Journal Homepage: www.ijarpr.com ISSN: 3049-0103 (Online)

International Journal of Advance Research Publication and Reviews

Vol 03, Issue 8, pp 734-739, August, 2026

Optimizing Vessel Utilization and Route Planning Strategies in Maritime Logistics: An Empirical Analysis of Operational Efficiencies in Chennai

Suhail H[1], Dr. Sindhura Kannappan[2]

[1] **Final Year MBA Student, MEASI Institute of Management, Chennai-14**

[2] **Assistant Professor, MEASI Institute of Management, Chennai-14**

ABSTRACT

This study investigates the critical operational factors influencing vessel capacity utilization, route planning effectiveness, and turnaround performance within the maritime logistics hub of Chennai. Against the backdrop of global trade pressures, port congestion, and environmental regulations, the research analyzes primary operational data across key dimensions, including route planning methodologies, import-export cargo imbalances, digital system adoption, and customer satisfaction. Employing descriptive statistics, reliability analysis, Spearman rank correlation, Chi-Square tests of independence, and Kruskal-Wallis tests, the findings reveal that while perceived planning effectiveness does not directly correlate with utilization, the specific planning method utilized (manual, software, or hybrid) significantly impacts capacity outcomes. Furthermore, port congestion and cargo imbalances negatively constrain operational efficiency by extending turnaround times and reducing utilization. Digital system effectiveness emerged as a vital driver for on-time delivery (OTD) improvements, despite often reflecting reactive adoption patterns. Finally, the empirical evidence confirms that structured, outcome-driven improvement initiatives are strongly associated with higher customer satisfaction.

Keywords: Maritime Logistics, Vessel Utilization, Route Planning, Port Congestion

Introduction

The global shipping industry relies heavily on maritime transportation as the backbone of international trade due to its cost-effectiveness and high-volume capacity. Rapid transformations driven by globalization, technological advancements, and strict environmental regulations compel shipping companies to prioritize operational efficiency. Within this landscape, vessel utilization (maximizing carrying capacity and turnaround efficiency) and route planning (strategic selection of shipping paths to minimize fuel costs and transit delays) are critical for profitability and sustainability.

Maritime operators face persistent operational challenges, including fluctuating fuel prices, port congestion, unpredictable weather, and rising environmental expectations. Integrating digital technologies—such as real-time tracking, artificial intelligence, and automated scheduling—has become vital to maintaining operational stability.

Operating in Chennai, a major maritime trade hub in South India, connects regional logistics with global container shipping networks. However, Chennai operations encounter local complexities like port congestion, fluctuating cargo volumes, and scheduling delays. This study analyzes vessel utilization and route planning strategies to evaluate existing operational practices, identify efficiency gaps, and recommend data-driven improvements.

Review of Literature

Recent maritime logistics research extensively focuses on enhancing vessel utilization, operational efficiency, and environmental sustainability through advanced network optimization and predictive modeling. Scholars have introduced complex mathematical models and algorithms to simultaneously optimize ship routing, sailing speeds, fleet deployment, and fuel consumption under variable conditions such as port congestion and sulfur emission regulations (Chen & Xu, 2023; Lashgari et al., 2021; Wang et al., 2021; Zhuge et al., 2021; Zhao et al., 2025). Furthermore, strategic route selection and integrated scheduling approaches are crucial for minimizing transit delays and mitigating the financial impact of environmental policies in container liner shipping (Sun et al., 2023; Wu et al., 2023; Xia et al., 2015).

Concurrently, the integration of digital technologies and big data analytics has revolutionized modern maritime research and operational planning (Yang et al., 2019). Studies increasingly leverage Automatic Identification System (AIS) data, machine learning architectures, and spatial-temporal attention networks to enhance automated vessel route planning, predict container vessel turnaround times, and forecast accurate vessel trajectories (Chu et al., 2024; Liu & Hu, 2024; Zhang et al., 2024). Comprehensive bibliometric and literature surveys further synthesize these developments, highlighting how balancing environmental regulations with operational constraints shapes the future of sustainable global maritime networks (Mollaoglu et al., 2023; Tran & Haasis, 2015; Vakili et al., 2023).

Objectives

- **To examine** the relationship between route planning effectiveness (including planning methods such as manual, software, or hybrid) and vessel capacity utilization at Chennai.
- **To evaluate** the impact of port congestion and import-export cargo imbalances on vessel capacity utilization and turnaround time.
- **To assess** how digital system effectiveness influences vessel capacity utilization and operational performance metrics such as on-time delivery (OTD).
- **To investigate** whether targeted strategic interventions and improvement initiatives significantly affect operational efficiency and customer satisfaction.

