Al-Kharaj: Journal of Islamic Economics and Business
Volume 7 (4), 2025
P-ISSN: 2686-262X; E-ISSN: 2685-9300

Dynamic System Analysis of Vannamei Shrimp Supply Chain: Evaluation of Distribution Delays in Cold Chain Logistics at Exporting Companies

Nurhijriani Kasim[1], Yudha Prambudia[2], Iphov Kumala Sriwana[3]

[1,2,3]Industrial Engineering Study Program, Telkom University, Indonesia

Email: hijrianikasim0027@gmail.com , prambudia@telkomuniversity.ac.id , iphovkumala@telkomuniversity.ac.id

Keywords:
vannamei shrimp, cold chain logistics, dynamic systems, distribution, export quality

Abstract

Vannamei shrimp is one of Indonesia's leading export commodities that relies heavily on the efficiency of cold chain logistics to maintain product quality during shipping. Purpose: This study aims to analyze the factors causing distribution delays in the vannamei shrimp supply chain at a seafood exporting company in Makassar, South Sulawesi, and evaluate their impact on product quality, return rates, and export prices. Methods: The method used is the System Thinking and System Dynamics approach, by building a dynamic system model using Vensim software. Data were obtained through literature studies, interviews, field observations, and historical distribution data for 2023. Results: The results show that an average distribution delay of 12–18 hours causes an increase in temperature during transportation by 2–3°C, resulting in a decrease in shrimp quality and an increase in return rates of up to 7% of total monthly exports. Through simulations of improvement scenarios, the model shows that optimizing the criteria for export-worthy shrimp and increasing the efficiency of distribution rates can reduce the number of damaged shrimp and increase export volume. Model validation tests with a MAPE value of 5.16% indicate a good match between the simulation results and actual conditions in the field. Implications: This research is expected to be a reference for exporting companies in designing strategies to improve cold chain logistics to increase the competitiveness of Indonesian shrimp products in the international market.

INTRODUCTION

Vannamei shrimp (Litopenaeus vannamei) is a leading commodity in Indonesia's fisheries sector, contributing significantly to seafood exports. In 2022, Indonesian shrimp exports reached approximately 240,000 tons with a value of over USD 2.2 billion, making it the largest contributor to national fisheries exports (Akmal, 2021; Hidranto, 2022; Mustafa et al., 2024; Satrio et al., 2023). South Sulawesi, particularly Makassar Regency, is one of the main areas for vannamei shrimp production and export. Export companies in Makassar play a crucial role in the supply chain, from processing and storage to distribution to international markets such as the United States, Japan, and the European Union (Akmal, 2021).

However, one of the main challenges in the vannamei shrimp supply chain is distribution efficiency within the cold chain logistics system. Cold chain logistics is a refrigerated supply chain system that aims to maintain optimal temperatures during transportation to maintain product freshness and quality. Delays in distribution can cause temperature fluctuations, which impact shrimp quality degradation, increase product returns, and reduce competitiveness in the international market (Mustafa et al., 2024).

A study conducted on seafood products, namely fish, involved an experiment in distributing fish at room temperature of 26°C-27°C for approximately 10 hours. By the 8th hour, the fish were no longer fresh (Aminatuzzuhra et al., 2016). Consequently, if there is a delay, the exporting company experiences financial losses due to a decrease in selling price and an increase in customer return rates. In addition, fluctuations in shrimp prices in the international market are also often associated with instability in the logistics system and distribution delays (Satrio et al., 2023). In the context of Makassar, exporting companies face several factors that cause distribution delays, such as a lack of refrigerated storage infrastructure, limited reefer transportation, and obstacles in the export administration process. Therefore, it is important to understand how delays in cold chain logistics affect shrimp quality, return rates, and market prices, and how system models can be used to address these issues.

Several previous studies have examined the vannamei shrimp supply chain (Nurmiati, 2022), and the challenges of distribution and export of frozen shrimp products in Indonesia (Mashari, 2019). According to the Journal of Marine and Fisheries Socioeconomics, the vannamei shrimp supply chain in Indonesia can be classified into three main parts: supply (raw materials and production), distribution, and marketing. Each part plays a crucial role in ensuring the efficiency and quality of the product until it reaches consumers (Zamroni, 2021). Other research shows that cold chain logistics can extend the shelf life of goods and increase product competitiveness in the international market (Mustafa et al., 2024). However, there is still a gap in research regarding how dynamic systems can be used to model and simulate the impact of distribution delays on shrimp export quality and prices.

