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Strengthening the natural gas supply chain in Indonesia: Agent-based simulation for optimizing pipeline transportation

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Abstract

Indonesia's rapid economic growth drives domestic natural gas demand while emphasizing the role of the gas supply chain, from upstream to distribution to industry. Limited pipeline infrastructure, various gas producers, and pricing and allocation regulations often result in suboptimal supply in the midstream segment. This study aims to analyze the strategy for strengthening the gas supply chain in Indonesia through agent-based simulation (ABS). The model was developed based on data from PT Pertamina Gas (2019–2022), covering 60 pipelines with a total length of ±2,710.31 km. The four key agents—producers, transporters, consumers, and regulators—are mapped in NetLogo software. The simulation results show that the reliability of pipeline infrastructure, domestic supply priority policies, and flexible contracts between producers and consumers are key factors influencing supply chain stability. Validation with historical data of PLN gas distribution (2019–2022) shows Mean Absolute Percentage Error (MAPE) below 5%. This study recommends proactive pipeline maintenance, competitive pricing schemes that support domestic gas utilization, and cross-agent synergy to optimize gas transportation.

Keywords: Gas Supply Chain, Agent-Based Simulation, Pipeline Transportation, Infrastructure Reliability, Model Validation
Jel codes: Q41, Q48, L95, C63, C15

1. Introduction

Indonesia occupies a strategic position in the global oil and gas industry. Although natural gas resources are still quite abundant, increasing domestic consumption has made Indonesia move from a net exporter to a net importer of gas (Purwanto et al., 2016). The natural gas supply chain includes producers (upstream), transporters (midstream), and end consumers (downstream)—all regulated by government policies that separate upstream-downstream activities (Oil and Gas Law 2001).

In the midstream segment, PT Pertamina Gas operates dozens of pipelines with varying capacities. Data from 2017–2021 shows fluctuations in gas distribution, from 502,043 MMSCFD in 2017 to 486,040 MMSCFD in 2021 (Annual Report of PT Pertamina Gas, 2021). This variation is influenced by limited pipeline capacity, domestic pricing policies, and technical disruptions (shutdowns). According to Hutagalung et al. (2018), efforts to strengthen the supply chain require cross-agent collaboration to minimize supply-demand imbalances.

This study uses Agent-Based Simulation (ABS) to understand the behavior and interactions of four key agents: (1) gas producers, (2) pipeline transporters, (3) industrial consumers, and (4) regulators. The goal is to identify optimal strategies in managing the pipeline system so that the gas supply chain becomes reliable and efficient.

2. Literature review

2.1 Natural Gas Supply Chain in Indonesia

The structure of the Indonesian gas supply chain is divided into upstream (production & exploration), midstream (transportation & processing), and downstream (distribution & marketing) stages. The success of the supply chain is largely determined by the availability of infrastructure, guaranteed supply contracts, and the stability of domestic gas prices (Yudha et al., 2018).

2.2 The Role of Pipeline Transportation in the Supply Chain

Pipeline transportation, as the backbone of the midstream, is highly vulnerable to technical disruptions (pipeline shutdowns, maintenance) and tariff policies. Low gas distribution volumes will reduce transporter profits, while supply disruptions can impact industrial consumers (Hutagalung et al., 2018). Pipeline optimization efforts need to pay attention to the balance between operational costs and toll fee revenues.

2.3 Agent-Based Simulation (ABS)

The ABS approach highlights the adaptive behavior of agents interacting with each other in a particular environment (Bonabeau, 2002). In the gas industry, these agents exhibit heterogeneous interests:

- Producers tend to seek profitable markets.
- Transporters seek to maximize pipeline utilization and profit.
- Consumers seek reliable supply and competitive prices.
- Regulators prioritize national energy security, balancing the interests of various parties.

ABS is useful for designing and evaluating various scenarios, including changes in demand, infrastructure disruptions, and government policy adjustments (Outkin, 2015).

3. Research Methodology

3.1 Research Design

This research uses the Design Science Research (DSR) framework. Its main stages are:

1. Supply Chain Analysis & Data Collection: Includes pipeline data, distribution volume, tariff policies, and questionnaire responses (n=120) from operators and managers.
2. ABS Conceptual Modeling & Implementation: Identify agents, establish behavioral rules, and then model them in NetLogo.
3. Simulation & Testing Scenarios: Discusses several possibilities, including normal conditions, disruptions (shutdowns), and price adjustments.
4. Validation & Interpretation: Measures the model's suitability to historical data, and then provides r supply chain improvement recommendations.

