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Efficiency and Sustainability of Bangkok Port Barge Transport: A Comparative Analysis with Feeder Vessels Under Thailand's Logistics Strategy

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ABSTRACT

This study assessed the effectiveness and sustainability of using barge versus feeder vessels to transport containerized cargo to Bangkok Port, Thailand. A survey of 387 stakeholders in marine logistics was conducted from October to December 2024. Multiple regression analysis (MRA) showed that cost-effectiveness, environmental impact, and operational flexibility primarily influenced transport mode choice, explaining 56.2% of the variance. Cost-effectiveness emerged as the key factor, while environmental impact was the strongest predictor of perceived sustainability. While operators favored feeders due to cost and time efficiency, barges scored higher due to environmental friendliness and operational flexibility. Notably, 68% of respondents preferred barges for short routes under 100 km due to their role in reducing road congestion and pollution. Furthermore, 73% expected greater barge use over the next five years, driven by technology and environmental policies. Improved waterway infrastructure would lead 82% to use barges more frequently, and 76% believed better intermodal integration would enhance logistics efficiency. This study is limited to the context of Thailand's domestic maritime logistics and stakeholder perceptions, which may not be fully generalizable to other ASEAN or global port systems. Future research should explore multi-country comparative studies and assess longitudinal trends as green port policies evolve across Southeast Asia.

1. INTRODUCTION

Container shipping supports over 80% of global trade. As supply chains grow and cities densify, efficient and sustainable port logistics have become increasingly urgent—especially where congestion and emissions are acute [1, 2].

One such context is Bangkok Port (BKP), Thailand's oldest and most centrally located seaport. Situated 25 kilometers inland from the Gulf of Thailand along the Chao Phraya River, BKP operates within a dense metropolitan region of over 17 million people. This setting creates logistical bottlenecks, urban freight conflicts, and environmental stress, necessitating reevaluating its container transport systems.

Historically, container transport to and from BKP has relied on feeder vessels, in line with Thailand's maritime infrastructure and regional shipping practices [3, 4]. However, the growing demand for alternative transport modes—particularly container-on-barge (COB) systems—has drawn increasing attention from shippers, port authorities, and environmental agencies [5, 6]. Barges offer potential advantages in operational flexibility [7], cost-effectiveness, and significantly lower emissions compared to road and short-sea transport [8, 9].

While the use of barges for container transport has been studied extensively in Europe—where dense inland waterways and harmonized policy environments such as the EU Green Deal have enabled scalable COB networks [5, 10, 11], limited research has examined the feasibility of such models in Southeast Asian urban ports. Southeast Asian ports like BKP face unique logistical and governance challenges, including fragmented jurisdictional control, seasonal river navigability, underdeveloped intermodal linkages [12], and poor policy coordination across municipal and national levels [5, 13].

This study addresses this critical gap by comparing barge versus feeder vessel transport at BKP. Unlike the European-centered literature emphasizing institutional efficiency and modal integration, this research investigates the operational and sustainability trade-offs of modal choice within Bangkok's complex urban ecosystem.

This research supports key priorities outlined in Thailand's 20-Year National Strategy (2018-2037), including logistics modernization [14], freight system decentralization, and sustainable infrastructure investment. These goals are further advanced by the Eastern Economic Corridor (EEC) initiative [15], where BKP serves as a strategic intermodal gateway connecting Thailand's capital with coastal and inland logistics corridors.

Accordingly, this study investigates the potential of barge transport as a sustainable alternative to feeder vessels into and out of BKP, emphasizing logistical efficiency and stakeholder perception. The research is guided by the following research

questions (RQs) and hypothesis (H):

RQ1: What factors influence the efficiency and sustainability of barge transport compared to feeder vessels for container shipping to BKP?

RQ2: How do key Thai maritime logistics stakeholders perceive barge transport's feasibility and potential as an alternative or complement to feeder vessels?

RQ3: What are the broader implications of increased barge usage for the overall performance and sustainability of BKP's urban logistics network?