To bridge this gap, this study uses a Systems Thinking and System Dynamics approach to map the factors influencing distribution delays and their impact on exporters' business sustainability. The system dynamics model allows for scenario simulation and evaluation of improvement strategies to increase supply chain efficiency (Borshchev & Filippov, 2004). This study has several main objectives, namely:

a. Analyzing the factors causing distribution delays in cold chain logistics
b. Measuring the impact of delays on shrimp quality, return rates, and export prices
c. Develop dynamic system models to simulate various distribution scenarios and understand the interactions between variables in the supply chain.
d. Providing recommendations for supply chain efficiency improvement strategies for shrimp exporters in Makassar, South Sulawesi

This research is expected to provide a real contribution in increasing the efficiency of the vannamei shrimp supply chain and assist exporters in increasing product competitiveness in the global market.

The vannamei shrimp supply chain in Indonesia generally consists of three main components: supply (raw materials and production), distribution, and marketing. Each component plays a crucial role in ensuring the efficiency and quality of the product reaching consumers (Zamroni, 2021). In the context of distribution, the implementation of cold chain logistics has been proven to extend the shelf life of fishery products and increase competitiveness in the global market (Mustafa et al., 2024).

A previous study by Rahman et al. (2021) identified that the main constraints in the fishery product supply chain were limited cold storage infrastructure and unstable distribution chains. These findings are reinforced by the findings of this study, which not only confirm these issues but also add to our understanding of how cold chain efficiency directly impacts product selling

prices. Meanwhile, Wijaya et al. (2020) showed that optimizing cooling systems can reduce product quality loss by up to 15%, and in this study, improvements to the cold chain logistics system were estimated to reduce return rates by up to 4%.

However, although various studies have highlighted the importance of cold logistics, there remains a gap in research integrating a dynamic systems approach to model and simulate the impact of distribution delays on shrimp export quality and prices. Therefore, a dynamic systems approach is relevant to fill this gap, particularly in the context of policy analysis and strategic decision-making in the export fisheries sector.

METHODS

Research Design

This study uses a Systems Thinking and System Dynamics approach to analyze distribution delays in cold chain logistics within the vannamei shrimp supply chain of an exporting company in Makassar, South Sulawesi. This approach allows modeling the dynamic relationship between the factors causing delays and their impact on shrimp quality and export prices (Aminudin, 2014). A dynamic system model was developed using Vensim software to simulate various supply chain improvement scenarios.

Research Procedures

This research was conducted in several stages as follows:

a. Problem Identification and Literature Study
   1) Collecting data from journals, books, and industry reports related to cold chain logistics and vannamei shrimp supply chain
   2) Analyze the factors that influence distribution delays and their impact on export quality and prices.

b. Data collection
   1) Historical data was obtained from a shrimp exporting company in Makassar, South Sulawesi, including distribution data, product quality, and export prices in 2023.
   2) Interviews with stakeholders such as farmers, distributors, and logistics managers.
   3) Direct observation of the distribution process and cold chain storage system.

c. Data Processing and Analysis
   1) A dynamic system model was developed using Vensim to describe the relationships between variables in the supply chain.
   2) Simulations were conducted to see the impact of distribution delays on quality, return rates, and export prices.
   3) Model validation testing is carried out by comparing simulation results with the company's historical data.

d. Model Testing and Evaluation

1) Testing was conducted by comparing scenarios without intervention and with intervention to improve cold chain logistics efficiency.
2) The simulation results were analyzed using statistical methods to test the significance of changes in export quality and prices.

e. Preparation of Recommendations

Based on the simulation results, an optimal strategy to reduce distribution delays and increase the competitiveness of export products is formulated.

Data Acquisition and Statistical Testing

a. The data obtained includes variables such as distribution time (days), storage temperature (°C), return rate (%), and export price (USD/kg).
b. Statistical analysis using regression tests and sensitivity analysis to determine the factors that most influence distribution delays.
c. The model is tested by cross-validation using historical data to ensure the fit between the model and real conditions in the field.

