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Full Length Article

Effect of COVID-19 pandemic on freight volume, revenue and expenditure of deendayal port in India: An ARIMA forecasting model

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ABSTRACT

Shipping sector is vital to Indian economy, making it crucial to understand the economic impact of the COVID-19 pandemic on port operations to develop strategies for future resilience. This study examines the effects of COVID-19 on Deendayal Port, a key Indian port, by analyzing freight volume, revenue, and expenditure data from April 2012 to October 2022. Autoregressive Integrated Moving Average (ARIMA) modeling covers pre-COVID, two COVID-19 waves, and post-COVID scenarios. Ordinary Least Squares (OLS) regression models for revenue and expenditure evaluate economic losses. The results show 6.2% decline in freight volume during the first wave, with a decrease from 123.4 million tons (Mt) to 115.8 Mt, leading to a monthly average loss of 0.6 Mt. The second wave saw recovery, with freight volume increasing from the forecasted 127.6 Mt to 129.6 Mt, resulting in a monthly gain of 0.2 Mt. Revenue losses during wave 1 were 215 crore INR, while wave 2 saw a revenue increase of 57 crore INR. The study highlights the importance of operational efficiency and managing key cost drivers like volume and manpower to maintain financial stability. These findings lay a foundation for future research to strengthen the shipping industry's resilience and sustainability in post-pandemic world.

1. Introduction

The global shipping industry, essential to international trade, transports over 80% of global merchandise by volume, playing a vital role in economic growth and globalization (UNCTAD, 2021). Ports are critical nodes in this industry, contributing 1-3% annually to the global Gross Domestic Product (GDP) (Ben-Hakoun et al., 2016). India's maritime sector has grown significantly due to its expanding economy and role as a global manufacturing hub, with a logistics sector valued at approximately US$ 125 billion (Patil & Sahu, 2017; Sinha, 2016). In 2018, India's exports totaled US$ 323.1 billion, contributing 19.1% to GDP, with imports reaching US$ 507.6 billion, with sea transport accounting for about 95% of volume and 70% of value (Mindur, 2019).

The COVID-19 (SARS-COV-2) pandemic introduced significant challenges to the global shipping industry, including disruptions in India's port operations, logistics, and supply chains (Haghani et al., 2023). Lockdowns, travel restrictions, and reduced demand led to declining trade volumes, capacity constraints, and logistical bottlenecks (Yazır et al., 2020). Ports faced crew rotation disruptions, closures, and delays, highlighting vulnerabilities in global supply chains (HSBA, 2022). Despite India's growth in freight volume over the last decade (see Fig. 1), there remains a gap in accurate demand forecasting for port development, which is crucial for effective infrastructure investment and operational efficiency (Li et al., 2024; Patil & Sahu, 2017).

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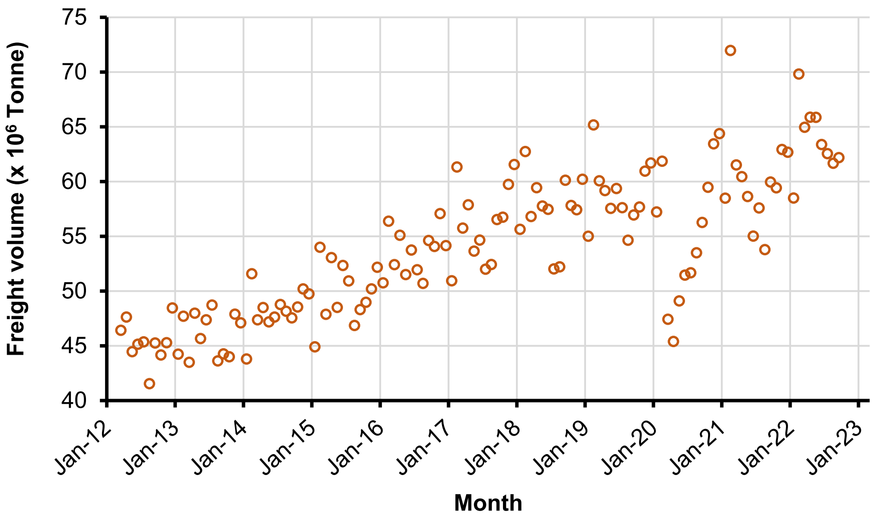

Fig. 1. Yearly temporal variations in cumulative freight volume of major ports in India from April 2012 to October 2022.

While research has examined the effects of COVID-19 on ports in developed nations, there is a need for focused studies on ports in developing countries, like India, to develop tailored strategies for sustainable operations (Gu et al., 2023). Existing studies on India's shipping industry during the pandemic have not adequately addressed port-level responses or quantified the monetary losses to port businesses (Bandyopadhyay & Bhatnagar, 2023; Ian et al., 2020; Narasimha et al., 2021; Singh et al., 2021), but they have not sufficiently addressed port-level responses or quantified the monetary losses to port businesses. Moreover, most studies have examined the pandemic's effects at a national level, overlooking the importance of analyzing localized impacts at the port or regional level.

This study addresses a significant gap in understanding the economic impacts of the COVID-19 pandemic on port operations by focusing on Deendayal Port, India's largest port by freight volume. Deendayal Port was selected due to its strategic location on key international trade routes and its capacity to handle a diverse range of cargo, making it an exemplary case of how major ports adapt to significant external shocks. The availability of detailed data for this port facilitates a comprehensive analysis of the broader effects of global trade disruptions. To assess changes in freight volume and their financial impacts on the port's revenue and expenditure, this study employs the Autoregressive Integrated Moving Average (ARIMA) model, which is well-suited for forecasting non-stationary time series data, particularly in contexts where freight volumes are suddenly influenced by market shifts (Saxena & Yadav, 2022).

This study makes several key contributions. First, it provides an economic analysis specific to Deendayal Port, addressing a gap in the literature that often overlooks individual ports in favor of broader national or regional studies. Focusing on specific metrics like freight volume, revenue, and expenditure, the study offers a detailed understanding of how the pandemic impacted port operations. Second, it underscores the importance of localized impact assessments, revealing the unique challenges and responses required at individual ports. This localized approach is essential for developing targeted strategies to enhance resilience. Finally, the study presents practical policy recommendations based on its detailed analysis, offering guidance for future investments and strategies in the maritime sector. Overall, this research fills critical gaps in existing literature and provides valuable insights and strategies to help the maritime industry develop more resilient and efficient port operations in response to global disruptions like the COVID-19 pandemic.

The novelty of this study is its focused analysis of the COVID-19 pandemic's economic impact on Deendayal Port, India's largest by freight volume, using the ARIMA forecasting model. Unlike broader studies on the pandemic's effects on shipping in developed nations, this research uniquely examines localized impacts at a port-specific level in a developing country. The ARIMA model provides detailed forecasts of changes in freight volume, revenue, and expenditure, offering valuable insights for stakeholders to make informed decisions (Gu et al., 2023).

The framework of the paper is structured as follows: Section 2 reviews pertinent scholarly works; Section 3 delineates the research methodology; Section 4 discusses the study's findings; Section 5 offers policy recommendations to strengthen the resilience of the port and shipping industry; Section 6 concludes the paper with a summary of key points and suggestions for future research.

2. Literature review

The present study aims to explore the impact of the COVID-19 pandemic on the operational efficiency of India's shipping logistics sector. This section has been subdivided into two parts to provide a comprehensive overview of the literature: the influence of COVID-19 on global logistics and the effects of the pandemic on the logistics industry within India.

2.1. Unequal impact of COVID-19 on ports: developing vs. Developed countries

The COVID-19 pandemic has highlighted and worsened the weaknesses of ports worldwide, showing apparent differences between the challenges faced by ports in developed and developing countries. These differences emphasize the importance of focusing research on ports in developing countries and creating strategies to improve their resilience and efficiency.

