN-based classifier

**Evaluation & Interpretability:**
- Metrics:Accuracy, Precision, Recall, F1-score
- **SHAP analysis:**
  i. Before & after augmentation
  ii. Assess impact on **decision patterns**

## Results

### Model Performance

**Before Augmentation (Original Data):**
- **XGBoost–Random Forest**
  - Accuracy: **>90%** (Belgium & UK)
- **RNN–AdaBoost**
  - Moderate performance
- **GAN-based classifier**
  - Lower accuracy
  - Limited **minority-class representation**

**After cGAN Augmentation:**
- Accuracy increased across **all models**
- **Recall improved significantly**
  - Better detection of **high-risk events**
- **GAN-based model**
  Improved to **~90% accuracy**

**Key Concern:**
- Hybrid models reached **near-perfect accuracy**
- → Indicates potential **overfitting**

| Dataset | Model | Accuracy | Precision | Recall | F1-score |
|---|---|---|---|---|---|
| **Belgium (original dataset)** | XGBOOST & RF | 93% | 93% | 93% | 93% |
| | RNN & AdaBoost | 83% | 82% | 83% | 82% |
| | GANS | 76% | 64% | 76% | 66% |
| **UK (original dataset)** | XGBOOST & RF | 92% | 92% | 92% | 91% |
| | RNN & AdaBoost | 85% | 84% | 85% | 84% |
| | GANS | 79% | 80% | 79% | 74% |
| **Belgium (Augmented dataset)** | XGBOOST & RF | 100% | 100% | 100% | 100% |
| | RNN & AdaBoost | 100% | 100% | 100% | 100% |
| | cGANS | 90% | 90% | 90% | 90% |
| **UK (Augmented dataset)** | XGBOOST & RF | 100% | 100% | 100% | 100% |
| | RNN & AdaBoost | 100% | 100% | 100% | 100% |
| | cGANS | 91% | 90% | 91% | 91% |

### Overfitting and Generalization

**Key Observation:**
- Models reached **~100% accuracy** after augmentation
- Strong indication of **overfitting to synthetic patterns**

**Performance Behavior:**
- **Recall improved significantly**
- **Precision improved only slightly**
- → Increased sensitivity, but limited improvement in **true positive accuracy**

**Model Stability:**
- Performance **varied across cross-validation folds**
- Synthetic data showed **lower variability**
- → Reduced complexity → **risk of memorization**

**Implications:**
- Models may learn **artificial structures**, not real behavior
- Creates a trade-off:
  - 📊 **Higher metrics**
  - vs. ⚠️ **Lower real-world reliability**

⍰ Critical issue for **safety-sensitive applications**

## Feature Importance and Model Interpretability

**Key Predictors (Pre-Augmentation):**
- **Speed-related variables** → strongest influence
  - Mean speed
  - High-level speeding indicators
- **Harsh braking** → critical for detecting *Avoidable Accidents*

**Impact of Data Augmentation:**
- Feature importance **shifted after GAN augmentation**
- Models relied more on **synthetic feature patterns**

**Implications:**
- Augmentation may **alter learned risk representations**
- Improved balance ≠ **unchanged model logic**
- Raises concerns about:
  - **Interpretability**
  - **Robustness**

## Conclusions

**Key Findings:**
- Conditional GANs **reduce class imbalance** in risky driving data
- Improve:
  - 📈 **Recall**
  - 📊 **Overall accuracy**

**Limitations:**
- ⚠️ Risk of **overfitting** with synthetic data
- ⚠️ Potential **distortion of feature importance**

**Interpretation:**
- Near-perfect accuracy may indicate **memorization**, not generalization

**Implications:**
- In safety-critical systems:
  - **Robustness** and **Interpretability**
  - are as important as **Performance**

## Future Research

i. External validation & **transferability testing**
ii. Advanced **GAN-based data augmentation**
iii. Stronger **regularization methods**
**iv. Simulation frameworks** for safe deployment

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