Devices and Tools Used

a. Software: Vensim for dynamic system modeling and SPSS for statistical analysis.
b. Measuring Tools: Digital thermometer to monitor storage temperature during distribution.

With this method, it is hoped that the research can provide accurate insights in optimizing cold chain logistics for the vannamei shrimp export industry in Indonesia.

RESULTS

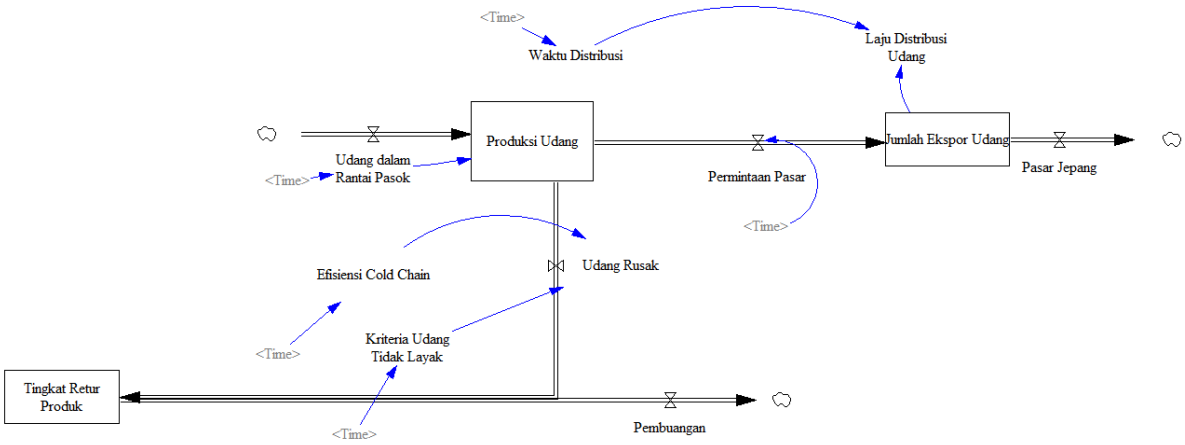
Research Findings

This study identified that delays in the vannamei shrimp supply chain at a seafood exporting company in Makassar, South Sulawesi, significantly impact shrimp quality and prices. Based on historical data from 2023, there is a pattern of fluctuations in distribution times, with an average delay of 12-18 hours. This causes a 2-3°C increase in temperature during transportation, resulting in decreased product quality and an increase in return rates of up to 7% of total monthly exports.

The Stock and Flow Diagram (Figure 1) illustrates the distribution flow of shrimp products from the production process to the Japanese market. The process begins with Shrimp Production, the primary source of shrimp supply. The resulting shrimp will flow through the supply chain through the Shrimp variable in the Supply Chain. However, during the process, there is a possibility that some shrimp will experience damage, indicated by the Damaged Shrimp flow. This damage is influenced by two main factors: Cold Chain Efficiency as an indicator of storage quality during distribution, and the Unfit Shrimp Criteria, which is the standard for assessing shrimp quality. Shrimp declared damaged will be discarded through the Disposal flow, which will then contribute to the Product Return Rate if returned from the market due to

unsuitable quality. Shrimp that meet the standards will be distributed further through the Shrimp Distribution Rate flow to the Shrimp Export Quantity, which is then forwarded to the Japanese Market. This distribution speed is influenced by Distribution Time and will be adjusted to Market Demand from Japan. Market demand is one of the driving factors in determining the amount of shrimp that must be produced and exported. Feedback from the Product Return Rate to the system will encourage improvements in the production and distribution sectors to maintain the quality of exported shrimp.

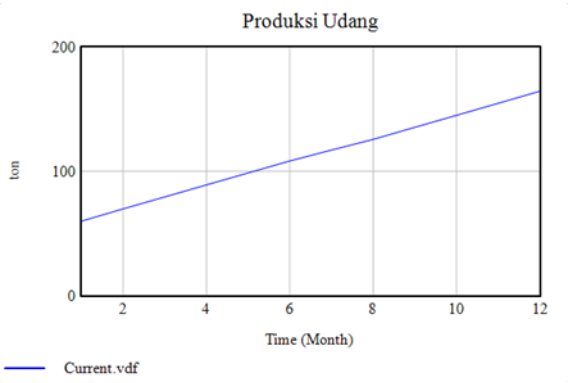
Figure 1. Stock Flow Diagram



Shrimp Production Sub Model

The shrimp production submodel is influenced by the number of shrimp in the supply chain, damaged shrimp, and market demand. The simulation results are as follows:

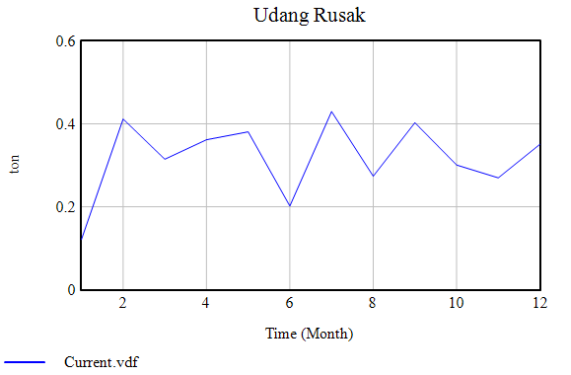
Figure 2. Shrimp Production Diagram



The graph above shows a consistent increase in shrimp production over the 12-month period. Shrimp production began at 60 tons. Production continued to increase linearly, reaching approximately 180 tons in the 12th month. This stable and increasing trend illustrates the potential for long-term shrimp production expansion, provided it is supported by appropriate policies, technology, and distribution.

Damaged Shrimp Sub Model

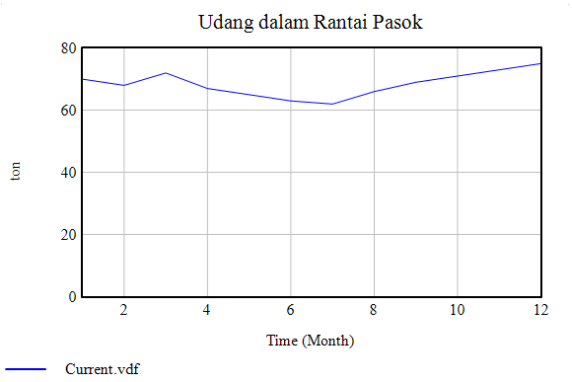
Figure 3. Diagram of Damaged Shrimp



The graph above shows fluctuations in the number of damaged shrimp over a 12-month period. In general, the number of damaged shrimp ranged from 0.2 to 0.45 tons per month. The observed pattern does not show a consistent upward or downward trend, but rather tends to fluctuate. In the second month, the number of damaged shrimp peaked at around 0.42 tons, then declined in the sixth month to around 0.2 tons. The rate of increase occurred again in the seventh and ninth months, before declining again. This fluctuation could be caused by several factors, such as the quality of the distribution process, post-harvest processing, or unstable storage conditions.

Shrimp Sub Model in the supply chain

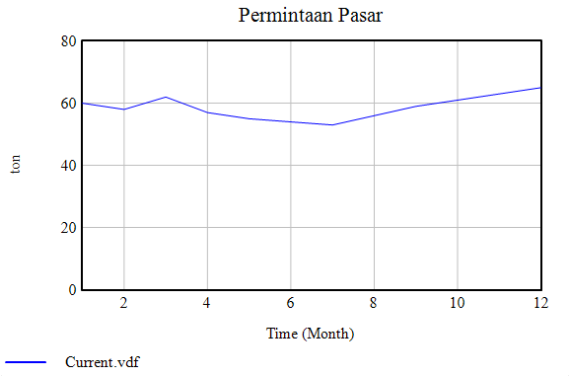
Figure 4. Diagram of Shrimp in the Supply Chain



The graph above shows the development of shrimp quantities in the supply chain over a 12-month period. Generally, shrimp quantities in the supply chain range from 60 to 75 tons. Shrimp quantities were recorded at around 70 tons in the initial period, then experienced slight fluctuations over the following months. A decline occurred, reaching a low of around 62 tons in the sixth month. Shrimp quantities experienced a gradual upward trend, reaching around 78 tons in the twelfth month. This fluctuating movement indicates that the supply chain system still faces challenges in maintaining stable shrimp distribution.