2.1.1. Infrastructural deficits

Ports in developing countries often face significant infrastructural deficits, which the pandemic has magnified. Unlike their counterparts in developed nations, these ports frequently lack the advanced technological systems and robust physical infrastructure necessary to adapt to sudden changes in trade volumes and operational demands. For example, the study on the impact of COVID-19 on transportation in Lagos, Nigeria, highlights how infrastructural deficits exacerbated the pandemic's impact on port operations (Mogaji, 2020). These limitations hinder the ability of ports in developing countries to implement effective contingency measures and maintain operational efficiency during crises. In contrast, ports in developed countries, equipped with advanced infrastructure, could leverage digital technologies and robust contingency plans to mitigate disruptions (Alamoush et al., 2022).

2.1.2. Limited financial resources

Financial constraints further compound the challenges faced by ports in developing countries. These ports often operate with limited governmental support and have restricted access to the financial resources needed for infrastructure upgrades and technological advancements. This financial vulnerability contrasts sharply with the situation in developed countries, where ports received substantial governmental backing to deploy digital technologies and sustain operations during the pandemic (Singh & Misra, 2020). The lack of financial resources in developing countries limits immediate response capabilities and hampers long-term strategic planning and investment in resilience-building measures.

2.1.3. Economic vulnerabilities

The economic structure of developing countries often exacerbates the impact of port disruptions. Many developing nations have economies heavily reliant on a few key sectors, such as agriculture, fisheries, and oil exports. The pandemic-induced disruptions in port operations have had cascading effects on these sectors, leading to significant economic challenges. For instance, research on the impact of COVID-19 on fisheries in Indonesia's Pondokdadap Fishing Port demonstrated significant reductions in fish production and fishers' income, highlighting the broader economic vulnerabilities tied to port disruptions (Muntaha et al., 2023). Similarly, fluctuations in global oil prices have affected oil-exporting developing countries, which often rely on ports for oil exports, further complicating their economic recovery (Anderson & Engebretsen, 2020).

2.1.4. Lack of technological advancements

The pandemic has accelerated the need for ports to integrate smart and digital technologies to enhance resilience and efficiency. However, ports in developing countries often lag in technological adoption due to financial and infrastructural constraints. This technological gap makes them less adaptable to crises, as they cannot leverage advanced modeling techniques and digital tools to predict and adjust operations effectively (Millefiori et al., 2021; Xu et al., 2021). In contrast, ports in developed countries have been able to utilize advanced forecasting models and digital infrastructure to mitigate the impact of the pandemic on maritime trade (Koyuncu et al., 2021).

2.1.5. Longer recovery times

The recovery from pandemic-induced disruptions has been slower for ports in developing countries than those in developed regions. This prolonged recovery is attributed to weaker infrastructure, limited financial resources, and economic dependencies that hinder swift recovery. For example, while ports in developed regions like Western Europe experienced significant trade losses, their recovery was relatively swift due to strong governmental support and advanced infrastructure (Verschuur et al., 2021). In contrast, ports in developing countries, small island states and low-income economies experienced more severe and prolonged trade disruptions with limited recovery options.

2.1.6. Need for focused research

Given these unique challenges, there is a pressing need for focused research on the impact of COVID-19 on ports in developing countries. Such research should identify impacts that make ports in developing countries more susceptible to global disruptions. Understanding the impact is crucial for creating targeted strategies to enhance resilience. Research should also focus on developing tailored strategies that address the unique challenges faced by these ports, including exploring financial and operational improvements that can support their capacity to withstand future disruptions.

Moreover, research focusing on ports in developing nations is essential for informing global trade practices. By understanding the impact of the pandemic on these ports, research can contribute to more equitable and sustainable global trade practices. This knowledge is essential for ensuring that developing nations are better integrated into global supply chains and can recover more swiftly from global crises. For instance, studies on the global economic impacts of COVID-19 using high-frequency shipping data revealed widespread port-level trade losses, with the largest absolute losses found for ports in developing nations (Verschuur et al., 2021). Such insights underline the importance of developing tailored strategies to enhance resilience, improve infrastructure, and ensure the sustainable operation of ports globally, particularly in underrepresented major developing nations witnessing global trade growth. Therefore, while the existing literature has provided valuable insights into the effects of COVID-19 on ports in developed nations, there is a clear and pressing need for focused research on ports in developing countries. Such studies are crucial for developing tailored strategies to enhance resilience, improve infrastructure, and ensure the sustainable operation of ports globally, particularly in underrepresented major developing nations such as India, witnessing global trade growth.

2.2. Effect of COVID-19 on logistics sector in India

In the Indian context, few studies have attempted to analyze the effect of the pandemic on the logistics sector. Singh et al. (2021) examined the impact of COVID-19 on Indian logistics and food supply chains and found that matching supply and demand in a vast PDS (public distribution system) network became increasingly difficult due to changing scenarios with the growth of infected cases and recovery.

An assessment by Saxena and Yadav (2022) using the ARIMA forecasting method estimated the financial impact of COVID-19 on India's rail freight revenue to be a loss of INR 16712.68 crores. A separate investigation by Bandyopadhyay and Bhatnagar (2023), leveraging survey data from 98 individuals in India's PMT (ports, multimodal logistics, and transport) sector, identified a significant contraction in the employment of about 21.4%. Interestingly, they discovered that over 61.5% of those surveyed predicted a postponement in capital spending for the 2021 and 2022 fiscal years, signaling upcoming supply-side issues. Further, a study by Narasimha et al. (2021) revealed that India's prime seaports, handling 90% of its international commerce, experienced a slump during the pandemic. Based on stakeholder-generated qualitative data, almost a fifth of the experts concurred that the social and economic landscapes might not return to their pre-COVID-19 status. Sudan and Taggar (2021) identified that India's logistics sector faced significant disruptions post-pandemic, including transportation issues, service delays, and sluggish customs processes. These disruptions caused delays and required rerouting of shipments. As restrictions ease, enterprises are recovering, and the study emphasizes the need for faster recovery and resilience through digitizing supply chains. This includes implementing intelligent transportation systems (ITS), assistive technology (ALS), and adopting Industry 4.0 practices.

2.3. Methodology in previous related studies

In analyzing the impact of freight volume changes on port revenue and expenditure, selecting an appropriate methodological approach is crucial. Previous studies have employed various methods to assess the effects of the COVID-19 pandemic on ports, but they present limitations that make them less suitable for our specific research objectives. A summary of studies assessing the impact of the pandemic on ports across different regions has been summarized in Table 1.

Qualitative methods, such as expert opinion surveys and in-depth interviews (Mańkowska et al., 2021; Mannan et al., 2021; Narasimha et al., 2021), are valuable for capturing industry insights but cannot quantify changes in freight volume and their direct financial implications. (Bandyopadhyay & Bhatnagar, 2023) combined T-tests with qualitative surveys to assess cargo volume declines, providing descriptive insights but lacking the predictive capabilities to understand future trends. Panel regression models used to analyze the impact of local COVID-19 cases on vessel arrivals and air quality (Gu & Liu, 2023; Gu et al., 2023), are effective for handling cross-sectional data but are more focused on relationships across different entities rather than modeling trends within a single time series. System dynamics models (Liu et al., 2023; Zhou et al., 2022) simulate complex interactions over time but require extensive data and assumptions, making them less straightforward for direct application to historical data for forecasting. The difference-in-differences approach (Guerrero et al., 2022) is helpful for causal inference across regions but is less suitable for understanding dynamic patterns within a single port's data. Similarly, while (Millefiori et al., 2021) provided important quantitative insights into global vessel mobility, their approach did not explore the temporal dynamics over time, which is essential for understanding the evolution of changes in freight volume and their financial impacts.

