Sustainable Impact Study

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Abstract

This study analyzes the sustainable impacts of optimizing ship scheduling in the Panama Canal - a vital maritime route responsible for ≈ 6% of global trade. This approach aims to tackle the Sustainable Industries and Transport Challenge, focusing on the United Nation's SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production). A 40% reduction in freshwater usage is observed in the optimized timetables. This reduction has several benefits such as a reduction in CO2 emmissions and increased water security in Panama.

Keywords—Panama Canal, SDG, Freshwater Conservation

Contents

1. Sustainable Industries and Transport SDG

The sustainable industries and transport challenge focuses on the eco-friendly innovation of transportation and industries to foster a sustainable economy. The core aims of this challenge are adopted from the United Nations Sustainable Development Goals (SDG) and specifically focus on SDG 9 and SDG 12. The goals respectively aim to "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation", and "Ensure sustainable consumption and production patterns". The optimization of ship scheduling at the Panama Canal tackles this SDG challenge by reducing vital resources needed for the operation of the canal. This allows for a more sustainable transport industry within the vital global trade[10]

2. Project Outline

The Panama Canal is a pivotal maritime route that connects the Atlantic and Pacific Oceans, significantly reducing travel distances for global shipping. By enabling vessels to bypass the lengthy and treacherous journey around the southern tip of South America, the canal has been instrumental in facilitating international trade and bolstering economic growth since its completion in 1914.[6] The canal saves roughly 13,000 kilometres on the journey, reducing C02 emissions for the journey.

In recent years, the Panama Canal has faced significant challenges due to water scarcity from the more frequent droughts. These conditions have led to decreased water levels in Gatún Lake, threatening both the canal's operational capacity and the freshwater supply for local populations.[1] This has led to ships making the longer journey around South America, releasing more CO_2. The aim of our project is to implement a timetable that incorporates water saving measures to increase the amount of crossings possible during drought periods, reducing freshwater usage and the amount of CO_2 released in global trade.

3. Expected Sustainability Benefits

3.1. Environmental Benefits

Our project's optimized ship schedules offer multiple environmental benefits for the operation of the Panama Canal. The locks in the canal transport ships using water from the surrounding canal watershed and local environment- namely Gatún Lake. The freshwater of Gatún Lake is a vital resource and serves as the primary source of drinking water for Panama City. Currently, a single ship uses approximately 200 million liters of freshwater per crossing.[5] By implementing the optimized timetable, a reduction of up to 40% in freshwater usage can be observed compared to baseline water costs.

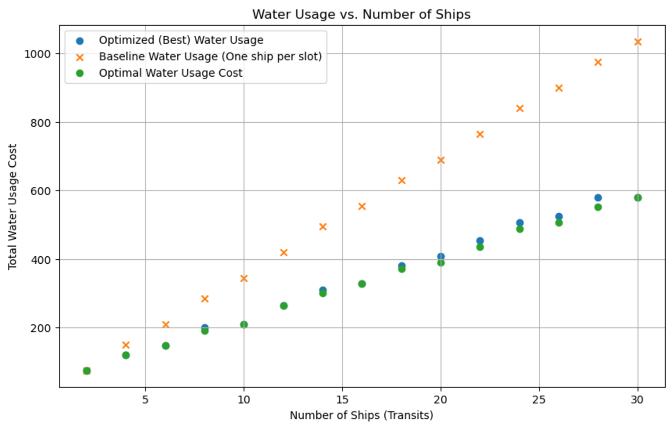

Figure 1. Proof of Concept reduction in water usage for timetabled operations versus current operation usage

As seen in Figure 1, the QUBO algorithm is capable of producing timetables that align closely with optimal water usage while also accounting for dynamic factors needed in real-time scheduling. This result contributes to Target 12.2 of UN's SDG 12 which strives to achieve the sustainable management and efficient use of natural resources.[10]

In addition to improving water usage, our scheduling approach has the ability to significantly reduce current fuel consumption and CO2 emissions due to longer ship journeys. In recent years, the canal has been experiencing a stark increase in drought caused by climate change. In the 2024 fiscal year, the Panama Canal Authority saw a 29% drop in transits due to severe drought. The alternative ship routes are longer and therefore increase emissions and fuel consumption.[3] A common alternative route involves traveling around the southernmost tip of South America, adding 15000 km to a ship's journey. A single large container ship uses an additional 100 tons of fuel to complete this journey.[9] Assuming all rejected vessels take this route, an estimate of additional fuel consumption is obtained as follows:

$$\frac{\text{No. transits in 2024}}{100 - \text{Percent decrease}} * \text{Percent decrease} \approx \text{Rejected transits} \quad (1)$$

$$\text{Rejected Transits} * 100 = \text{Total fuel (in tons)} \quad (2)$$

Based on the above calculation, the water saved due to optimized scheduling could prevent over 405,000 tons of additional fuel being consumed during such a drought in one year.

