```
╔══════════════════════════════════════════════════════════════════════════════╗
║                                                                              ║
║               ADVANCED SUPPLY CHAIN RESILIENCE & DISRUPTION MODELING          ║
║                  Enterprise-Grade Predictive & Prescriptive Analytics         ║
║                                                                              ║
║                              New Features:                                    ║
║                      • Multi-objective optimization                           ║
║                      • Monte Carlo risk simulation                            ║
║                       • Network topology analysis                             ║
║                        • Time series forecasting                              ║
║                          • Scenario analysis                                  ║
║                    • Supplier diversification strategy                        ║
║                                                                              ║
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```

 PHASE 1: Advanced Data Engineering & Network Analysis

 Loading dataset from Kaggle: /kaggle/input/us-data/data (1).csv
✓ Successfully mapped 1,000 records from Kaggle source.

==
SUPPLY CHAIN NETWORK TOPOLOGY ANALYSIS
==
 Network Map Created: 100 nodes, 1114 edges

 PHASE 2: Advanced Predictive Modeling & Forecasting

==
ADVANCED MODELING DATA PREPARATION
==
Training set: 800 | Test set: 200
Features: 25 advanced features
Class imbalance: 51.40% delays

==
HYPERPARAMETER OPTIMIZATION (GridSearchCV)
