Microenterprise Density Prediction System

Final Project Presentation

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Project Overview

Objective:

- Forecast microenterprise density across U.S. counties
- Handle socioeconomic complexity and uncertainty
- Build a robust, scalable predictive system

Data Source:

- GoDaddy Microbusiness Density Forecasting
- 3M+ county-level observations
- Temporal + socioeconomic variables

Project Evolution

Workshop 1: Systemic Analysis
Workshop 2: Architecture Design
Workshop 3: Quality & Risk Management
Workshop 4: Simulation & Validation

Key Challenge

Managing chaos, nonlinearity, and external shocks in socioeconomic systems

Workshop 1: Systemic Analysis

System Characteristics Identified:

- **Multicausality:** Income, unemployment, demographics
- **Nonlinearity:** Complex variable interactions
- **Sensitivity:** Small changes $\rightarrow$ large effects
- **Chaos:** External shocks (crises, pandemics)

Key Insight:

"The system behaves as a dynamic socioeconomic ecosystem requiring adaptive modeling and continuous monitoring"

Complexity Factors

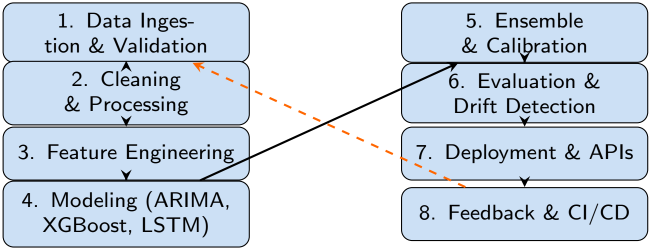
- High dimensionality
- Temporal dependencies
- Data noise & gaps
- Unpredictable events

Solution Approach

Robust preprocessing +
Hybrid modeling +
Feedback loops

Workshop 2: System Architecture

Eight-Layer Modular Architecture



Standards: ISO 9000, CMMI Level 3, Six Sigma

Workshop 3: Quality Assurance & Risk Management

Quality Controls:

- Schema validation
- Anomaly detection
- Drift monitoring
- Traceability documentation
- Automated testing

Risk Analysis:

Risk	Mitigation
Data integrity	Schema validation
Model drift	Auto-retraining
Security	Role-based access
Coordination	Clear roles & tools

Project Management

Methodology: Agile-Scrum
Tools: GitHub, Trello, MLflow
Roles: Manager, Analyst, Developer, Tester

Result

Robust, traceable, production-ready system

Workshop 4: Simulation Framework

Dual Simulation Approach

Data-Driven Simulation

Purpose: Baseline evaluation

Approach:

- Real historical data
- Random Forest model
- Stable conditions

Results:

- RMSE = 0.0727
- No drift detected (p ¿ 0.999)
- High predictive accuracy

Event-Based Simulation

Purpose: Stress testing

Perturbations:

- Income shocks (-15%)
- Unemployment spikes
- Noise injection

Observations:

- System sensitivity confirmed
- Recovery mechanisms activated
- Ensemble stabilization effective

Both approaches validate architectural robustness

Machine Learning Results

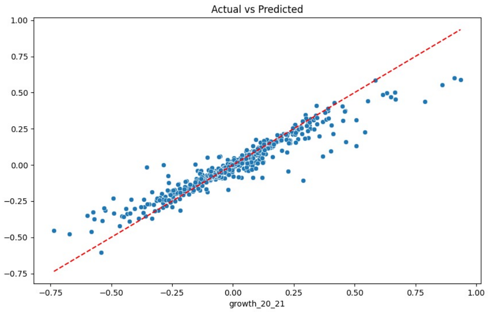
Random Forest Model:

- 100 estimators
- Median imputation
- Standard scaling
- Temporal features

Performance Metrics:

Metric	Value
RMSE	0.0727
MAE	0.0589
Drift p-value	0.9999

Actual vs Predicted



Interpretation

Model captures temporal trends with high fidelity and maintains stability across training cycles