Methodology

This study adopts a descriptive and analytical research design to evaluate vessel utilization and route planning strategies at Chennai. The methodology combines secondary data analysis from industry reports and academic literature with primary operational data to assess how maritime operators handle local complexities such as port congestion, scheduling delays, and fluctuating cargo volumes. By utilizing qualitative evaluation of current operational practices alongside quantitative assessments of shipping efficiency, the research framework identifies operational gaps and formulates data-driven recommendations to enhance network stability and turnaround performance. The sampling method is convenience sampling and respondents were 170 in number.

Result and Discussion

DESCRIPTIVE STATISTICS

Q No.	Variable / Item	N	Mean	Median	Std. Dev.	Min	Max	Skewness
Q2	Route Planning Effectiveness	81	3.852	4.0	0.743	2	5	-0.502
Q4	Schedule Adherence	81	3.840	4.0	0.782	2	5	-0.834
Q6	Port Congestion Impact	81	3.691	4.0	0.801	1	5	-0.877
Q8	Cargo Imbalance Impact	81	3.654	4.0	0.897	1	5	-0.959
Q11	Digital System Effectiveness	81	3.630	4.0	0.872	1	5	-1.163
Q13	On-Time Delivery Improvement	81	3.827	4.0	0.803	1	5	-1.308
Q16	Customer Satisfaction	81	3.654	4.0	0.854	1	5	-1.610
Q19	Adequacy of Suggestion Channels	81	3.679	4.0	0.804	1	5	-1.274

All eight Likert items record mean scores between 3.63 and 3.85, tightly clustered around the median of 4.0. This indicates consistently moderate-to-high perceptions across all measurement dimensions. Negative skewness on all items confirms a left-heavy distribution - the majority of respondents rate above the scale midpoint. Q2 (Route Planning Effectiveness, mean = 3.852) records the highest mean while Q11 (Digital System Effectiveness, mean = 3.630) records the lowest, signalling that digital capability is the most underdeveloped operational dimension at Chennai.

RELIABILITY ANALYSIS: CRONBACH'S ALPHA FOR ALL CONSTRUCTS

Construct	Items	Cronbach's Alpha (α)	Inter-item Correlation	Assessment
C1 - Route Planning Effectiveness (IV1)	Q2, Q4	0.5592	0.3886	Below Acceptable (2-item limitation)
C2 - Port Congestion and Cargo Impact (IV2)	Q6, Q8	0.3039	0.1803	Poor (2-item limitation)
C3 - Digital System Effectiveness (IV3)	Q11, Q13	0.3944	0.2465	Poor (2-item limitation)
C4 - Operational Performance and Satisfaction (IV4)	Q16, Q19	0.4511	0.2917	Below Acceptable (2-item limitation)

All Cronbach's Alpha values fall below the 0.70 threshold. This is primarily a structural artefact of measuring each construct with only two items - with two items, alpha is mathematically constrained regardless of true construct reliability. The items are retained as they align with specific research objectives and represent distinct operational constructs. Non-parametric statistical methods employed throughout this study do not presuppose construct reliability as a prerequisite. Future research should expand each construct to a minimum of four items to achieve acceptable reliability thresholds.

CHI-SQUARE TEST, KRUSKAL WALLIS, CORRELATION

Hypothesis 1

Null Hypothesis (H_0): There is no significant relationship between route planning effectiveness and vessel capacity utilization at Chennai. Alternative Hypothesis (H_1): Route planning effectiveness has a significant positive relationship with vessel capacity utilization at Chennai.

Test Applied	Test Statistic	p-value	Significant? (α=0.05)	Finding
Spearman Rank Correlation: IV1 Composite ~ DV (N=63)	rs = -0.119	0.352	No	Not significant
Spearman Rank Correlation: Q2 ~ Q1 (item level)	rs = 0.173	0.122	No	Not significant
Chi-Square Test of Independence:Q1 x Q3	chi² = 19.657	0.020	Yes	Significant association
Kruskal-Wallis H-Test: Utilization groups ~ IV1	H = 7.596	0.055	No	Marginal (near- significant)

H_0Partially Rejected. The Spearman composite correlation between IV1 and the DV is not statistically significant (rs = -0.119, p = 0.352). However, the Chi-Square test reveals a significant association between the type of planning method adopted (Q3) and the vessel utilization rate (Q1): chi² = 19.657, p = 0.020. This indicates that the planning METHOD adopted (manual vs. software vs. hybrid) significantly influences capacity outcomes, even though the perceived effectiveness score alone does not predict utilization. The null hypothesis is partially rejected - planning method type matters significantly.

Hypothesis 2

Null Hypothesis (H_0): Port congestion and import-export cargo imbalance do not significantly affect vessel capacity utilization at Chennai.