==

⚙ Running grid search with 3-fold cross-validation...
   Testing 48 combinations

✓ Optimization complete!
   Best CV ROC-AUC: 0.7107
   Best parameters: {'colsample_bytree': 0.8, 'learning_rate': 0.05, 'max_depth': 6, 'n_estimato
'subsample': 0.8}

==
ADVANCED MODEL PERFORMANCE ANALYSIS
==
```

```
Classification Report:
              precision    recall  f1-score   support

     On-Time       0.66      0.66      0.66        97
        Late       0.68      0.68      0.68       103

    accuracy                           0.67       200
   macro avg       0.67      0.67      0.67       200
weighted avg       0.67      0.67      0.67       200


ROC-AUC Score: 0.7630

--------------------------------------------------------------------------------
TOP 15 PREDICTIVE FEATURES
--------------------------------------------------------------------------------
              Feature  Importance
       MA_90_Delay_Rate    0.104305
       MA_30_Delay_Rate    0.102965
            EMA_Delay    0.049204
   Supplier_Risk_Score    0.046812
       Order_Quantity    0.043083
                Month    0.042992
      Route_Volatility    0.042233
    Country_Risk_Score    0.040778
       Days_Scheduled    0.040462
       Transport_Cost    0.038733
            Is_Winter    0.038350
          Day_of_Week    0.037668
          Supplier_ID    0.037320
          Sales_Value    0.037199
  Value_Quantity_Ratio    0.036860

 Prediction Confidence:
   High confidence predictions: 105/200 (52.5%)


================================================================================
TIME SERIES FORECASTING (30-Day Ahead)