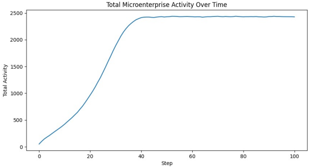
Configuration:

- Grid: 50×50 cells
- Steps: 100 iterations
- Gaussian noise: $\sigma = 0.05$
- Growth threshold: 0.6
- Decay probability: 0.02

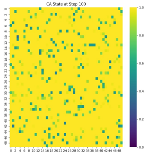
Emergent Phases:

1. Growth (steps 0-40)
2. Stabilization (steps 40-60)
3. Steady-state (steps 60+)

Activity Over Time



Grid State at Step 100



Model Comparison & Integration

Approach	Characteristics
Random Forest	High accuracy, smooth predictions, robust under stable conditions, low drift
Cellular Automata	Nonlinear dynamics, sensitive to perturbations, emergent behaviors, stress-testing
Historical Baseline	Ground truth patterns, low volatility, reference trajectory

Integrated Interpretation

- **ML model:** Optimal for forecasting and operational deployment
- **CA model:** Reveals chaotic tendencies and resilience capacity
- **Together:** Comprehensive understanding of system dynamics

Dataset Summary

Data Source:

- GoDaddy Kaggle Competition
- County-level U.S. data
- Full temporal coverage
- 3M+ observations

Key Variables:

- `microbusiness_density`
- `population`
- `median_income`
- `unemployment_rate`

Preprocessing Pipeline:

1. Schema validation
2. Missing value treatment
3. Outlier detection (IQR)
4. Normalization (MinMax)
5. Feature engineering (lags, windows)
6. Version control & metadata

Final Dataset Quality

- 100% completeness (target variable)
- 95%+ completeness (features)
- Uniform scaling

Key Results & Achievements

- ✓ **Systemic understanding** of socioeconomic complexity achieved
- ✓ **Eight-layer architecture** designed following ISO 9000, CMMI, Six Sigma
- ✓ **Quality assurance** framework with risk mitigation strategies
- ✓ **Dual simulation approach:** data-driven + event-based validation
- ✓ **ML model accuracy:** RMSE = 0.0727, no drift detected
- ✓ **CA emergent behavior:** growth, stabilization, steady-state phases
- ✓ **Robust project management:** Agile-Scrum with clear roles
- ✓ **Complete documentation:** traceability and reproducibility ensured

Result: Production-ready forecasting system capable of handling uncertainty, adapting to perturbations, and maintaining long-term stability

Lessons Learned

Technical Insights:

- Chaos management requires ensemble methods
- Drift detection is critical for long-term stability
- Feature engineering drives model performance
- Redundancy improves fault tolerance

Methodological Insights:

- Iterative refinement essential
- Clear documentation prevents errors
- Version control enables reproducibility

Project Management:

- Agile approach provided flexibility
- Role definition reduced conflicts
- Weekly sprints maintained momentum
- Early feedback improved quality

Interdisciplinary Integration:

- Systems thinking + ML = holistic solution
- Simulations validate theoretical insights
- Engineering standards ensure rigor

Future Work

Technical Enhancements:

- Cloud deployment (AWS/Azure)
- Real-time data streaming
- Deep learning models (LSTM, Transformer)
- SHAP-based interpretability
- Multi-region comparative analysis

System Expansion:

- Interactive dashboards for policymakers
- Mobile application for field analysis
- Integration with external APIs
- Enhanced CA rules with richer variables
- Automated report generation

Long-term Vision

Transform the system into a comprehensive decision support platform for economic development and microenterprise policy planning

Project Summary

The Microenterprise Density Prediction System demonstrates how **systems engineering methodologies** can effectively model **complex socioeconomic phenomena**.

Core Contributions

- Integrated systemic analysis, robust architecture, and validated simulations
- Combined ML predictions with CA emergent behavior modeling
- Established quality assurance and risk management framework
- Delivered scalable, adaptive, production-ready forecasting platform

The system is ready for deployment and continuous improvement

Thank You!

Questions?

Project Repository:
`https://github.com/Sukedas/Systems-Analysis-and-Design-Project`

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