Market Demand Sub Model

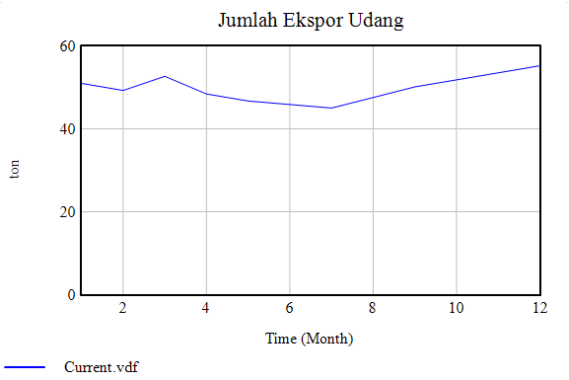
Figure 5. Market Demand Diagram



The graph above shows the development of market demand for shrimp over a 12-month period. Market demand in the first month was recorded at around 60 tons. There was a slight increase, reaching around 63 tons in the third month, but then gradually declined, reaching a low of around 53 tons in the seventh month. Demand in the seventh month began to slowly increase again, reaching around 65 tons by the end of the period (the 12th month). The resulting pattern indicates fluctuations in market demand, but with an upward trend towards the end of the period. These fluctuations in demand can be influenced by various factors such as changes in consumption trends, global market conditions, or seasonal factors.

Shrimp Export Quantity Sub Model

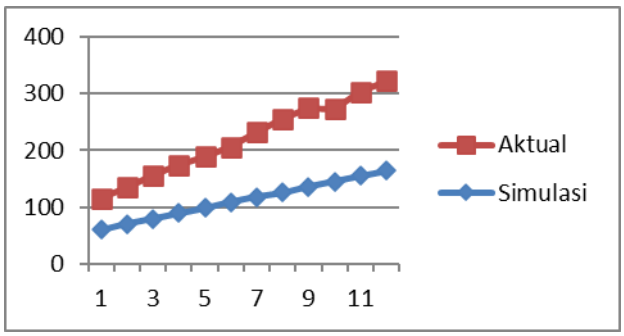
Figure 6. Diagram of Shrimp Export Quantity



The graph above shows the development of shrimp exports over a 12-month period. Shrimp exports in the initial month were around 50 tons. The figure increased to around 54 tons in the third month, before gradually declining to reach a low of around 44 tons in the seventh month. After the seventh month, exports showed a slow and steady upward trend, reaching around 57 tons in the twelfth month. This movement pattern indicates that despite a decline midway through the period, export volumes have successfully rebounded to near their initial levels.

Validation Test

Figure 7. Validation Test Diagram

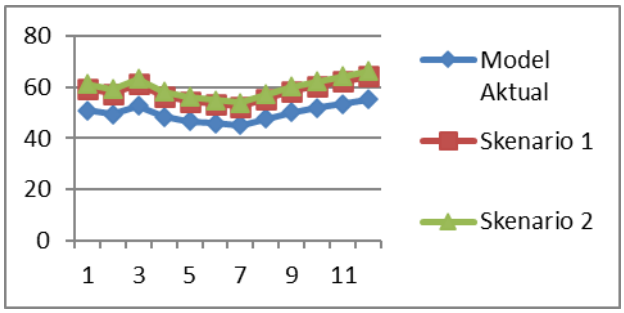


The validation test results yielded a MAPE value of 5.16%. These results indicate that the simulation model is valid because it does not deviate significantly from actual conditions or field conditions.

DISCUSSION

Repair Scenario

Figure 8 Repair Scenario Diagram



Improvements were made by improving the criteria for unfit shrimp and the distribution rate in scenario 1. Meanwhile, in scenario 2, shrimp supply was increased. Both improvement scenarios were assessed as providing improvements that could boost shrimp exports.

Comparison with Previous Research

A previous study by Rahman et al. (2021) found that the main constraints in the seafood supply chain were cold storage infrastructure and distribution chain instability. This study corroborates these findings but provides additional insight into the relationship between cold chain efficiency and its impact on selling prices. A study by Wijaya et al. (2020) also found that optimizing cooling systems can reduce product quality loss by up to 15%. In this study, improvements in cold chain logistics were estimated to reduce return rates by up to 4%.