2.4. Research gaps

The literature lacks a detailed study of the financial impacts of the COVID-19 pandemic on individual ports, especially in developing countries like India. Although many studies have examined the economic effects of COVID-19 on logistics sectors globally and within India, they often overlook specific financial aspects of ports, such as volume, revenue, and expenditure. Furthermore, the methods used in existing research frequently lack the granularity needed to capture these financial details at the port level. Most research focuses on national or regional effects, offering limited insight into the local impacts at the port level. This gap makes it difficult to develop targeted response strategies. Additionally, while some studies discuss the broader impacts of COVID-19 on ports, there is little research on how ports in developing countries can improve their resilience and adaptability to such disruptions. The current literature also lacks policy recommendations based on detailed analyses of individual ports serving as benchmarks for other ports, which are important for guiding future investments and strategies in the maritime sector.

3. Methodology

The sections explain the case study, i.e., the Deendayal port, and the detailed methodology of the present study.

Table 1
Review of studies on assessment of effect of pandemic on ports.

Source	Study Area	Method adopted	Findings
Narasimha et al. (2021)	India	Qualitative assessment (based on expert opinion)	The expert survey results indicate a notable lack of preparedness for COVID-19 among maritime organizations.
Bandyopadhyay and Bhatnagar (2023)	India	T-test, qualitative assessment (ranking based survey)	Cargo volume handled per day declined by 13%, and the average drop in cargo handled per day for Category B respondents was 43%.
Millefiori et al. (2021)	Global level (various cities)	Quantitative, evidence-based assessment	The variation in mobility is as follows: between −5.62% and −13.77% for container ships, between +2.28% and −3.32% for dry bulk, between −0.22% and −9.27% for wet bulk.
Mańkowska et al. (2021)	Poland	Qualitative assessment (interviews), and inductive reasoning method	The pandemic significantly affected freight rates for dry and liquid bulk cargoes. Also, decline in port transshipment volumes for many dry bulk commodities and increased storage times for petroleum products contributed to reduced transshipment levels at terminals.
Gu et al. (2023)	Shenzhen, Hong Kong, and Singapore	Panel regression analysis	For vessels arriving at ports in Shenzhen, Hong Kong, and Singapore, local increases in newly confirmed COVID-19 cases negatively affect the number of dry bulk and liquid bulk vessels, with significance at the 5% level. Specifically, a 1% rise in local epidemic severity results in a 0.078% decrease in dry bulk vessels and a 0.025% decrease in liquid bulk vessels.
Gu and Liu (2023)	China	Panel regression analysis	The COVID-19 pandemic and port congestion significantly influence air quality in port cities.
Liu et al. (2023)	China	Classical SEIR model using the system dynamics theory	The results indicate that in scenarios with lower epidemic prevention and control levels, increasing investment in smart port technologies can further improve outcomes.
Guerrero et al. (2022)	Global level (various cities)	Difference-in-differences methodology	The study finds that COVID-19 mitigation measures implemented by governments impacted regional port hierarchies differently, reducing port concentration in Europe and Africa and causing an increase in Asia and North America.
Zhou et al. (2022)	China	System Dynamics (SD) model	The results indicate that during the initial months of the pandemic, ports and carriers may experience economic losses due to reduced demand caused by COVID-19. Additionally, the recovery process and economic impacts are influenced by the combined effects of manufacturing, transportation, and port operation capacities.
Mannan et al. (2021)	Bangladesh	Qualitative assessment (in-depth interviews with stake-holders etc.)	Chittagong Port maintained continuous operations throughout the pandemic; however, uncertainty surrounding the pandemic led to delays in cargo release. Consequently, the port's storage capacity was reached, causing a bottleneck in cargo discharging and resulting in extended vessel queues at the outer anchorage. As a result, the waiting period for vessels, turnaround time, and dwell time all increased significantly.

3.1. Case study

Deendayal Port, previously known as Kandla Port, is a major seaport near Gandhi Dham in the Kutch District of Gujarat state, western India (refer to Fig. 2). This multi-cargo port is a critical gateway for India's western and northwestern hinterland on international trade routes to the Middle East and Upper Gulf (Bhadauriya et al., 2020). It has 14 dry cargo berths totaling 3.15 km and six oil berths for handling loading and chemicals (Deendayal Port Trust, 2022, 2021).

The port is the oldest in India and has recently become the busiest major port. Its share of traffic handled by all major ports has continuously increased, indicating its significance to the Indian economy (Bhadauriya et al., 2020). Deendayal Port plays a significant role in the Indian economy by providing a vital link for international trade. It handles various cargo types, including dry and liquid bulk, container, and general cargo. Its strategic location and excellent infrastructure have contributed to its success, making it one of India's most crucial ports. Despite the prevailing limitations imposed by the COVID-19 pandemic on the handling of goods, the Deendayal Port Trust achieved a notable accomplishment by surpassing the threshold of 100 million metric tons (MMT) on January 10, 2022, becoming the first port in India to reach the feat (PIB, 2022). Vessel movement and cargo operations were affected by COVID-19 due to the limited availability of labor and trailer drivers (Waterfront, 2021). The pandemic and subsequent imposition of a national lockdown have adversely affected port operations, causing delays and reducing cargo handling capacity (Deendayal Port Authority, 2021, 2020). The Deendayal Port Trust intends to augment its cargo handling capabilities significantly through the involvement of the private sector (Bhadauriya et al., 2020). Considering the significant role of Deendayal port in India's

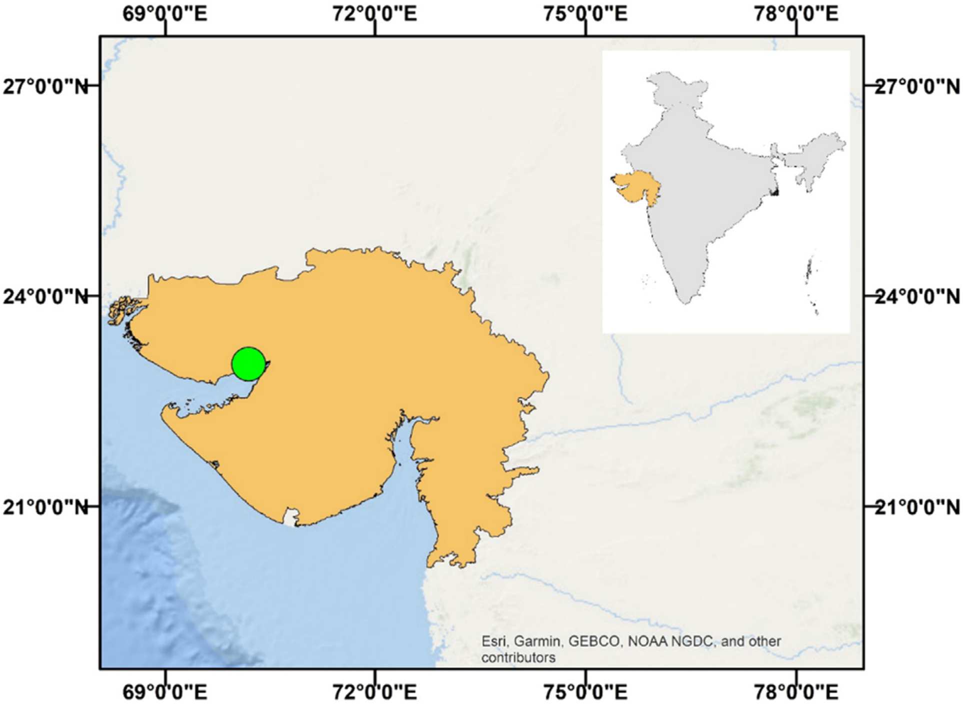

Fig. 2. The case study area of Deendayal port is in the state of Gujrat, and India is on the top right. (Color should be used for this figure in print).

economy, understanding the impact of the pandemic on its operations and expenditure is essential for developing suitable resilient policies by policymakers.

3.2. Approach

The methodology of this study primarily consists of six steps and uses a modified approach given by Saxena and Yadav (2022). A detailed methodology diagram is provided in Fig. 3.