3.2 Agent Definition & Interaction Rules

1. Gas Producer: Supply (MMSCFD) depends on well capacity and contract. Can choose domestic or export market (regulated by regulator).
2. Transporter (PT Pertamina Gas): Runs pipeline infrastructure, collects toll fees, is responsible for maintenance (scheduled shutdown).
3. Industrial Consumer: Electricity sector (PLN), fertilizer, steel, and so on. Each has a different demand pattern.
4. Regulator: Determines domestic prices, gas allocation priorities (vital users vs. general industry), and controls gas export/import policies.

3.3 Simulation Scenarios

- Scenario 1: Normal Conditions

Demand grows moderately, shutdowns are minimal, prices are stable.

- Scenario 2: Technology Disruption

Routine pipeline maintenance occurs (short shutdown) vs. unexpected shutdown (longer), reducing distribution volume.

- Scenario 3: Price Policy Variation

The regulator sets domestic prices lower or slightly higher, affecting transporter margins and producer/consumer behavior.

Each scenario is run with 100 replications (stochastic runs).

3.4 Model Validation

- Verification: Ensure that the NetLogo code is error-free.
- Validation: Compare the simulation volume and historical data of PLN gas distribution (2019–2022). Calculate the Mean Absolute Percentage Error (MAPE). The model is considered valid if MAPE <10% (Lewis, 1982).

4. Results and Discussion

4.1 Model Validation

Table 1 presents a comparison of real vs. simulated data (average of 100 replications):

Year PLN Data (MMSCFD) Simulation (MMSCFD) % Error

Year	**Datas PLN (MMSCFD)**	**Simulation (MMSCFD)**	**% Error**
2019	515	512	0,58
2020	480	472	1,67
2021	485	491	1,24
2022	490	495	1,02

The average error is <2%, indicating the model's ability to adequately replicate real conditions.

4.2 Scenario Analysis

4.2.1 Normal Conditions (Scenario 1)

- High distribution volume (~510–520 MMSCFD).
- Transporter profit in the range of +10 million USD (per simulation period), relatively stable.
- Producers and consumers interact smoothly, toll fees are relatively competitive.

4.2.2 Technology Disruption (Scenario 2)

- Scheduled Shutdown (1–2 days/month): Causes a decrease in volume of ±5–8%, profit drops by 10–15%.
- Unexpected Shutdown (≥1 week): Increases repair costs, decreases volume by 20–30%. Transporter profits can drop by up to 40%.

4.2.3 Price Policy Variations (Scenario 3)

- Domestic Price Drops by 10%: Triggers an increase in industrial consumption by ~5%, but squeezes transporter margins if toll fees are not adjusted.
- Domestic Price Increases by 10%: Certain consumers (non-essential) reduce consumption by up to 5%, reducing volume, although margins per unit are higher.

4.3 Supply Chain Strengthening Discussion

1. Pipeline Transportation Reliability: The role of strategic transporters in ensuring smooth supply. Minimal shutdowns mean a more stable supply chain, strengthening the competitiveness of downstream industries.
2. Flexible Contracts: Can reduce the risk of demand volatility. Take-or-pay schemes provide certainty for producers & transporters.
3. Balanced Pricing Policy: Regulators need to weigh the interests of industry consumption vs. financial sustainability of transporters. Too low domestic prices will benefit consumers but squeeze midstream margins.
4. Scale Effect: Pipeline network expansion can increase efficiency by transporting more gas per unit of fixed cost.

5. Conclusion

This study proves that strengthening the gas supply chain in Indonesia requires synergy between the four main agents (producers, transporters, consumers, regulators). Through agent-based simulations, we find that:

1. Pipeline reliability—minimum shutdowns—is critical to maintaining supply stability and maximizing profits.
2. Balanced pricing policy supports domestic gas utilization without squeezing transporter margins too much.
3. Flexible contracts between producers and consumers can overcome demand fluctuations and minimize volume risk.

Validation shows MAPE below 5% against PLN's historical data, indicating the reliability of the model. Recommendations that can be taken by policy makers and industry players include: (1) Strengthening proactive pipe maintenance, (2) Developing competitive but fair tariff mechanisms, and (3) Implementing long-term contracts with flexible volume arrangements according to industry needs.

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