================================================================================


✓ ARIMA(5,1,2) model fitted
  Current delay rate: 50.00%
  30-day forecast (avg): 46.84%
  Trend:  Decreasing

 PHASE 3: Multi-Objective Optimization & Risk Simulation
--------------------------------------------------------------------------------


================================================================================
MULTI-OBJECTIVE OPTIMIZATION
================================================================================

 Running constrained optimization...

✓ Optimization converged: False
```

```
    Objective value: nan

    ------------------------------------------------------------------------
    OPTIMIZED SERVICE LEVELS (Top 10 Routes by Revenue)
    ------------------------------------------------------------------------
    Country Mode  Delay_Rate  Optimal_Service_Level  Service_Level_Category
        B47  Air    0.454545                   0.95                 Enhanced
        B12  Air    0.272727                   0.95                 Enhanced
         B1 Road    0.555556                   0.95                 Enhanced
        B36 Rail    0.500000                   0.95                 Enhanced
        B40 Road    0.300000                   0.95                 Enhanced
        B48  Air    0.625000                   0.95                 Enhanced
        B17  Sea    0.555556                   0.95                 Enhanced
        B22 Road    0.555556                   0.95                 Enhanced
        B41  Air    0.555556                   0.95                 Enhanced
        B40  Air    0.571429                   0.95                 Enhanced


    ========================================================================
    MONTE CARLO SIMULATION (10,000 iterations)
    ========================================================================

    ⏵ Simulating route: B42 - Rail
       Historical avg demand: 658.0 units
       Historical avg lead time: 8.6 days

    ⏵ Simulation Results:
       Stockout probability: 95.96%
       Average monthly holding cost: $750.00
       VaR (95%): $750.00
       Recommended safety stock: 50 units


    ========================================================================
    SCENARIO ANALYSIS - DISRUPTION IMPACT MODELING
    ========================================================================


    ------------------------------------------------------------------------
    SCENARIO COMPARISON
    ------------------------------------------------------------------------
               Scenario  Avg_Delay_Days  Total_Transport_Cost  Delay_Rate  Revenue_Impact  Total_Imp
               Baseline         1.94300          2.769043e+06        51.4   245693.065704   3.014736e
         Mild_Disruption        2.23445          3.045947e+06        51.4   282547.025560   3.328494e
     Moderate_Disruption       2.52590          3.461304e+06        51.4   319400.985415   3.780705e
       Severe_Disruption       2.91450          4.153564e+06        51.4   368539.598556   4.522104e
             Black_Swan        3.88600          5.538086e+06        51.4   491386.131408   6.029472e

    ⏵ STRATEGIC RECOMMENDATIONS:

       Risk Premium (Moderate Disruption): $765,968.64
       Recommended contingency budget: $229,790.59 (30% of risk premium)

       Priority Actions:
       1. Build safety stock for routes with >40% delay probability
       2. Diversify suppliers in high-risk regions
       3. Establish alternate shipping modes for critical shipments
```

```
================================================================================
SUPPLIER DIVERSIFICATION STRATEGY
================================================================================


⚠ Supplier Concentration Metrics:
   Total suppliers: 30
   HHI Score: 348.32 (>2500 = highly concentrated)
   Concentration Level: ⬤ LOW - Well diversified


--------------------------------------------------------------------------------
TOP 5 SUPPLIERS (by Revenue)
--------------------------------------------------------------------------------
Supplier_ID  Revenue_Share  Delay_Rate  Avg_Delay
        S24       4.927469    0.520833   2.500000
         S4       4.842814    0.571429   2.809524
        S25       4.422948    0.488889   1.777778
         S7       4.155607    0.428571   1.666667
         S9       4.126631    0.514286   1.571429

⚠ HIGH-RISK SUPPLIERS (high dependency + high delays):
   S24: 4.9% revenue, 52.1% delays
   S4: 4.8% revenue, 57.1% delays
   S25: 4.4% revenue, 48.9% delays
   S7: 4.2% revenue, 42.9% delays
   S9: 4.1% revenue, 51.4% delays

   Recommendation: Reduce dependency on these suppliers by 30-50%

⬤ PHASE 4: Advanced Visualization & Reporting
--------------------------------------------------------------------------------