H1: While feeder vessels are currently the dominant mode due to legacy infrastructure and practices, barge transport has strong potential to enhance sustainability and efficiency—particularly along short-distance, congestion-prone urban routes within [5, 6].

H2: Stakeholders will assess modal alternatives based on a combination of cost, environmental performance, and operational flexibility, with a growing preference for low-emission and traffic-resilient options [5, 7, 9].

This research contributes empirically and conceptually to Southeast Asia's expanding sustainable urban port logistics literature. By applying modal choice theory and sustainable logistics frameworks to a high-density, real-world urban context, the study offers new insights that can inform:

- Strategic infrastructure investment
- Modal integration and transport policy alignment
- Stakeholder engagement in freight system planning

Ultimately, the findings aim to support academics, port planners, and policymakers in designing data-driven, context-sensitive strategies that enhance urban mobility, reduce emissions, and strengthen Thailand's position in regional trade competitiveness [16]—particularly concerning other ASEAN logistics hubs such as Cambodia [12], Vietnam [17], Indonesia [18], and Singapore [19].

The following sections present a thematically structured literature review, followed by the study's methodology, results, discussion, and conclusions that outline the broader implications of our findings.

2. LITERATURE REVIEW

This literature review synthesizes contemporary academic work on the comparative analysis of container transport modes—specifically feeder vessels and barge operations—in urban port contexts. The focus is on modal choice determinants, environmental sustainability, regional operational distinctions, stakeholder and policy dynamics, and technological innovation. The aim is to position BKP within the emerging global dialogue on sustainable, intermodal freight systems while identifying a critical research gap in Southeast Asian urban logistics.

2.1 Modal choice determinants

Intermodal Freight Transport (IFT) is a cornerstone of efficient and sustainable logistics systems, combining multiple modes to optimize performance. Numerous studies have explored the complex factors influencing mode choice. For example, Craig et al. [7] and Arencibia et al. [20] identified both quantitative factors (e.g., cost, transit time) and qualitative factors (e.g., reliability, flexibility), often referred to as “hard” and “soft” service attributes, respectively.

IFT has gained traction as a mechanism to reduce emissions [21], lower costs [22], and enhance network resilience. Synchromodal transport—where mode choice adapts dynamically to system conditions—is also gaining prominence [23, 24] due to its ability to optimize delivery times, costs, and environmental impact. It builds upon intermodal transport but allows adjustments based on real-time conditions and information throughout the journey. These frameworks are highly relevant to our study, which adopts modal choice theory to investigate barge vs. feeder vessel usage into BKP, emphasizing performance under urban congestion and sustainability constraints.

Arencibia et al. [20] also noted the persistent gap in the literature regarding inland waterway applications in Asian urban contexts, where congestion mitigation and modal efficiency are critical. This gap is directly addressed in our comparative research.

2.2 Environmental sustainability

Sustainability increasingly plays a central role in maritime logistics, driven by climate imperatives and the tightening of emissions regulations. Inland Waterway Transport (IWT) is positioned as a low-emission alternative to road-based freight, with studies such as Calderón-Rivera et al. [2] and Burgstahler [8] having confirmed the environmental advantages of barge operations in urban settings.

Solano et al. [9] have presented empirical evidence from Colombia, where optimized barge operations resulted in a reduction in fuel consumption by over 20%. Similarly, Bu and Nachtmann [5] provided a global review of "Container on Barge" (COB) logistics, emphasizing the lower emissions and reduced congestion associated with barge transport. These benefits align with Thailand’s environmental goals under its 20-Year National Strategy [14], offering a promising alternative to road- and feeder-based container delivery to BKP.

In comparing barge and feeder modes, it becomes clear that sustainability gains are often tempered by infrastructure and navigability constraints, particularly in cities like Bangkok, where seasonal river depths and policy fragmentation play limiting roles.

2.3 Regional and operational context

While European studies emphasized integration, efficiency, and coordinated governance [6, 10, 11], urban ports in Southeast Asia operate under markedly different conditions. For example, Bu and Nachtmann [5] and Chang and Thai [13] report that ports such as BKP faced significant urban congestion, fragmented oversight, and limited intermodal coordination.