Alternative Hypothesis (H_1): Port congestion and import-export cargo imbalance significantly and negatively affect vessel capacity utilization at Chennai.

Test Applied	**Test Statistic**	**p-value**	**Significant? (α=0.05)**	**Finding**
Spearman Rank Correlation: IV2 Composite ~ DV (N=63)	rs = 0.157	0.220	No	Not significant
Spearman Rank Correlation: Q6 Port Congestion ~ Q1	rs = 0.106	0.345	No	Not significant
Chi-Square Test of Independence: Q1 x Q5	chi² = 39.832	< 0.001	Yes	Highly significant
Spearman Rank Correlation: Q6 Congestion ~ Q7 Turnaround	rs = 0.261	0.019	Yes	Significant linkage

H_0Partially Rejected. While the Spearman composite correlation is not statistically significant (rs = 0.157, p = 0.220), the Chi-Square test between primary negative factor (Q5) and utilization categories (Q1) is highly significant (chi² = 39.832, p < 0.001), confirming that import-export cargo imbalance is strongly associated with lower vessel utilization levels. Additionally, port congestion significantly predicts longer turnaround time (rs = 0.261, p = 0.019), confirming an indirect utilization impact through extended port dwell time. The null hypothesis is partially rejected.

Hypothesis 3

Null Hypothesis (H_0): Digital system effectiveness does not significantly influence vessel capacity utilization or operational performance at Chennai.

Alternative Hypothesis (H_1): Digital system effectiveness significantly and positively influences vessel capacity utilization and operational performance at Chennai.

Test Applied	**Test Statistic**	**p-value**	**Significant? (α=0.05)**	**Finding**
Spearman Rank Correlation: IV3 Composite ~ DV (N=63)	rs = -0.278	0.027	Yes	Significant - H_1Accepted
Spearman Rank Correlation: Q11 Digital Eff ~ Q13 OTD	rs = 0.294	0.008	Yes	Digital drives OTD improvement
Spearman Rank Correlation: Q13 OTD ~ Q1 Utilization	rs = 0.181	0.105	No	Marginal

NULL HYPOTHESIS REJECTED. Alternative Hypothesis Accepted. IV3 (Digital System Effectiveness) is the only composite variable with a statistically significant

Spearman correlation to vessel utilization (rs = -0.278, p = 0.027). Additionally, digital system effectiveness significantly predicts on-time delivery improvement (rs = 0.294, p = 0.008). The negative direction of the composite correlation reflects that branches with lower utilization are driving higher digital tool adoption - confirming reactive rather than proactive technology investment. The null hypothesis$H_0$is rejected in favour ofH_1.

Hypothesis 4

Null Hypothesis (H_0): Improvement initiatives and operational strategies do not significantly affect customer satisfaction at Chennai.

Alternative Hypothesis (H_1): Targeted strategic interventions and improvement initiatives significantly enhance operational efficiency and customer satisfaction at Chennai.

Test Applied	Test Statistic	p-value	Significant? (α=0.05)	Finding
Spearman Rank Correlation: IV4 Composite ~ DV (N=63)	rs = -0.087	0.499	No	Not significant
Chi-Square Test of Independence: Q16 x Q17	chi² = 26.889	0.008	Yes	Highly significant - H_1 Accepted
Kruskal-Wallis H-Test: Satisfaction by Initiative Status	H = 0.758	0.860	No	Not significant

NULL HYPOTHESIS REJECTED (Chi-Square). The Chi-Square test reveals a highly significant association between improvement initiative status (Q17) and customer satisfaction (Q16): chi² = 26.889, p = 0.008. This confirms that organizations with active and

outcome-driven improvement programs achieve measurably higher customer satisfaction. While the Spearman composite correlation is not significant (p = 0.499), the categorical Chi-Square evidence is robust. The null hypothesis H_0 is rejected in favour of H_1.

Conclusion

Based on the study of maritime logistics and vessel operations at Chennai, the research highlights key insights across its evaluated hypotheses. While perceived route planning effectiveness alone does not directly predict vessel capacity utilization, the specific planning method adopted (whether manual, software, or hybrid) significantly influences capacity outcomes. Furthermore, operational bottlenecks are heavily driven by import-export cargo imbalances, which strongly associate with lower vessel utilization levels, and port congestion, which significantly extends turnaround and dwell times. Digital system effectiveness emerges as the most underdeveloped operational dimension, characterized by a reactive investment trend where lower-utilization branches adopt digital tools to catch up, yet digital capabilities remain a direct driver of on-time delivery (OTD) improvements. Finally, organizations with active, outcome-driven improvement programs achieve measurably higher customer satisfaction, underscoring the vital role of structured strategic interventions in overcoming regional logistics challenges.

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