**Card Transaction Fraud Data Preparation Report**

**Part 1: Data Cleaning Process**

**1. Outlier Handling**

* **Extreme Amount Filtering**: Removed 1 transaction with Amount > 3,000,000 (non-fraudulent Mexican retail purchase in pesos).
* **FedEx Microtransactions**: Flagged 7,592 transactions from FEDEX with amounts between $3.62–$3.80 using amount\_okay but retained them in the dataset.

**2. Exclusions**

* **Transaction Type**: Excluded 355 non-purchase transactions (types A, D, Y), retaining only type P (97,497 transactions).

**3. Imputation**

**Merchnum (Merchant Number)**

* Replaced '0' with NaN and imputed 1,164 missing values via Merch description mappings.
* Generated new unique IDs for 515 unmatched descriptions (e.g., "RETAIL CREDIT ADJUSTMENT" → "unknown").

**Merch State**

* Filled missing states hierarchically:
  1. Merch zip mappings (primary)
  2. Merchnum/Merch description mappings (secondary)
  3. Categorized non-U.S. states as "foreign" and unresolved cases as "unknown".

**Merch Zip**

* Imputed missing zips using:
  1. Merchnum/Merch description mappings
  2. Most populous zip code for the state if unresolved
  3. Defaulted to "unknown" for adjustments.

**Part 2: Variable Creation Summary**

**Summary Table of Created Variables**

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| --- | --- | --- |
| **Variable Group** | **# Variables** | **Description** |
| **Target Encoding (TE)** | 3 | Smoothed fraud risk scores for Merch state, Merch zip, and Dow using historical fraud rates. |
| **Entity Interaction Variables** | 148 | Composite keys (e.g., card\_merch, card\_zip) to track relationships between entities (card, merchant, zip, etc.). |
| **Days Since Variables** | 23 | Days since last transaction for each entity (e.g., Cardnum\_day\_since, Merchnum\_day\_since). |
| **Transaction Count Variables** | 1,449 | Number of transactions per entity over 0/1/3/7/14/30/60-day windows. |
| **Amount Statistics Variables** | 644 | Mean/max/median/total transaction amounts per entity over rolling windows. |
| **Amount Ratio Variables** | 644 | Ratios of current amount to historical metrics (e.g., actual/avg, actual/max). |
| **Velocity Change Variables** | 368 | Short-term vs. long-term activity ratios (e.g., count\_1 / count\_7). |
| **Variability Variables** | 414 | Mean/max/median deviation in transaction amounts over time windows. |
| **Unique Entity Count Variables** | 230 | Unique secondary entities (e.g., zips) linked to primary entities (e.g., cards). |
| **Geospatial Variables** | 7 | Distance between consecutive transactions and flags for implausible distances (>1,000 miles). |
| **Temporal Variables** | 5 | Weekend indicator (Is\_Weekend), hour of day, and time since midnight. |
| **Behavioral Flags** | 12 | High amount for merchant, state inconsistency, merchant dominance score. |
| **Foreign Transaction Variables** | 3 | Indicators for non-U.S. merchant zips. |
| **Benford’s Law Features** | 2 | Anomaly detection in transaction amount digit distributions (excluded due to overfitting). |
| **Miscellaneous Features** | 428 | Derived metrics (e.g., velocity ratios normalized by days since, interaction variables). |

**Key Variable Group Descriptions**

1. **Target Encoding (TE)**:
   * Converts categorical fields into fraud risk scores using logistic smoothing on historical data.
   * Trained only on pre-2010-11-01 data to prevent temporal leakage.
2. **Entity Interaction Variables**:
   * Created by concatenating entity IDs (e.g., card\_merch = Cardnum + Merchnum) to track behavioral patterns across linked entities.
3. **Time-Based Aggregates**:
   * Rolling window statistics (0/1/3/7/14/30/60 days) for counts, amounts, and ratios.
   * Examples: card\_merch\_count\_7, Merchnum\_avg\_30.
4. **Velocity Change Variables**:
   * Detect sudden spikes in activity (e.g., count\_1 / count\_7 > 3 indicates rapid activity increase).
5. **Geospatial Variables**:
   * Computed haversine distance between consecutive merchant zips using geopy.
   * Flags transactions with implausible geographic jumps (>1,000 miles within 24 hours).
6. **Behavioral Flags**:
   * Is\_Weekend: Weekend transaction indicator.
   * State\_inconsistency: Card used in multiple states within 24 hours.
   * Merchant\_dominance\_score: Fraction of a card’s transactions at its most frequent merchant.

**Design Principles**

* **Temporal Integrity**: Variables for a transaction use only prior data (no future-looking aggregates).
* **Hierarchical Imputation**: Leveraged relationships between fields (e.g., zip → state) to maximize data utility.
* **Smoothing**: Applied to target encoding and Benford’s Law metrics to stabilize rare categories.

This pipeline transformed raw transaction data into a structured dataset optimized for real-time fraud detection.

**New Variables for Fraud Detection**

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| --- | --- | --- |
| **Variable Name** | **Description** | **Logic** |
| **distance\_from\_last\_transaction** | Haversine distance (miles) between current and previous transaction for the same card. | Calculated using geopy with consecutive merchant zips. Missing zips set to 0. |
| **Is\_Weekend** | Binary flag (1/0) for transactions occurring on Saturday/Sunday. | Derived from Date using datetime.weekday(). |
| **Hour\_of\_Day** | Hour of transaction (0-23) as a numeric feature. | Extracted from Date using datetime.hour. |
| **velocity\_1h\_vs\_24h** | Ratio of transactions in the last 1 hour to the last 24 hours for the same card. | (count\_1h + 1) / (count\_24h + 1) to avoid division by zero. |
| **amount\_deviation\_from\_avg** | Absolute difference between current amount and cardholder’s 30-day average. | abs(Amount - Cardnum\_avg\_30). |
| **new\_merchant\_flag** | Binary flag (1/0) indicating if the merchant has never been transacted by the cardholder before. | 1 if Merchnum not in card’s historical Merchnum list prior to current transaction, else 0. |
| **cross\_border\_24h** | Binary flag (1/0) if the card was used in a different country within 24 hours. Non-U.S. Merch state categorized as 'foreign'. | Check if Merch state differs from prior transaction’s state and one is 'foreign' within 24 hours. |
| **amount\_rounded** | Binary flag (1/0) for transactions where the amount is a whole number (e.g., $20.00). | 1 if Amount % 1 == 0, else 0. |
| **minutes\_since\_last\_tx** | Minutes elapsed since the cardholder’s previous transaction. | (Current transaction time - Last transaction time).total\_seconds() / 60. |
| **high\_risk\_category\_ratio** | Percentage of a cardholder’s transactions in high-risk merchant categories (e.g., jewelry, electronics) over the past 90 days. | (count\_high\_risk\_90 / count\_total\_90). High-risk categories predefined via external merchant code lists. |