Step 1 involves extracting secondary data on freight volume, freight revenue, and expenditure from IndiaStat for the Deendayal port from April 2012 to October 2022 (IndiaStat, 2023). In Step 2, the data is processed in Microsoft Excel using filters, sorting, and tabulation. Additionally, time series data is plotted to identify any visual outliers and abnormalities in the data. Step 3 involves dividing the freight volume data into three major periods: pre-COVID (April 2012 to February 2020), COVID (March 2020 to February 2022), and post-COVID (March 2022 to October 2022) (refer to Fig. 4). The COVID period is divided into two waves, wave 1 (March 2020 to February 2021) and wave 2 (March 2021 to February 2022), to understand if there is a significant change in the Deendayal port's performance under the threat of COVID over time. Step 4 categorizes wave 1 and wave 2 into two different scenarios.

The initial scenario proceeds under the business-as-usual (BAU) approach, considering the effects of COVID-19, whereas the latter scenario operates without considering these effects. ARIMA modeling is used to estimate the freight volume in the second scenario. Details of the ARIMA modeling are provided in a sub-section. In Step 5, the freight volume from the first scenario is deducted from that of the second scenario to quantify the COVID-induced loss in freight volume. The study makes two primary assumptions for this calculation: first, if the COVID-19 outbreak had not occurred, the growth in freight volume would have continued along its historical trajectory; and second, the statistical relationship between revenue and freight volume, as well as between revenue and expenditure, would have remained consistent throughout the COVID-19 period. In Step 6 for expenditure estimation, the study developed two linear regression models using SPSS, one based on historical freight volume and revenue data, and another based on historical expenditure and revenue data. Using the regression models, the loss in freight revenue is estimated first, and then the freight revenue is used to estimate expenditure. The fit of the regression models is checked using threshold values of $R^2_{adjusted}$.

3.3. ARIMA modeling

The ARIMA technique, developed by Box and Jenkins, is widely recognized for its effectiveness in time series forecasting. This model is particularly suitable for our study due to its capability to handle non-stationary data, which is typical in freight volume series affected by sudden market shifts like the COVID-19 pandemic. The ARIMA model's strength lies in its ability to model both the autoregressive (AR) and moving average (MA) components while integrating differencing (I) to stabilize the mean of the time series

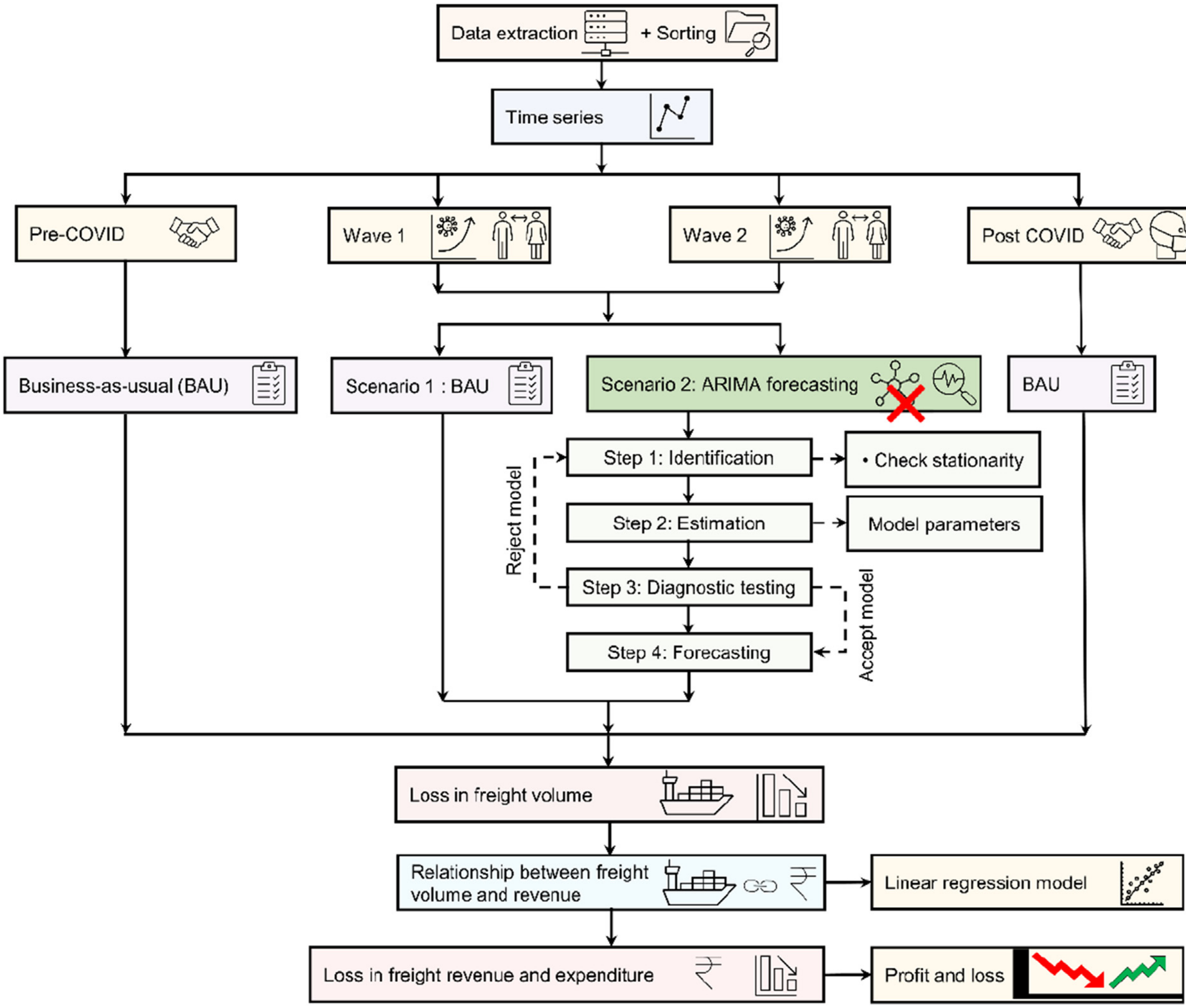

Fig. 3. Detailed methodology flow diagram. (Color should be used for this figure in print).

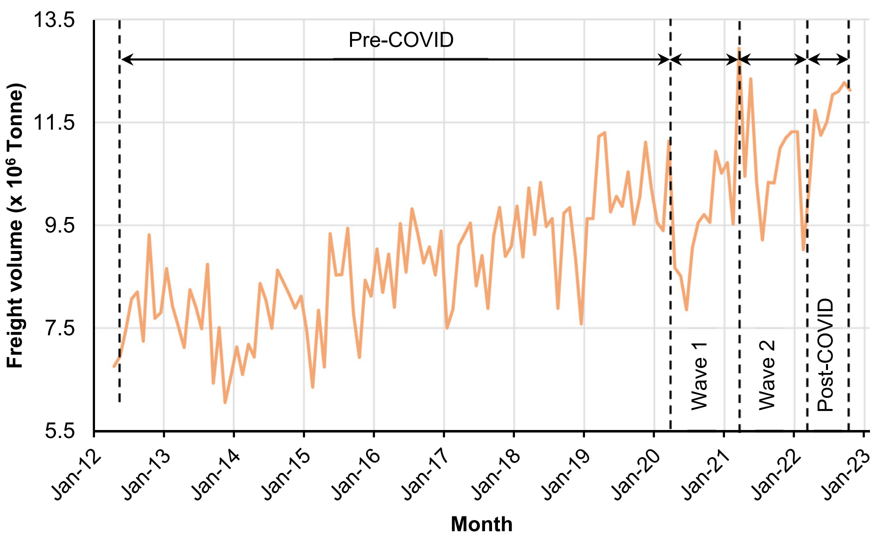

Fig. 4. Monthly temporal variations in cumulative freight volume of Deendayal port are divided into four periods, i.e., Pre-COVID, Wave 1 of COVID, Wave 2 of COVID, and Post-COVID.

