EMISSION REDUCTIONS THROUGH JIT ARRIVAL STRATEGIES

by participants

Tan Kai El, Loke Sheng Jun, Soh Jung Xuan Team participants

ABSTRACT

Port congestion remains a critical challenge in global maritime logistics, affecting both operational efficiency and environmental sustainability. The Port of Singapore, one of the busiest in the world, experiences significant congestion due to its strategic geographical location and extensive trade agreements. This paper explores the implementation of Just-In-Time (JIT) Arrival strategies to mitigate congestion, optimize fuel consumption, and reduce emissions. By analyzing Automatic Identification System (AIS) data and incorporating port-specific emission factors, we identify key relationships between vessel speed, waiting duration, and carbon emissions. Our findings indicate that by adjusting vessel speeds to an optimal average of 9.02 knots and limiting anchorage times, we can achieve a 32% reduction in carbon emissions during the anchorage period. Additionally, strategic scheduling and regulation of the number of vessels at docking stations are crucial in minimizing waiting times and enhancing port operations. The study demonstrates that JIT Arrival strategies not only address environmental concerns but also improve the economic efficiency of port operations, offering a sustainable solution for the future of maritime logistics.

1 INTRODUCTION

Port congestion remains a significant issue for global maritime logistics, impacting efficiency and environmental sustainability.[1] Vessels often experience prolonged waiting times before berthing, leading to increased fuel consumption, emission generation, and additional operational costs. Moreover, the Port of Singapore is one of the busiest ports in the world, handling global shipping containers and crude oil.[2], [3] This is due to its geographical advantage and Free Trade Agreements (FTA) with countless other countries.[4] As a result, Singapore heavily relies on imports and exports to survive and thrive, in turn exacerbating this issue of port congestion. This paper aims to investigate the application of Just-In-Time (JIT) Arrival strategies in Singapore's port operations to reduce waiting times and optimize fuel consumption. By analyzing vessel behavior through AIS data and incorporating port-specific emission factors, we propose strategies that ensure vessels arrive at the port just in time for berthing, thus reducing idle time, emissions, and associated costs. We explore the relationship between waiting times, vessel speed, and carbon emissions and present methodologies to improve operational efficiency.

2 DATA ANALYSIS

```python
port_call_data["waiting_time_minutes"] = (
    pd.to_datetime(port_call_data["current_latest_visit_time_utc"]) -
    pd.to_datetime(port_call_data["current_earliest_visit_time_utc"])
).dt.total_seconds() / 60

# view waiting times
print(port_call_data[["imo", "current_port_name", "waiting_time_minutes"]].head())

# average waiting time per port
avg_waiting_time = port_call_data.groupby("current_port_name")["waiting_time_minutes"].mean()
print(avg_waiting_time)

✓ 0.0s                                                                 Python
```

```
       imo current_port_name  waiting_time_minutes
0  1013327         Singapore             11.833333
1  1015820         Singapore            947.700000
2  1028437         Singapore              0.000000
3  1043011         Singapore            766.633333
4  8353245         Singapore            246.000000
current_port_name
Singapore    235.794299
Name: waiting_time_minutes, dtype: float64
```

Fig. 1 Waiting Duration Calculation

By filtering and manipulating the data from the problem statement datasets provided, we were able to extract crucial information pertaining to the waiting duration required by every ship which was on average 236 minutes. This is achieved by calculating the difference between the latest visit time (UTC) and the earliest visit time (UTC), allowing us to equate the waiting duration.

```python
# merge distance data with port call data on IMO
merged_data = port_call_data.merge(distance_data, on="imo", how="left")

# calculate the time available before arrival
merged_data["time_available_hours"] = (merged_data["waiting_time_minutes"] + merged_data["duration_minutes"]) /

# calculate the required speed (knots)
merged_data["required_speed_knots"] = merged_data["distance_nm"] / merged_data["time_available_hours"]

# view the recommended speeds
print(merged_data[["imo", "current_port_name", "required_speed_knots"]].head())

# average speed needed per port
avg_speed_needed = merged_data.groupby("current_port_name")["required_speed_knots"].mean()
print(avg_speed_needed)
```

✓ 0.0s Python

```
       imo current_port_name  required_speed_knots
0  1013327         Singapore              1.496660
1  1015820         Singapore              1.736545
2  1028437         Singapore              8.545058
3  1028437         Singapore              0.031587
4  1043011         Singapore              2.527894
current_port_name
Singapore    9.025895
Name: required_speed_knots, dtype: float64
```

Fig. 2 Required Speed Calculation

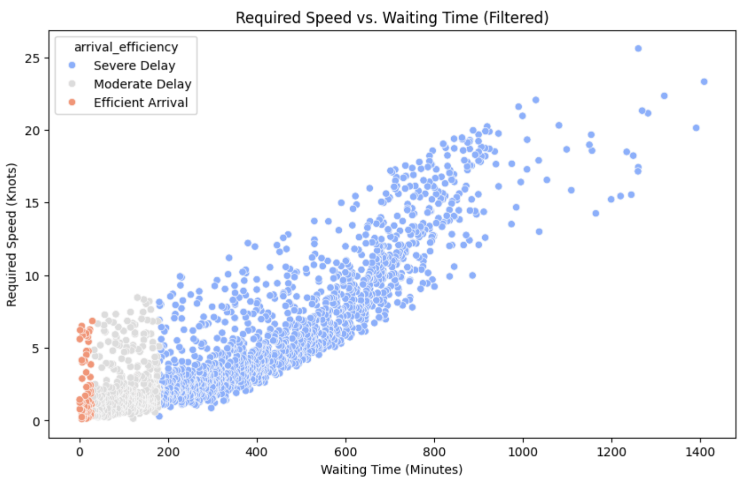
On top of that, we were able to calculate the speed required for all ships to approach and leave the Port of Singapore in order to minimise waiting duration and allow as many ships to dock as quickly as possible. This was achieved by calculating the quotient of the distance the ship is away from the dock over the total time (sum of waiting duration and remaining voyage duration). This results in an average required speed for all ships to operate at to be 9.02 knots.