In Europe, policy instruments like the EU Green Deal actively support the expansion of barge transport [25]. In contrast, Southeast Asia lacks cohesive regional logistics frameworks, making barge adoption more complex. Efforts to promote barge usage in the region must address hyper-local challenges, including Bangkok’s chronic traffic congestion, limited last-mile connectivity, and inconsistent barge infrastructure.

Koning [10] has proposed that restructured barge service networks—such as trunk lines combined with terminal-level distribution—only partially work as these models require adaptation to Southeast Asia’s informal economies and decentralized port governance structures. This contextual divergence underscores both the novelty and relevance of the

present study, which focuses specifically on the urban logistics environment of Southeast Asia, using BKP as a strategic case study.

2.4 Stakeholder and policy impacts

Stakeholder acceptance and regulatory frameworks play a pivotal role in shaping the feasibility of modal transitions. Esser et al. [26] examined how policy incentives and environmental regulations guided freight systems toward more sustainable transport modes. Similarly, Giusti et al. [23] highlighted synchromodal flexibility and client-centric policies as critical levers that enabled modal shift.

In Thailand, logistics policy was embedded in the EEC initiative [15], which promoted BKP as a multimodal hub within a decentralizing national freight system. However, policy fragmentation among municipal, provincial, and national bodies remains a bottleneck—an issue that was also observed in studies of other ASEAN ports, such as Ho Chi Minh City and Chattogram [5].

Bjørgen et al. [27] advocated collaborative governance models, in which stakeholder engagement (e.g., port authorities, logistics firms, urban planners) enabled integration. For Bangkok, stakeholder views—particularly regarding cost, environmental trade-offs, and service reliability—need to be accounted for when evaluating mode viability.

2.5 Technological innovations

Maritime logistics is also being rapidly reshaped by technological innovation, with numerous studies illustrating how ports and feeder services are adopting innovative systems for efficiency gains [4, 28-30]:

1. Automation: Rotterdam's Maasvlakte II, using AGVs (autonomous ground vehicles) and AI (artificial intelligence) - based berth planning, illustrates what is possible under ideal governance and capital investment conditions [31];
2. IoT (Internet of Things) and Digital Twins: Real-time visibility improves barge scheduling, cargo tracking, and predictive maintenance [32];
3. Blockchain: Enhances trust and transparency across intermodal supply chains [33];
4. AI & ML (machine language): Optimize feeder routing, emissions control, berth allocation, and fuel usage [29].

However, the Bangkok context faces barriers to tech integration: high cost, regulatory lag, and labor force readiness. Thus, the tech must be introduced incrementally, suited to BKP's operational maturity. However, predictive analytics—especially in modeling fuel optimization [9]—can immediately support barge viability assessments.

2.6 Theoretical framework and research gap

This literature review confirms substantial research on intermodal logistics, barge transport, and maritime sustainability. However, a key research gap remains in urban Southeast Asian contexts, where port congestion, fragmented governance, and environmental constraints intersect uniquely.

To address this, the present study draws upon:

- Modal Choice Theory [20];
- Sustainable Logistics Frameworks [2, 34, 35];
- Urban Port Logistics Theory [36];
- Technological Systems Innovation [37];
- Policy and Governance Models [26, 27].

By combining these perspectives and applying them to BKP's case, the research provides a regionally grounded and policy-relevant contribution to the discourse on intermodal logistics and sustainable urban ports.

3. METHODS

The research applies a quantitative research design to investigate the efficiency and the sustainability of employing barges as transport modes for container transport to Bangkok Port compared with feeder vessels [17, 38, 39]. The methodology is structured to answer the research questions and verify the proposed hypotheses, thus offering a comprehensive and systematic data collection and analysis investigation.

3.1 Research design

A cross-sectional survey design was adopted, allowing data collection from a large sample at a single point in time. This design is well-suited for analyzing the factors influencing transport mode choices and stakeholder perceptions regarding efficiency and sustainability.