(Ho & Xie, 1998). This makes it a robust choice for forecasting in scenarios with abrupt changes and trends, as observed during the pandemic.

Compared to other forecasting methods, ARIMA offers several advantages. It is more flexible in accommodating various patterns in time series data, including trends, seasonality, and irregular fluctuations (Ho & Xie, 1998; Tang & Deng, 2016). Methods like exponential smoothing may fail to capture our dataset's complex temporal dependencies and variations. For example, exponential smoothing techniques, such as Holt-Winters, assume a certain level of stability in the data and might not adapt well to sudden disruptions like those caused by the pandemic (Chatfield et al., 2001). Additionally, regression is often inadequate for non-stationary data and cannot effectively model the intricate patterns present in our dataset. Machine learning models, while powerful, often require large datasets and extensive computational resources, which may not always be practical for specific applications with limited data like port freight forecasting (Hyndman & Athanasopoulos, 2018). Moreover, machine learning models may not provide the interpretability and simplicity needed for stakeholders to understand and utilize the forecasts effectively.

ARIMA's iterative approach of model identification, parameter estimation, and diagnostic checking ensures that the model is well-suited to the specific data characteristics, leading to more accurate and reliable forecasts (Ho & Xie, 1998; Tang & Deng, 2016). This adaptability is crucial for our study, where the pandemic has introduced significant volatility and non-linear trends in freight volume data.

Several studies have demonstrated the efficacy of the Autoregressive Integrated Moving Average (ARIMA) model in forecasting port and maritime data. ARIMA has been shown to improve forecasting accuracy. For instance, a study proposed a variation of the ARIMA model to forecast port traffic, demonstrating superior performance compared to individual models (Shin et al., 2008). Similarly, Gargari et al. (2019) developed a hybrid ARIMA model for predicting short-term container vessel traffic volume at Rajaee Port, Iran, achieving better accuracy and insights into container traffic behavior. Koutroumanidis et al. (2006) also applied ARIMA models to forecast fishery landings in Thessaloniki, Greece, using ARIMA to improve forecasting accuracy. Laome et al. (2021) addressed the issue of outliers in time series data by using ARIMA additive outlier, which improved the accuracy of forecasting foreign tourist visits to Port Tanjung Priok. Similarly, Kim et al. (2011) used ARIMA models to forecast container volume at ports, emphasizing the need to incorporate various factors to enhance future predictions. Shivhare et al. (2019) developed an ARIMA-based forecasting tool, demonstrating its applicability in port and maritime contexts by predicting patterns with better accuracy. These studies collectively show that ARIMA models provide accurate forecasts for port and maritime data by leveraging their strengths in handling both linear and non-linear patterns. These studies highlight the robustness and adaptability of ARIMA models in diverse data forecasting contexts, highlighting their suitability for our study. This is important for predicting freight volume trends at Deendayal Port amidst COVID-19 disruptions.

The procedural steps for executing an ARIMA model have been provided by Tang and Deng (2016). The ARIMA (p,d,q) model is an amalgamation of the Autoregressive AR(p), Moving Average MA(q), and the combined ARIMA (p,q) elements. Representing non-seasonal ARIMA models as ARIMA (p,d,q), with p, d, and q as non-negative integers, is prevalent (Giraka & Selvaraj, 2020). Here, 'p' signifies the order of the autoregressive model in terms of time lags (Saxena & Yadav, 2022; Zhao et al., 2018).

As given in Eq. (1), in the first case, the AR (p) model is as follows:

$$y_t = c + \alpha_2 L y_{t-2} + \cdots \ldots + \alpha_p L^p \gamma_{t-p} + \varepsilon_t \tag{1}$$

As depicted in Eq. (2), the second, the MA (q) model is represented as:

$$y_t = c + \varepsilon_t + \theta_1 L \varepsilon_{t-1} + \theta_2 L^2 \varepsilon_{t-2} + \cdots . + \theta_q L^q \varepsilon_{t-q} \tag{2}$$

The third ARIMA (p,q) model corresponds to Eq. (3):

$$y_t = c + \alpha_1 L y_{t-1} + \alpha_2 L^2 y_{t-2} \ldots \ldots + \alpha_p L^p \gamma_{t-p} + \varepsilon_t + \theta_1 L \varepsilon_{t-1} + \theta_2 L^2 \varepsilon_{t-2} + \cdots + \theta_q L^q \varepsilon_{t-q} \tag{3}$$

Where both α and θ are the parameters to be estimated, and L is the lag operator.

The optimal values of p, d, and q must be determined to develop an ARIMA model for forecasting. This is typically achieved through statistical tests and visual inspection of plots, such as the autocorrelation function (ACF) and partial autocorrelation function (PACF). Once the appropriate ARIMA model has been identified, it can be used to forecast future time series values. In this paper, we employ the ARIMA modeling technique to analyze the impact of the COVID-19 pandemic on the Deendayal port's freight volume, revenue, and expenditure, considering pre-COVID, two waves of COVID-19, and post-COVID scenarios.

4. Results

The monthly data on the volume of freight traffic handled, revenue, and expenditure for the major port in India from April 2012 to October 2022 is used in the present study. The average monthly freight volume for the pre-COVID (April 2012 to February 2020) and post-COVID (March 2022 to October 2022) phases of the Deendayal port has been 8.57 Mt and 11.66 Mt, respectively. The COVID phase in the present study is divided into two scenarios. First, BAU depicts the impact on freight volume from COVID-19, and the second scenario highlights the changes in the absence of COVID-19.

4.1. Scenario 1: BAU with COVID impact

During the pre-COVID period from April 2012 to February 2020, freight volume in the Deendayal port witnessed a yearly average growth of 4.4%. However, during the wave 1 phase of COVID, the average freight volume witnessed a negative growth of 5.6% to 9.65

Table 2
Deendayal port´s freight volume during COVID waves.

Wave 1	Freight volume (Mt)	Wave 2	Freight volume (Mt)
Mar-20	11.1	Mar-21	12.9
Apr-20	8.7	Apr-21	10.5
May-20	8.5	May-21	12.3
Jun-20	7.9	Jun-21	10.3
Jul-20	9.1	Jul-21	9.2
Aug-20	9.6	Aug-21	10.3
Sep-20	9.7	Sep-21	10.3
Oct-20	9.6	Oct-21	11.0
Nov-20	10.9	Nov-21	11.2
Dec-20	10.5	Dec-21	11.3
Jan-21	10.7	Jan-22	11.3
Feb-21	9.5	Feb-22	9.0

Table 3
Estimated values of Freight volume (in Mt) for Wave 1 phase of COVID.

Wave 1	Mar 2020	Apr 2020	May 2020	Jun 2020	Jul 2020	Aug 2020	Sep 2020	Oct 2020	Nov 2020	Dec 2020	Jan 2021	Feb 2021
Forecast	10.1	10.2	10.2	10.2	10.2	10.3	10.3	10.3	10.4	10.4	10.4	10.4
UCL	11.7	11.8	11.8	11.8	11.9	11.9	11.9	12.0	12.0	12.0	12.1	12.1
LCL	8.5	8.5	8.6	8.6	8.6	8.6	8.7	8.7	8.7	8.7	8.7	8.8

Here, UCL is upper confidence limit and LCL is lower confidence limit

Table 4
Estimated values of Freight volume (in Mt) for Wave 2 phase of COVID.