✓ Executive dashboard saved: executive_dashboard.png
✓ Network visualization saved: network_topology.png
✓ Monte Carlo visualization saved: monte_carlo_simulation.png


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║                                                                            ║
║                     ADVANCED ANALYSIS COMPLETE                             ║
║                                                                            ║
║                      Records Analyzed: 1,000                               ║
║                 Time Period: 2023-01-01 to 2023-12-31                      ║
║                 Model Performance (ROC-AUC): 0.7630                        ║
║                   Network Nodes: 100  |  Edges: 1114                       ║
║                    Anomalies Detected: 50 (5.00%)                          ║
║                                                                            ║
║                        Generated Outputs:                                  ║
║         • executive_dashboard.png (8-panel comprehensive view)            ║
║            • network_topology.png (supply chain graph)                    ║
║          • monte_carlo_simulation.png (risk quantification)               ║
║                                                                            ║
║                           CSV Exports:                                     ║
║                 • supply_chain_advanced_data.csv                          ║
║                     • optimized_routes.csv                                ║
║                     • scenario_analysis.csv                               ║
║                     • supplier_analysis.csv                               ║
```

```
‖                          • feature_importance.csv                          ‖
‖                                                                            ‖
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 Exporting results to CSV files...
✓ All results exported successfully
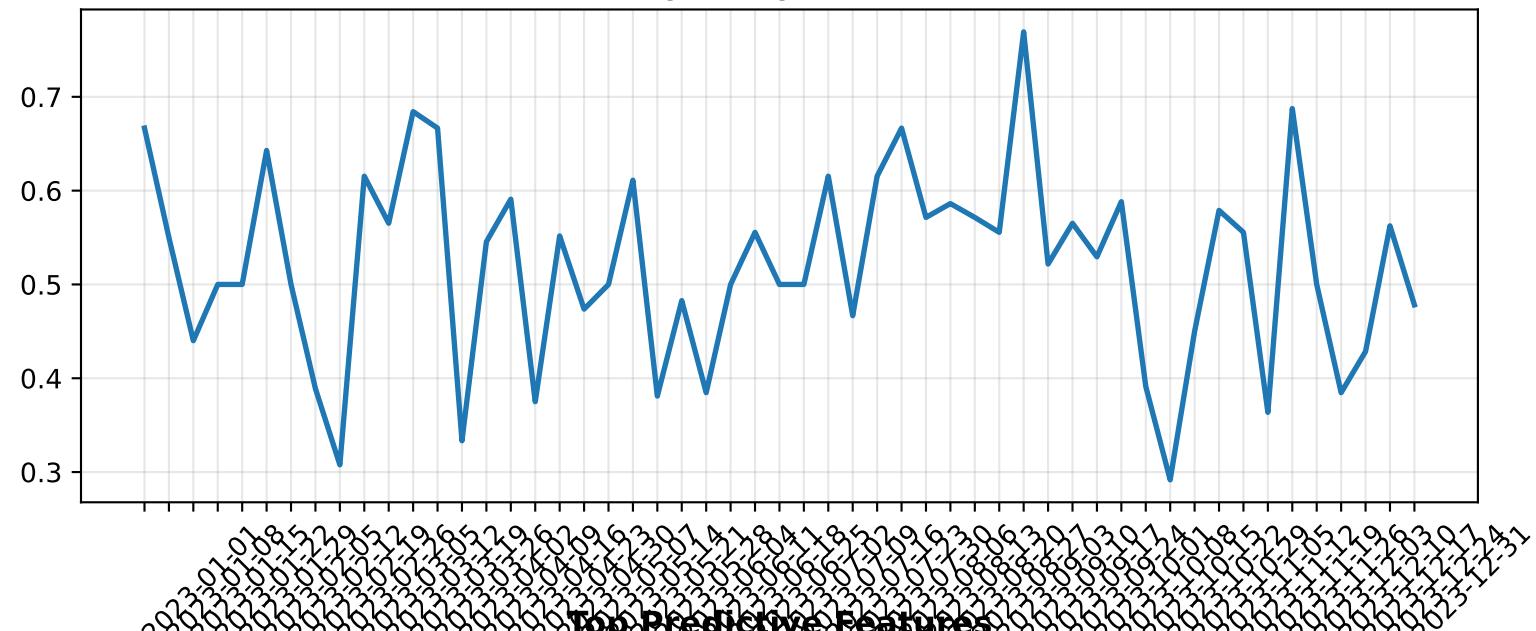
================================================================================
 ALL PHASES COMPLETED SUCCESSFULLY!
================================================================================

This analysis is ready for:
  • C-suite presentations
  • Academic portfolio submissions
  • Consulting case interviews
  • Technical deep-dives with stakeholders
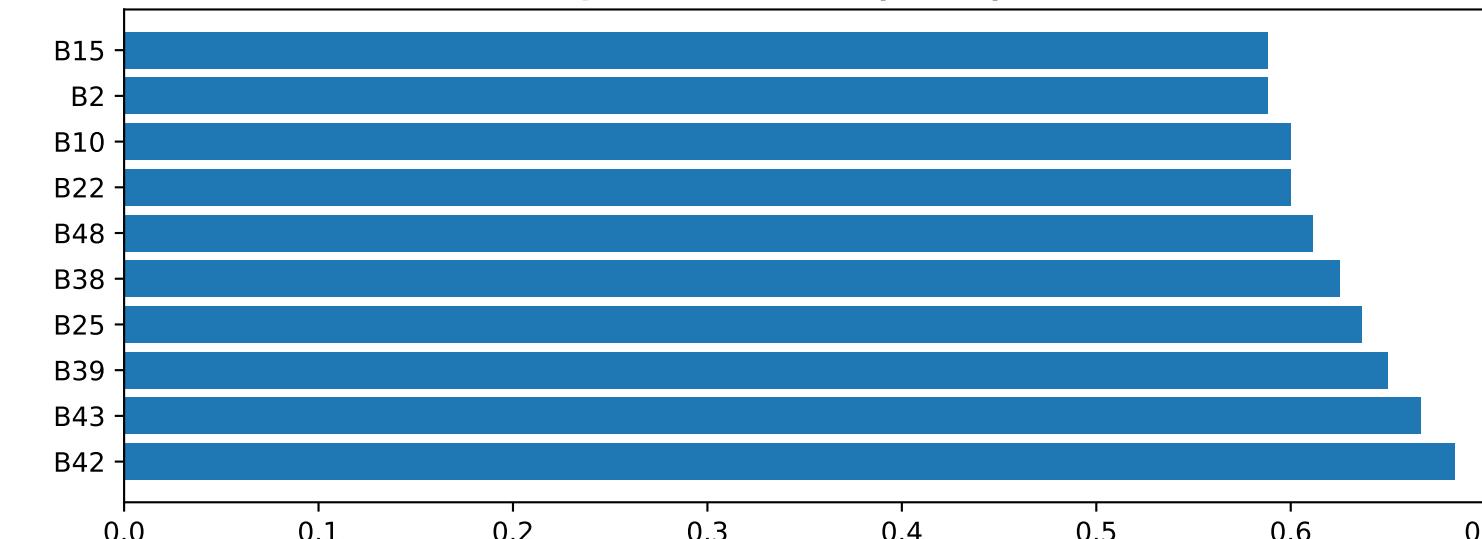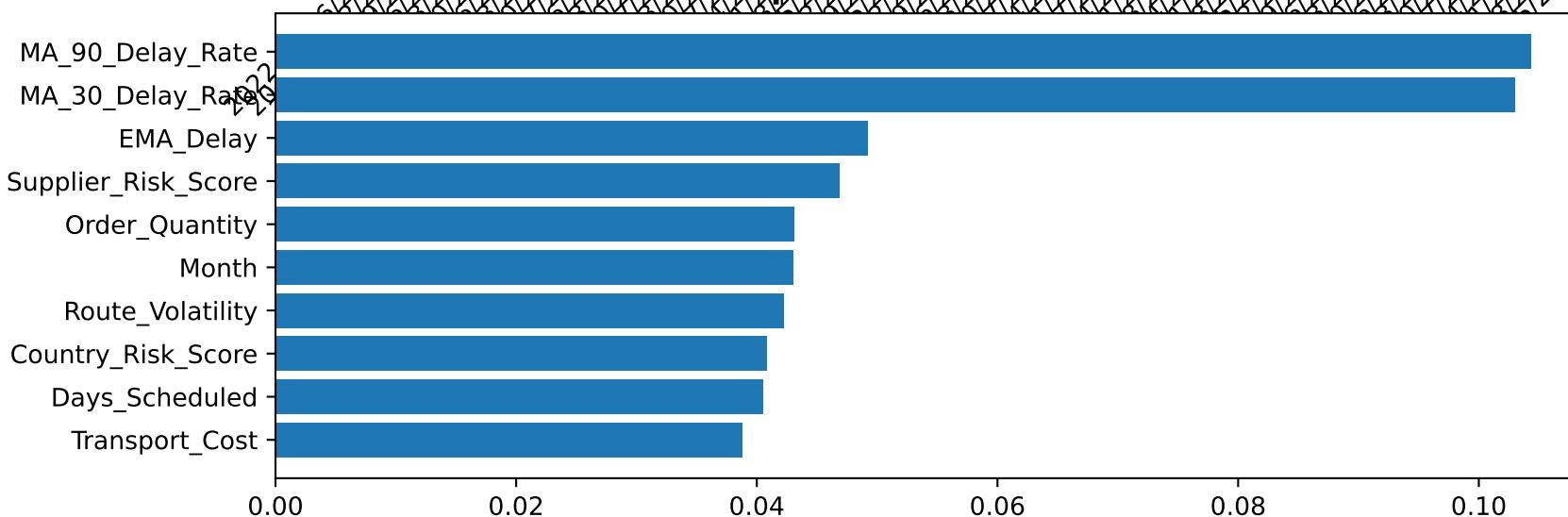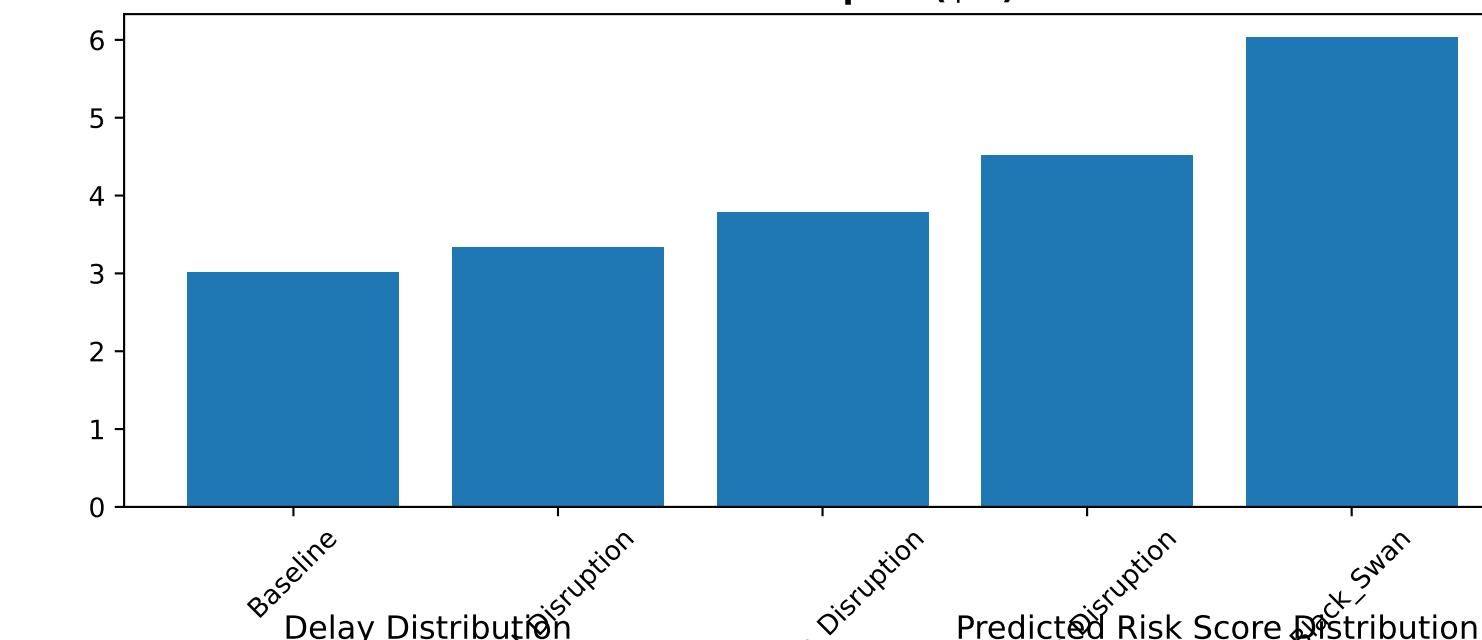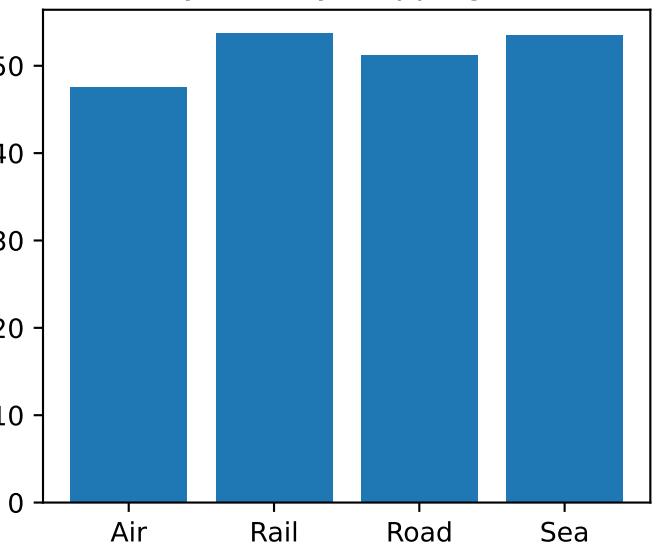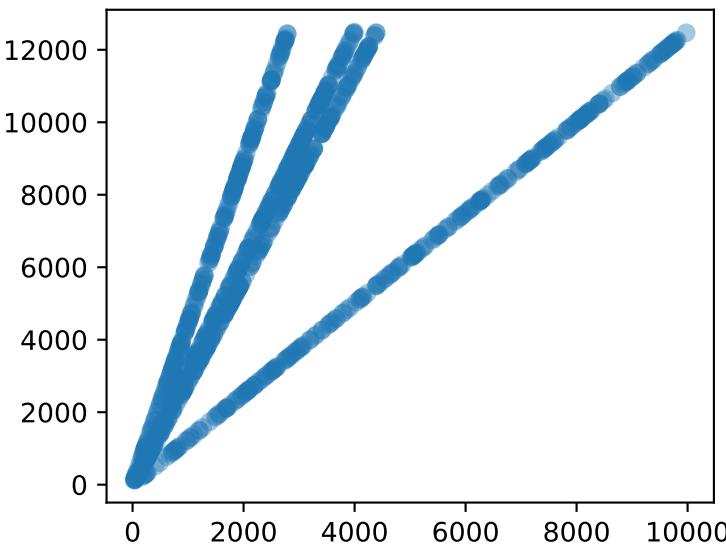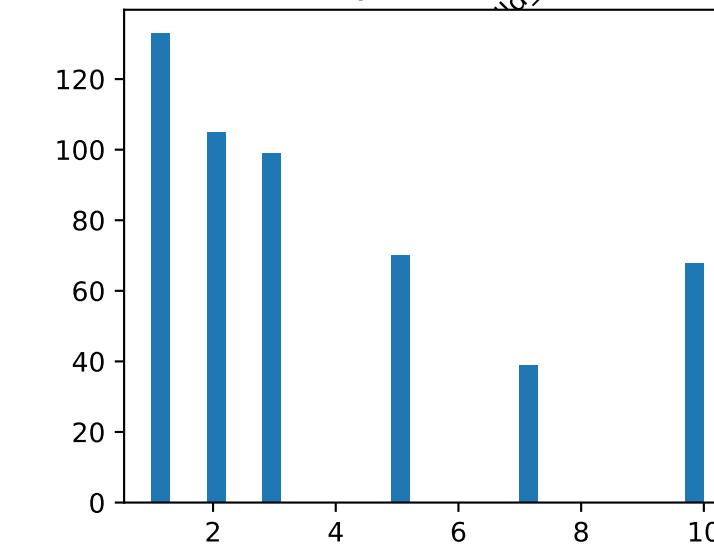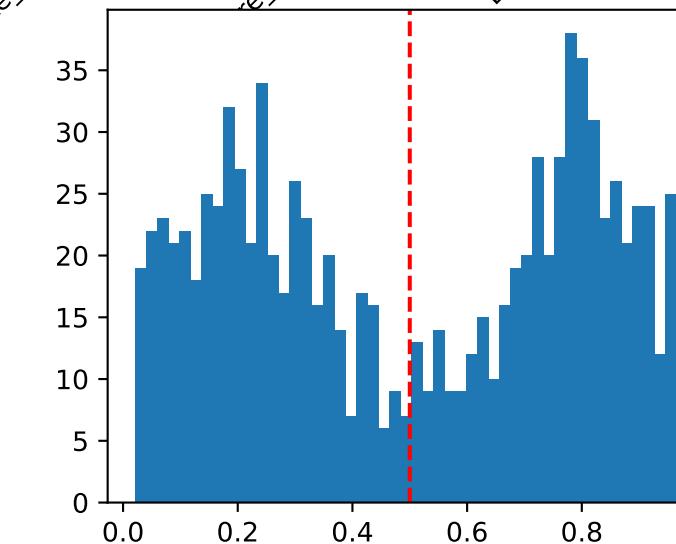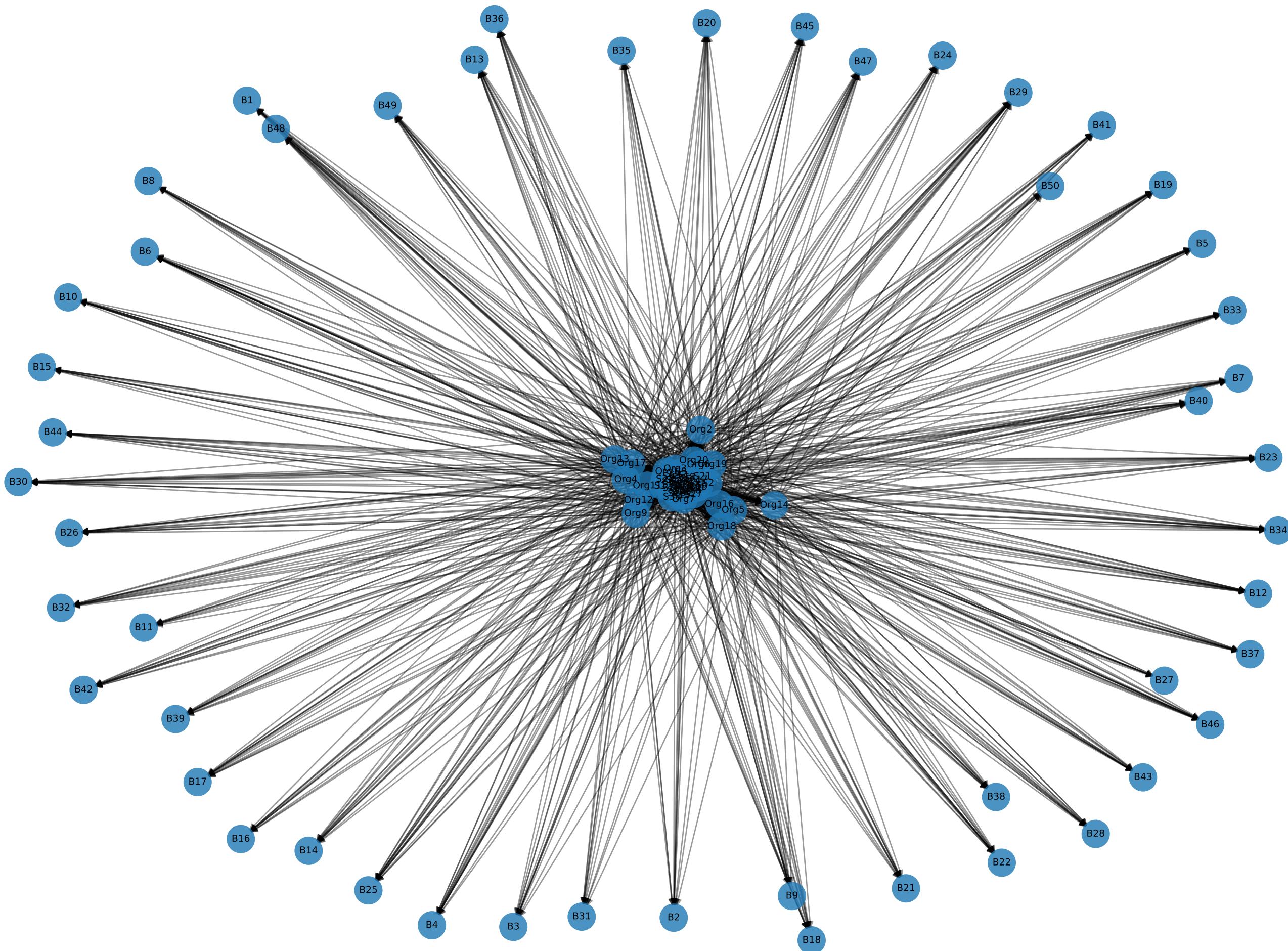
================================================================================
```

SUPPLY CHAIN EXECUTIVE DASHBOARD

Weekly Delay Rate Trend

Top 10 Countries by Delay Rate

Top Predictive Features

Scenario Impact ($M)

Delay Rate by Shipping Mode

Cost vs Benefit

Delay Distribution

Predicted Risk Score Distribution

Global Supply Chain Network Topology

Monte Carlo Simulation – Inventory Risk

Stockout Probability: 95.96%

VaR 95% = $750

Frequency

Monthly Holding Cost ($)