The decrease in fuel consumption and journey distance would result in a significant reduction in CO2 emissions. The most common form of fuel used by cargo ships today is Heavy Fuel Oil (HFO). HFO emits 3.15 tons of CO2 per ton of fuel. Assuming all redirected ships use HFO, optimized scheduling would prevent 1.28 million tons per year of CO2 from being emitted during a drought of such severity.[2] This outcome contributes to Target 9.1 of SDG 9 which aims to develop sustainable infrastructure that contributes to economic development.[10]

3.2. Social and Economic Benefits

The reduction in freshwater usage from Gatún Lake would provide major improvements in water security for Panama City. In January 2025, an average of 32.6 ships crossed the canal per day.[8] If the canal was to implement the optimized schedule while maintaining the number of daily ship transits, an estimated 3.08 billion liters of fresh water could be saved per day. This would be enough water to provide for Panama's entire population 13 times over. If not used for ship transiting, the excess freshwater can be utilized for agricultural purposes or supplied to Gatún Lake's hydroelectric plants which account for 30% of Panama's electricity.

The optimized timetable would allow for higher transit capacities during drought periods, leading to increased canal revenue.[4] The implementation of optimized scheduling would save enough water to increase the canal's current 32.6 daily transits back to the regular 36 per day. Assuming these ships transit using Neopanamax locks, the canal would bring in an additional 680,000 USD per day. During severe drought, the optimized scheduling has the potential to minimize the economic harm caused by reduced transits.[7]

4. Scalability & Deployment Roadmap

Currently the largest restriction to more sustainable operations at the Panama Canal arise from freshwater shortages caused by droughts. Our optimized scheduling offers an implementable solution to this issue. The infrastructure at the canal needed to implement such timetable already exists, with only water levels imposing restrictions. This is a major benefit as it allows for easy deployment at the canal once the timetables are obtained.

The successful integration of high-quality, real-time operational data is critical yet challenging. Current hardware limitations, particularly in terms of qubit count and noise, also pose barriers to scaling. However, as these challenges are gradually addressed through both technological advancements and algorithmic innovations, our roadmap provides a clear trajectory from enhanced model development and pilot testing to full-scale deployment in the FTQC era, ultimately promising substantial improvements in operational efficiency and water conservation.

5. Key Performance Indicators (KPIs) & Quantum Energy Efficiency

The KPIs outlined in Table 1 quantify the sustainable impact of optimized ship scheduling at the Panama Canal and how it tackles the challenge to develop sustainable industries and transportation. The KPIs measure reductions in vital resources as well as economic and environmental benefits based on the results obtained from our proof of concept.

Category	KPI	Measurement Metric
Environmental	Reduction in freshwater usage	40% decrease compared to baseline costs.
	Reduction in CO2 emissions	1,278,385 tons saved during 2024 drought
	Reduction in fuel consumption	405,837 tons of fuel saved during 2024 drought
Economic	Increase in ship transits	Current 32.6 daily crossings can return to 36
	Increase in canal revenue	Additional 680,000 USD per day in toll charges

Table 1. Key Performance Indicators for Sustainability Impact

Table 2 outlines the KPIs associated with using Post-Orion (400-2000 qubits) to obtain optimized ship schedules. Despite the relatively higher emissions associated with Post-Orion due to hardware and preparation time, the emissions associated with using suboptimal ship scheduling are far greater and pose a larger risk to the environment. These KPIs outline the sustainable benefits of adopting quantum technologies to implement such optimisation methods at the Panama Canal.

KPI	Post-Orion 400-2000 Qubits	Basic GPU Server
Execution Time for Final Computation (Hours)	6	916,259
Total Run Emissions (tCO per run)	0.0	79.9
Total Use-case Emissions (tCO incl. preparation)	0.2	79.9
Equivalent Run Emissions (kgCO per hour)	4.9	0.09
Hardware Manufacturing Emissions (tCO over lifetime)	2	2,176
Power Requirement (kW per run)	12.5	0.2
Overhead Provision for Cooling & Maintenance	3.5x	1.25x
Carbonation of Electricity (kgCO per MWh)	85	85
Time Required for Preparation (Hours)	600	100,000
Overhead Ratio for Preparation (%)	688%	100%

Table 2. Comparison of Quantum Computing and GPU Server for KPI Metrics

6. Conclusion

The optimization of ship scheduling in the Panama Canal tackles the Sustainable Industries and Transport SDG which is centered around the UN's SDG 9 and SDG 12. Our project successfully achieves this by creating optimal timetables using QUBO-based algorithms. Our proof of concept demonstrated a 40% decrease in freshwater usage leading to a decrease in CO2 emissions and increased ship transits during drought periods. Despite still facing scalability challenges, quantum technologies such as Post-Orion shows to be promising for the real-world implementation of such optimization challenges. Looking to the future, the infrastructure for the implementation of optimized timetables already exists at the Panama canal. Dynamic scheduling and fine-tuning of QUBO parameters can further improve the timetables to increase sustainability in the canal's operations.

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