3 OUR JIT STRATEGY

Just-In-Time Arrival involves predicting and adjusting vessel speeds so that ships arrive at the port just when they are needed, reducing or eliminating the time spent waiting.[5] This strategy requires an understanding of vessel schedules, port call data, and port capacity to optimize arrival windows.

3.1 LIMITING ANCHORAGE TIME

We trained a linear regression model to predict the optimal ship speed and the limit of the number of ships at the docking station.



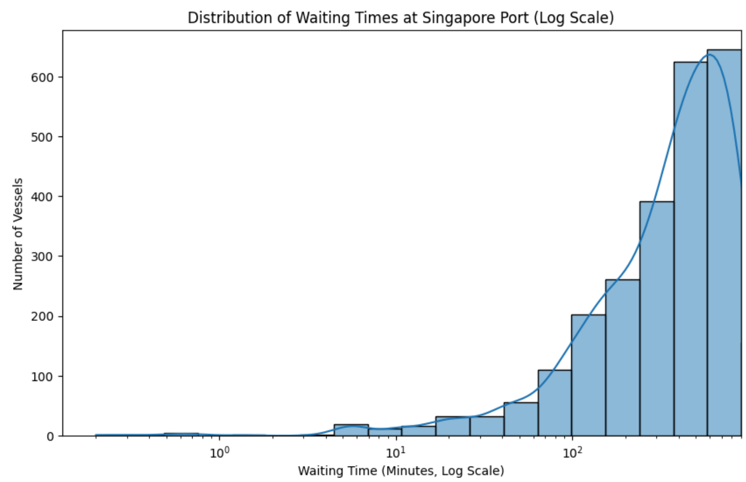


Fig. 3 Ship Speed Requirement w.r.t Wait Duration

Fig. 4 Wait Duration Distribution

We can conclude that for an efficient to moderate anchorage time, maximum ship speed should be 9.02 knots for a waiting time of 200 minutes. (**Fig. 3)** The port should also limit the number of vessels between 100-200 depending on the number of berths in order to maintain a waiting time of 10-100 minutes. **(Fig. 4)** Our Just-In-Time Arrival strategy has the potential to significantly reduce emissions and improve port operations in Singapore. By optimizing vessel arrival times, we can minimize waiting periods, leading to fuel savings, reduced emissions, and lower operational costs. This solution not only addresses environmental concerns but also enhances the overall efficiency of maritime logistics.

4 EMISSION REDUCTION

Using the methodology given, we calculated the total carbon emissions of ships during anchorage from June-July 2024 to be 570.5512454 metric tonnes, with the average waiting time of a ship to be about 0.7 hours.

However, we found that by limiting each ship to a maximum of 3 hours of anchorage time, the total carbon emissions can be reduced to 381.5562835 metric tonnes. This is a 32% decrease in the total carbon emissions from anchorage.

5 CONCLUSION

The implementation of Just-In-Time (JIT) Arrival strategies at the Port of Singapore presents a promising solution to the persistent issue of port congestion, which adversely affects global maritime logistics. By leveraging AIS data and port-specific emission factors, our study demonstrates that optimizing vessel arrival times can significantly reduce waiting durations, lower fuel consumption and emissions. We were also able to facilitate smoother docking processes and minimize idle time. Furthermore, limiting the number of anchored ships at any point in time has proven to be beneficial in terms of the environment .

Our findings underscore the critical relationship between ship speed, waiting duration, and carbon emissions, highlighting the need for strategic scheduling and operational adjustments. By predicting optimal ship speeds and regulating the number of anchored ships, Singapore can enhance its port operations, reduce environmental impact, and maintain its competitive edge in global trade. Our JIT Arrival strategy not only addresses environmental sustainability but also improves the economic efficiency of port operations, proving to be a valuable tool in the pursuit of greener and more efficient maritime logistics.

BIBLIOGRAPHY

[1] Associate Editor. "The Impact of Port Congestion on Supply Chain Efficiency." Maritime Fairtrade, 2 Oct. 2023, maritimefairtrade.org/the-impact-of-port-congestion-on-supply-chain-efficiency/

[2] Jeslyn Lerh. "Marine Fuel Sales at Singapore Bunker Hub Hit Record Highs in 2024." Reuters, 16 Jan. 2025,
www.reuters.com/markets/commodities/marine-fuel-sales-singapore-bunker-hub-hit-record-highs-2024-2025-01-16/

[3] Lucas, Romero. "Singapore: Imports of Crude Oil 2022 | Statista." Statista, 2022, www.statista.com/statistics/981846/singapore-imports-of-crude-oil/

[4] Derek, Heng. "Continuities and Changes: Singapore as a Port City over 700 Years." Nlb.gov.sg, 2024, biblioasia.nlb.gov.sg/vol-1/issue1/nov-2005/continuities-changes-port-city/

[5] Millard, Ross. "How Can Just-In-Time Arrival Reduce Shipping Emissions?" Nautilus Labs, 11 Aug. 2023, nautiluslabs.com/resources/how-can-just-in-time-arrival-reduce-shipping-emissions/