Wave 2	Mar 2021	Apr 2021	May 2021	Jun 2021	Jul 2021	Aug 2021	Sep 2021	Oct 2021	Nov 2021	Dec 2021	Jan 2022	Feb 2022
Forecast	10.5	10.5	10.5	10.6	10.6	10.6	10.6	10.7	10.7	10.7	10.8	10.8
UCL	12.1	12.2	12.2	12.3	12.3	12.3	12.4	12.4	12.4	12.5	12.5	12.5
LCL	8.8	8.8	8.8	8.9	8.9	8.9	8.9	9.0	9.0	9.0	9.0	9.1

Here, UCL is upper confidence limit and LCL is lower confidence limit

Mt from the previous session (March 2019 to February 2020) of 10.22 Mt. This negative growth is significant considering that during the pre-COVID period, freight volume increased with increasing population and economic activities, reflecting a consistent upward trend. However, during the wave 2 phase, freight volume recovered to a monthly average of 10.82 Mt because the government relaxed lockdown and panic measures, suggesting that the relaxation of restrictions played a crucial role in normalizing port activities. This recovery indicates a marked difference in the freight volume trends between wave 1 and wave 2 of COVID-19, suggesting that the relaxation of restrictions played a crucial role in normalizing port activities. The monthly data for both wave 1 and wave 2 show considerable variability. For instance, in wave 1, the freight volume dropped to as low as 7.9 Mt in June 2020, while in wave 2, it peaked at 12.9 Mt in March 2021, indicating a robust recovery as restrictions were eased. This variability indicates the sensitivity of freight volume to external factors such as government measures and market conditions. The monthly freight volume for the wave 1 and 2 phases are provided in Table 2.

4.2. Scenario 2: Freight volume without the impact of COVID

Here, the ARIMA model is applied to estimate the freight volumes for the wave 1 and 2 phases. The correlogram diagrams of the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) in Fig. 5 highlight that the data is non-stationary; thus, the data is suitable for ARIMA modeling.

The ‘Expert Modeler’ function in SPSS estimates the ARIMA model’s p, d, and q values of 0, 1, and 1, respectively. The Ljung box test results are significant (Ljung & Box, 1978). Also, residual ACF and residual PACF values are not significantly different from zero, showing non-significant white noise. Therefore, the ARIMA model passes the fit test. The ARIMA model forecasted freight volumes close to the actual volumes for both waves, particularly for wave 2, where the actual freight volumes were slightly higher than the forecasted ones. This indicates the model’s robustness in capturing the underlying patterns and trends in the data. The ARIMA model’s confidence intervals (UCL and LCL) highlight the expected range of variability, which is helpful for planning and decision-making. The accuracy of forecasts also validates the reliability of ARIMA modeling for future projections.

The monthly forecasted values and their confidence intervals for wave 1 and 2 under scenario 2 are presented in Tables 3 and 4.

A comparison of freight volume between scenario 1 and scenario 2 for wave 1 and wave 2 in Table 5 shows that wave 1 decreased the Deenadyal port’s total freight volume from 123.4 Mt to 115.8 Mt, i.e., a monthly average loss of 0.6 Mt; whereas, during wave 2, the freight volume increased from the forecasted value of 127.6 Mt to 129.6 Mt, i.e., a monthly gain of 0.2 Mt. Interestingly, the results in Table 5 shows that the freight volume in the Deendayal port has improved during wave 2 of COVID compared to an

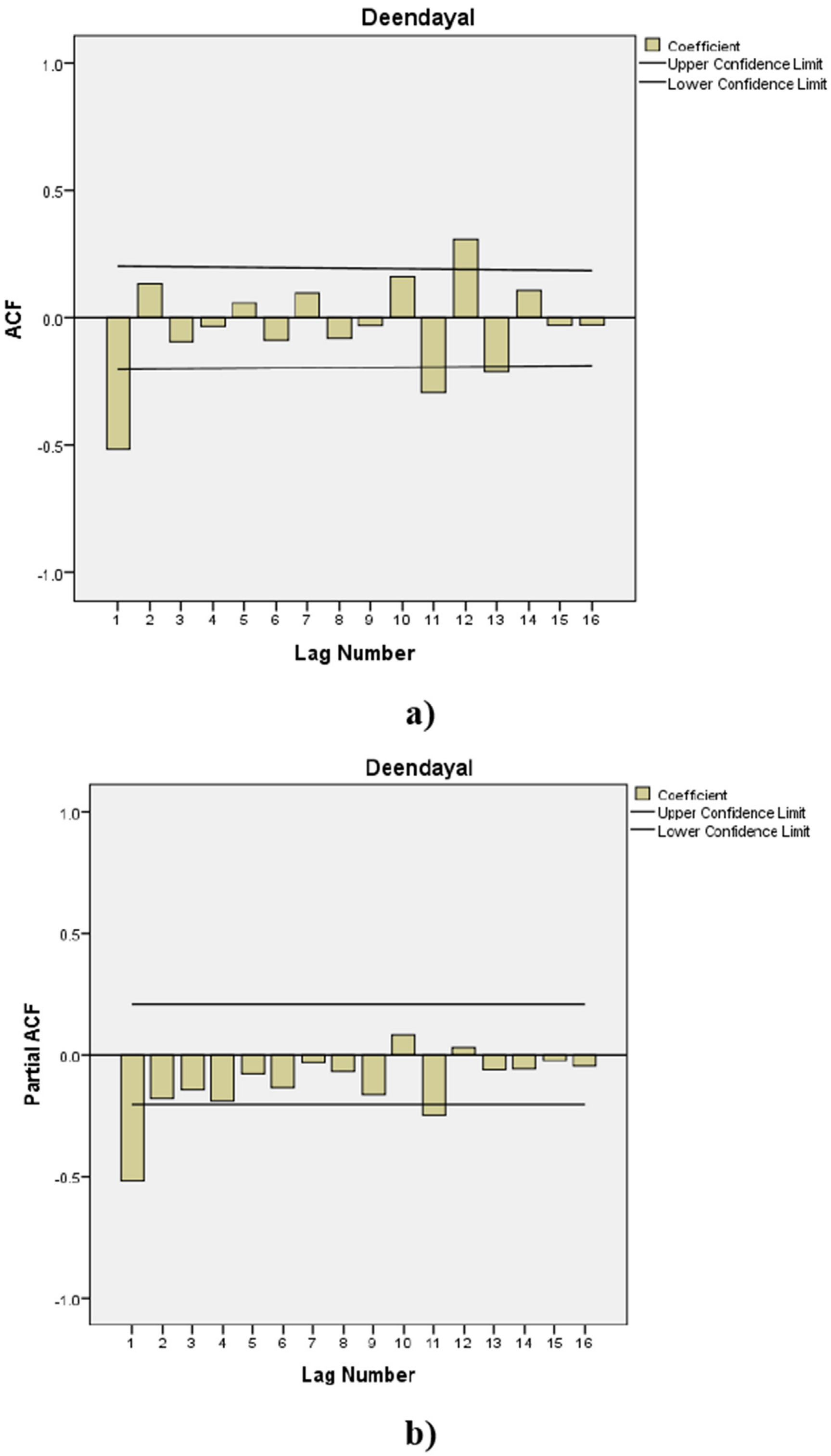

Fig. 5. Correlogram diagrams of auto-correlation and partial auto-correlation for the Deendayal port.

Table 5
Deendayal port´s freight volume (in Mt) during COVID waves and the difference between scenario 1 and scenario 2. (Color should be used for this Table in print).

Wave 1	Sceanrio 1: BAU	Scenario 2: without COVID	Gap	Wave 2	Sceanrio 1: BAU	Scenario 2: without COVID	Gap
Mar 2020	11.1	10.1	-1	Mar 2021	12.9	10.5	-2.4
Apr 2020	8.7	10.2	1.5	Apr 2021	10.5	10.5	0
May 2020	8.5	10.2	1.7	May 2021	12.3	10.5	-1.8
Jun 2020	7.9	10.2	2.3	Jun 2021	10.3	10.6	0.3
Jul 2020	9.1	10.2	0.9	Jul 2021	9.2	10.6	1.4
Aug 2020	9.6	10.3	0.7	Aug 2021	10.3	10.6	0.3
Sep 2020	9.7	10.3	0.6	Sep 2021	10.3	10.6	0.3
Oct 2020	9.6	10.3	0.7	Oct 2021	11	10.7	-0.3
Nov 2020	10.9	10.4	-0.5	Nov 2021	11.2	10.7	-0.5
Dec 2020	10.5	10.4	-0.1	Dec 2021	11.3	10.7	-0.6
Jan 2021	10.7	10.4	-0.3	Jan 2022	11.3	10.8	-0.5
Feb 2021	9.5	10.4	0.9	Feb 2022	9	10.8	1.8

Table 6
Coefficient of the regression models and their fit measures.

