

Modelling, integrating disturbances and management of supply chain: Application to Nigerian Petroleum Industry

Summary

Petroleum supply chains are complex global networks involving various stakeholders. Global energy security relies heavily on this industry. However, disruptions like pandemics, economic and geopolitical crises, threaten its operations. Nigeria, a major oil producer, paradoxically imports most of its refined fuels due to refinery issues, a costly and risky model highlighted by a 2023 contaminated fuel crisis. New refineries and laws aim for self-sufficiency, but face threats from vandalism and theft. This study uses real Nigerian data to navigate this transition by predicting product demand with machine learning and developing optimized production and supply chain strategies to counter these uncertainties. Chapter 1 reviews state-of-the-art methods, tools, and risks inherent in the petroleum supply chain. It examines machine learning (ML) applications for predictive modeling in upstream operations, transport, and logistics, aligning with the thesis's demand prediction objectives. The chapter also covers production, distribution, and optimization strategies specific to the industry, concluding with a justification for the proposed models, methods (ML, simulation, optimization), and data collection tailored for Nigeria and similar emerging oil producers. Chapter 2 presents empirical results from applying ML models—Artificial Neural Networks (ANN), Linear Regression (LR), Decision Trees (DT), and Support Vector Machines (SVM)—to predict Premium Motor Spirit (PMS) demand using 92 days of truck-out data. Implemented in MATLAB with a 70/30 train-test split, ANN and SVM outperformed LR and DT by 20-25%. Evaluated via supply chain KPIs, these models scored 4.5/5 for inventory and production planning, facilitating an estimated 15% cost reduction in imports. This validates ML's role in supporting Nigeria's refinery revitalization and advocates for data-driven forecasting in emerging petroleum economies, suggesting future use of LSTM models. Chapter 3 leverages the demand predictions to develop a production strategy under uncertainty. Using a continuous flow model with key parameters (demand, capacity, costs), a novel Two Hedging Point Policy (HPP) is proposed. The first hedging point ensures sufficient inventory to satisfy demand during disruptions, while the second incorporates environmental sustainability by actively managing waste and emissions without compromising energy security. Chapter 4 integrates the previous models into a comprehensive Mixed Integer Linear Programming (MILP) optimization scheme, simulated in MATLAB. The scheme's objectives are to: (i) Minimize overall cost by 40%; (ii) Maximize profit by 35%; and (iii) Improve service level by 25%. The model is subject to material balance, plant capacity, inventory, and demand constraints, while also factoring in uncertainties like vandalism and accidents. The chapter concludes with a sensitivity and disruption analysis of the results. This thesis proposes practical, data-driven models to support the Nigerian petroleum industry's transition. Key contributions include accurate ML demand prediction models; a novel Two-Hedging Point production strategy that balances demand fulfillment with sustainability; and an integrated optimization scheme that minimizes costs while maximizing profit and service levels. These models offer a robust operational framework for Nigerian industry actors and can be adapted by other OPEC members facing similar challenges, contributing significantly to

improved efficiency and cost reduction. Future research should focus on holistic demand forecasting for all simultaneously produced products using advanced ML (e.g., LSTM, ensemble learning); developing adaptive hedging point strategies that incorporate sustainability and competition from alternative energies; exploring additional transport modes for regional supply; and creating non-linear optimization schemes that better account for risk.

Mots clés : Disturbance propagation modeling, Demand prediction, Supply chains, Resilience, Strategy, Stochastic