Research Limitations

Some limitations of this study include:

a. The data used only covers a one-year period, so it does not fully reflect long-term trends.
b. External factors such as government policies and weather conditions have not been analyzed in depth.
c. The use of simulation models still requires additional validation through other case studies to improve prediction accuracy.

Causal Argument

Delays in distribution directly impact storage temperatures during transport, which then leads to a decline in shrimp quality. This decline in quality leads to increased product returns from overseas buyers, which ultimately impacts export prices. This creates a negative loop in the supply chain system, where delays cause economic losses for exporters.

Speculation and Deduction

If companies can adopt real-time temperature monitoring technology during distribution, it is predicted that return rates will decrease by more than 3%, and supply chain efficiency will increase. Furthermore, better predictability of seasonal patterns allows companies to manage inventory and distribution schedules more optimally. Based on the collected data, it can be concluded that a 10% increase in cold chain logistics efficiency can increase export profits by up to 5% in the long term. This research provides important insights for supply chain managers in the seafood industry, particularly in improving product quality and reducing losses due to export returns. The implementation of technology-based solutions is expected to improve system efficiency and enhance product competitiveness in the global market.

CONCLUSION

This study revealed that delays in the vannamei shrimp supply chain at seafood exporters in Makassar significantly impact shrimp quality and prices. Based on historical data from 2023, the average distribution delay reached 12-18 hours, resulting in a 2-3°C increase in temperature during transportation. This condition causes a decrease in product quality and increases the return rate by up to 7% of total monthly exports. Through Stock and Flow Diagram modeling, it is clear that the shrimp distribution process is significantly influenced by cold chain efficiency and shrimp eligibility criteria standards, with feedback in the form of product returns that can hamper export performance. Improvement efforts through two simulation scenarios showed promising results. The first scenario, which improved the criteria for unfit shrimp and optimized distribution rates, proved effective in reducing the number of damaged shrimp. Meanwhile, the second scenario, which also added an increase in shrimp supply, also contributed to increased exports.

REFERENCE

Akmal, SS (2021). Development of exports and imports in January 2021 in South Sulawesi Province. Central Statistics Agency of South Sulawesi Province.

Aminatuzzuhra, Purwaningsih, R., & Susanto, N. (2016). Simulation of Cold Chain System in Fish Distribution Chain to Measure Fish Quality Improvement in Semarang City. Industrial Engineering Online Journal

Borshchev, A., & Filippov, A. (2004). From System Dynamics and Discrete Event to Practical Agent Based From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools.www.xjtek.com

Aminudin, M. (2014). SIMULATION OF POTATO SUPPLY CHAIN DYNAMIC SYSTEM MODEL IN NATIONAL FOOD SECURITY EFFORTS.

Firman Hidranto. (2022, September). Improving the Cultivation of Indonesia's Prima Donna Exports. Indonesia.go.id.

Hamed, A., Jamil, S., & Rafiq, H. A. (2022). University branding and student satisfaction: The emerging landscape of universities in Pakistan. Pakistan Journal of Educational Research, 5(2), 429-449.

Imaroh, TS, & Mustofa, A. (2022). Defect reduction analysis to improve glass bottle packaging products quality using statistical process control (SPC) at PT. Muliaglass Container (MGC). Journal of Social Science, 3(5), 1003–1018.

Jirasukprasert, P., Arturo Garza-Reyes, J., Kumar, V., & Lim, M. (2014). A six sigma and DMAIC application for the reduction of defects in a rubber gloves manufacturing process. International Journal of Lean Six Sigma, 5(1), 2–21.

Mustafa, MFMS, Navaranjan, N., & Demirovic, A. (2024). Food cold chain logistics and management: A review of current development and emerging trends. In Journal of Agriculture and Food Research (Vol. 18). Elsevier BVhttps://doi.org/10.1016/j.jafr.2024.101343

Purwaningsih, R., & Susanto, N. (tt). SIMULATION OF COLD CHAIN SYSTEM IN FISH DISTRIBUTION CHAIN TO MEASURE THE IMPROVEMENT OF FISH QUALITY IN SEMARANG CITY.

Satrio, R., Irfani, YN, & Lasut, MRS (2023). Barriers and Efforts to Increase Shrimp Exports in Indonesia. ECOMA: Journal of Economics and Management, 1(3), 123–131. https://doi.org/10.55681/ecoma.v1i3.28.