Model	Variable	Coefficient (Unstandardized β)
Revenue Model	Constant	-1183.24
	Volume (Mt)	28.28
	Manpower	-0.04
	Turn-around Time (Days)	-45.05
	Pre-berthing Time (Days)	5.57
Fit Measure	Adjusted R^2	0.92
Expenditure Model	Constant	795.89
	Volume (Mt)	6.62
	Manpower	-0.17
Fit Measure	Adjusted R^2	0.41

expected decrease in freight volume during wave 1. This improvement highlights the port's resilience and ability to adapt to changing circumstances effectively.

4.3. Impact of COVID on freight revenue and expenditure

Two linear regression models were developed to understand the relationship between key operational variables and the financial performance metrics of revenue and expenditure. The models were based on pre-COVID historical data from 2010 to 2019. The Revenue model included all available predictors: Volume, Manpower, Turn-around Time, and Pre-berthing Time. In contrast, the Expenditure model was refined by excluding Turn-around Time and Pre-berthing Time, focusing only on Volume and Manpower, following a correlation analysis. Ordinary Least Squares (OLS) regression was used to estimate the models' parameters. The fit measures indicate that both models are within an acceptable range (Das et al., 2023; Ortúzar & Willumsen, 2011), making them suitable for analyzing the impact of COVID waves on revenue and expenditure. The details of the models are provided in Table 6.

Using the estimates of freight volume losses in Table 4 due to the COVID waves, the revenue loss was estimated to be 215 crore INR during the first wave of COVID, while in the second wave, revenue increased by 57 crore INR. Similarly, the estimated expenditure of Deendayal Port decreased by 50 crore INR during the first wave of COVID and increased by 13 crore INR in the second wave. The profit is calculated as:

$$profit(in\ Crore\ INR) = revenue(in\ Crore\ INR) - expenditure(in\ Crore\ INR) \tag{4}$$

Applying Eq. (4), Deendayal Port incurred a net loss of 165 crore INR during the first wave and generated a profit of 44 crore INR during the second wave. These results indicate that Deendayal Port significantly improved its overall operations during the second wave compared to the first. The transition from a loss in wave 1 to a profit in wave 2 highlights the port's enhanced operational efficiency and adaptive strategies during the pandemic. This shift also suggests that the port effectively capitalized on the recovery phase, turning an adverse situation into a profitable outcome.

5. Discussion, implications, and policy direction

The COVID-19 pandemic disrupted global supply chains, placing significant pressure on ports worldwide. This study employed the ARIMA forecasting model to assess the pandemic's economic implications on the port's freight volume, revenue, and expenditure and provides a view of how such disruptions impacted port operations and the pathways to recovery. While the findings are specific to this port, they offer insights with broader relevance to ports globally, particularly in understanding operational resilience and recovery dynamics under crisis conditions.

Deendayal Port's experience during the pandemic reveals critical patterns in freight volume trends. The sharp decline in freight volumes during the first wave of COVID-19, followed by a robust recovery in the second wave, underscores the port's ability to adapt to rapidly changing circumstances. This freight handling variability highlights port operations' sensitivity to external factors, such as government restrictions and economic activity levels. The post-pandemic increase in average monthly freight volume, from 8.57 Mt (pre-COVID) to 11.66 Mt, reflects a return to normalcy and an overall growth trajectory that resumed and even accelerated once the initial shock was absorbed. This recovery pattern can be observed in ports globally, where external conditions are essential in determining operational outcomes during crises (Narasimha et al., 2021; Xu et al., 2020). These findings align with the broader literature on organizational resilience, which emphasizes the importance of adaptability and flexibility in managing crises (Lee et al., 2013; Sharma et al., 2020).

This recovery can be attributed to the relaxation of lockdown measures and a gradual normalization of port activities. The ARIMA model effectively captured these trends, providing accurate forecasts that closely matched the actual volumes. This indicates the model's robustness and suitability for forecasting scenarios with abrupt changes and trends, as observed during the pandemic. The findings align with previous studies that demonstrated the effectiveness of ARIMA models in forecasting port traffic and managing uncertainties in maritime logistics (Gargari et al., 2019; Shin et al., 2008). The ability to predict demand and adjust operations accordingly is crucial in navigating the complexities of global trade, particularly when faced with sudden and unforeseen challenges (Musella, 2023; Narasimha et al., 2021).

The study emphasizes the importance of operational efficiency, particularly turn-around time and pre-berthing time, in driving revenue at Deendayal Port. These metrics are closely tied to the port's throughput and capacity utilization, which are critical for maximizing revenue. The observed relationship between these operational factors and revenue generation, coupled with their exclusion from the expenditure model, suggests that efficiency improvements can significantly enhance financial performance without a proportional cost increase. This insight is relevant for ports globally, where operational efficiency remains a key determinant of competitive advantage and financial sustainability (Moosavi et al., 2022).

In the expenditure model, Volume and Manpower emerge as the primary cost drivers, indicating that these factors are directly linked to the scale of operations. The study's findings suggest that managing these elements effectively is crucial for controlling costs, especially in environments where demand fluctuates. The focus on these cost drivers reflects the broader challenge of balancing operational needs with financial constraints, a common concern for ports worldwide. Understanding the relationship between operational scale and cost structure is essential for maintaining financial stability, particularly during economic volatility (Xu et al., 2020).

5.1. Implications

5.1.1. Literature implications

This study contributes to the growing body of literature on the economic impacts of the COVID-19 pandemic on port operations. It highlights the differential impacts on freight volume, revenue, and expenditure during different pandemic phases, offering insights into the resilience and adaptability of port operations under crisis conditions. This research fills a gap in the literature by focusing on a developing country's port, providing a localized perspective often overlooked in broader studies that focus on developed nations. Employing the ARIMA model highlights utilizing a robust methodological framework for forecasting in scenarios characterized by abrupt changes and trends. The findings highlight the model's effectiveness in handling non-stationary data and improving forecasting accuracy, as demonstrated in previous studies (Gargari et al., 2019; Laome et al., 2021).

5.1.2. Managerial implications

For port managers and operators, this study underscores the importance of operational efficiency in driving revenue and maintaining competitive advantage. Key metrics such as turn-around time and pre-berthing time are critical for maximizing throughput and capacity utilization, essential for enhancing financial performance without a proportional cost increase. The findings highlight the critical importance of flexibility and adaptability in operational strategies. Managers should focus on integrating digital technologies to improve these operational metrics and ensure continuity during disruptions. The contrasting outcomes between the two waves of COVID-19 suggest that proactive measures, such as flexible workforce management, streamlined logistics, and effective crisis management, are crucial for maintaining operational continuity. Managers should consider investing in forecasting tools like ARIMA to anticipate demand fluctuations and adjust operations accordingly. The demonstrated resilience of Deendayal Port during wave 2 indicates that ports can effectively leverage recovery phases to improve operational efficiency and financial outcomes (Shivhare et al., 2019). Additionally, fostering strong communication channels with stakeholders, including shipping companies and cargo owners, is crucial for timely decision-making and maintaining service levels during crises (Bandyopadhyay & Bhatnagar, 2023; Gu et al., 2023).

5.2. Policy directions

Based on the specific results of this study, some policy directions can be outlined to enhance the resilience and efficiency of port operations in future disruptions:

- The revenue losses during the first wave of the pandemic underscore the importance of diversifying revenue streams to mitigate the impacts of external shocks. Policies should promote the development of new revenue streams, such as value-added services and advanced cargo handling techniques, which can help ports maintain financial stability during crises. The increase in revenue during the second wave, despite ongoing challenges, indicates the potential for innovative solutions and new business models in the industry (Bandyopadhyay & Bhatnagar, 2023). Diversification can mitigate risks associated with dependency on specific cargo types and enhance overall operational flexibility (PIB, 2022).
- The COVID-19 crisis highlighted the need for robust supply chains. Developing a National Inventory of Logistics Assets (NILA) can bolster supply chain resilience by enabling real-time monitoring of logistic assets, increasing transparency, promoting stakeholder cooperation, and optimizing asset utilization (Linton & Vakil, 2020; Zavala-Alcívar et al., 2020). Such initiatives can help ports better manage disruptions and maintain operational continuity.
- The study's analysis of expenditure data, which showed a decrease during wave 1 and an increase during wave 2, suggests the need for policies that optimize resource utilization and reduce costs. Investments in advanced technological solutions for cargo handling, vessel operations, and logistical management should be prioritized to reduce dependency on manual processes. Technologies such as IoT, AI, and blockchain can enhance transparency, efficiency, and decision-making capabilities (Narasimha et al., 2021).
- The pandemic exposed vulnerabilities in global supply chains, emphasizing the need for improved coordination, information sharing, and collaboration among international ports and shipping companies. Establishing robust communication channels and contingency plans among global trade partners can mitigate the impact of similar disruptions in the future (Bandyopadhyay & Bhatnagar, 2023). Such policies can enhance overall resilience and ensure the continuity of global trade.
- The study underscores the effectiveness of using the ARIMA model to forecast freight volumes, highlighting the importance of digital tools in managing uncertainties. Policymakers should support investments in digital infrastructure that enable ports to leverage advanced forecasting models and real-time data analytics. This can enhance decision-making capabilities and improve the port's ability to adapt to sudden changes in demand (Gu et al., 2023).
- The results indicate that operational metrics such as turn-around and pre-berthing time significantly impact revenue generation. Policies should focus on optimizing these metrics through investments in infrastructure and technology. For example, automated cargo handling systems and streamlined customs processes can reduce delays and increase throughput, enhancing overall efficiency (Gu et al., 2023).
- The study shows that Deendayal Port was able to recover freight volumes during the second wave of COVID-19, suggesting the need for flexible response mechanisms. Policymakers should develop frameworks that allow ports to quickly adjust operations in response to changing conditions, such as fluctuating demand or government restrictions. This could include temporary regulatory adjustments and support for workforce management during crises (Bandyopadhyay & Bhatnagar, 2023).
- The financial analysis from the study reveals the impact of COVID-19 on revenue and expenditure, highlighting the need for financial resilience. Governments should provide financial support mechanisms, such as grants or low-interest loans, to help ports invest in resilience-building measures. This support can facilitate infrastructure upgrades and the adoption of new technologies, ensuring ports are better equipped to handle future disruptions (UNCTAD, 2022).
- The study suggests that collaboration between public and private sectors can enhance port resilience (Deendayal Port Trust, 2022, 2021). Policymakers should encourage public-private partnerships to share resources and expertise, particularly in infrastructure development and crisis management. These partnerships can lead to more coordinated and effective responses to disruptions (Bandyopadhyay & Bhatnagar, 2023).

6. Conclusions

This study involved a detailed analysis of freight volume, revenue, and expenditure data for Deendayal Port, covering April 2012 to October 2022. Data extraction was performed from IndiaStat, and subsequent processing was carried out, including filtering, sorting, and tabulating. Time series analysis was used to detect visual outliers and anomalies. The dataset was segmented into three major periods: pre-COVID (April 2012 to February 2020), COVID (March 2020 to February 2022), and post-COVID (March 2022 to October 2022), with the COVID period further divided into two waves for a detailed examination. ARIMA modeling approach was used to predict freight volumes without COVID-19 impacts, while linear regression models estimated changes in revenue and expenditure. The COVID-induced losses were calculated by comparing actual data with ARIMA estimates.

The results reveal that the pandemic significantly impacted the port's operations, with a negative growth of 6.2% in freight volume during wave 1 and subsequent recovery to a monthly average of 10.8 Mt during wave 2. The Deendayal port's total freight volume decreased from 123.4 Mt to 115.8 Mt during wave 1, resulting in a monthly average loss of 0.6 Mt. However, during wave 2, the freight volume increased from the forecasted value of 127.6 Mt to 129.6 Mt, resulting in a monthly gain of 0.2 Mt. Revenue losses during wave 1 were estimated to be 215 crore INR, while revenue increased by 57 crore INR during wave 2. The estimated expenditure of the Deendayal port decreased by 57 crore INR during wave 1 and increased by 50 crore INR in wave 2. Consequently, the port incurred a loss of 165 crore INR during wave 1 and a profit of 44 crore INR during wave 2. This demonstrates the significant improvement in the port's overall operations during wave 2 compared to wave 1. Also, this study highlights the critical importance of operational efficiency, particularly turn-around time and pre-berthing time, in driving revenue at Deendayal Port. These operational metrics are vital for optimizing throughput and capacity utilization, leading to enhanced financial performance without a corresponding cost increase. Additionally, the findings highlight the significance of volume and manpower as primary cost drivers, stressing the necessity of effectively managing these factors to maintain financial stability, especially in fluctuating demand environments. The study also provides policy directions to enhance the resilience of the port and shipping industry in the face of external shocks like pandemics. These recommendations include the development of a national inventory of logistics assets, diversification of revenue streams, optimization of resource utilization, and promotion of digitalization and automation in the industry. These insights provide valuable implications for Deendayal Port and offer broader relevance for ports globally, where achieving a balance between operational efficiency and cost management is essential for sustaining competitive advantage and financial viability.

Despite the comprehensive analysis, the study has notable limitations. It focuses solely on Deendayal Port, which may not represent the experiences of other ports in India. Additionally, the research does not explore the differential impacts of COVID-19 on various types of cargo, which could provide a more nuanced understanding of the pandemic's effects. Future research should address these gaps by including multiple ports and cargo categories and examining a broader range of factors influencing port performance during global disruptions. This would contribute to a more thorough understanding of the pandemic's impact on the shipping industry and support the development of more targeted and effective policies.

7. Future scope

This study provides valuable insights into the impact of the COVID-19 pandemic on India's port and shipping industry, specifically the Deendayal port. However, future research can explore some extensions of the present study and fill those knowledge gaps, which are as follows:

- First, the study focused on the Deendayal port, and the findings may not be generalizable to other minor ports in India. Therefore, future research could replicate this study on other minor ports in India to have a more comprehensive understanding of the impact of COVID-19 on the port and shipping industry in India.
- Second, the study analyzed the impact of COVID-19 on freight volume, revenue, and expenditure. Future research could explore the impact of COVID-19 on other aspects of the port and shipping industry, such as workforce safety, supply chain disruptions, and environmental sustainability.
- Third, the study did not consider the impact of COVID-19 on different types of cargo. Future research could explore how the pandemic has affected different types of cargo, such as dry bulk, liquid bulk, and containerized cargo, and their impact on the revenue and expenditure of the ports.
- Fourth, the study did not explore the impact of government policies and initiatives in mitigating the impact of COVID-19 on the port and shipping industry in India. For example, the study suggests policy directions for enhancing the industry's resilience and promoting digitalization and automation; it does not provide a detailed analysis of these policies' implementation challenges and feasibility. Future research could examine the implementation challenges and feasibility of the above policies, considering the institutional, regulatory, and cultural factors specific to India's port and shipping industry. Future research could analyze the effectiveness of different government policies and initiatives in the context of the pandemic and their impact on the resilience and sustainability of the industry.

Ethical approval

This article contains no studies with human participants or animals performed by authors.

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Data statement

All necessary data generated or used during this study appear in the main text.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Deepjyoti Das: Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Aditya Saxena:** Writing – original draft, Methodology, Conceptualization.

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