3.2 Participation selection and characteristics

Stakeholders who comprised the target population of 400 respondents included Thai maritime logistics operators. These included shipping lines, freight forwarders, port operators, logistics providers, and government agencies. The sample was determined through power analysis, targeting a medium effect size (f^2=0.15), alpha of 0.05, and power of 0.80, accounting for up to 10 predictors in the regression model.

A stratified random sampling strategy was utilized to ensure fair representation of major stakeholder categories [40]. The five stakeholder groups and their proportional allocations—Shipping lines and agents (25%), Freight forwarders/logistics providers (25%), Port operators (20%), Government agencies (15%), and other stakeholders (15%)—were informed by estimates from multiple resources [41-43]. This is consistent with reporting from Vietnam in which Long [44] wrote that there are five main transportation decision making stakeholders. These include the shipper, the receiver, carriers and agents, the government and the consumer.

Additionally, the Thai Ministry of Commerce's Department of International Trade Promotion has identified 11 trade associations involved in logistics activities [45] representing 34,582 companies as of September 2023. These sources outline the approximate workforce distribution in the logistics sector and guide the sample frame design to ensure representative participation across all key actor categories in Thailand's maritime logistics ecosystem. Participants for this study required a minimum of three years of relevant experience.

The questionnaire was developed based on validated instruments from prior transport and logistics studies [5, 20], then adapted to the Bangkok Port context through expert review and pilot testing.

3.3 Questionnaire development

The initial version of the questionnaire underwent a pilot

testing process involving 20 industry experts who did not participate in the main survey sample. The pilot sample included representation from all five stakeholder groups, and participants had an average of 12.4 years of industry experience.

Several key findings emerged from the pilot study, further refining the questionnaire. These included:

Question phrasing: Three questions were rephrased to improve clarity for respondents with diverse educational backgrounds.

Cultural adaptation: Two questions related to environmental preferences and priorities were amended to reflect the Thai business environment and priorities better.

Response scale: The anchors for the Likert scale were changed following feedback that the original scale endpoints were more extreme than is typically viewed as socially acceptable by Thai respondents.

Content validity: Pilot participants verified that all key factors influencing modal choice were adequately addressed.

Survey length: The questionnaire was shortened from 45 to 38 questions, improving completion times without undermining the comprehensiveness of the survey instrument.

Following the pilot study, agreement among experts concerning the relevance and appropriateness of all items was assessed using the Content Validity Index (CVI), with the revised questionnaire achieving a CVI score of 0.89. The questionnaire was developed in English before being translated into Thai using a back-translation approach that allowed the questionnaire to be tested and refined while maintaining linguistic and cultural accuracy.

Professional translators with specialization in technical and business terminology conducted the initial translation from English into Thai. A back translation into English was then undertaken independently by different translators, with any ambiguities, inconsistencies, or errors addressed accordingly.

3.4 Data collection methods

Data were collected using a structured questionnaire composed of five sections: demographics, determinants of mode choice, efficiency and sustainability perceptions, scenario-based preferences, and open-ended questions. The instrument was developed from validated sources in transport studies and adapted to the Thai context.

The online questionnaire was sent out via emails and professional networks. Researchers interviewed respondents in key logistics locations and industry events in Thailand for the offline survey. Together, these data sources allowed for various responses and holistic data collection. Finally, all participants in the study, including the pilot-study group and survey sample group, gave their informed consent before participating.

Data was collected from October to December 2024 using online distribution via professional networks and offline interviews at logistics hubs and events. Informed consent was obtained from all participants.

3.5 Data analysis methods

The collected data were analyzed using both descriptive and inferential statistical analysis. The study used multiple regression analysis (MRA) to assess the importance of factors influencing the choice between barge and feeder vessel transport and their perceived efficiency and sustainability [46].

The data analysis process involved:

(1) Data cleaning and preprocessing were undertaken to handle missing values and outliers.

(2) Descriptive statistical analysis was used to summarize participant characteristics and overall response patterns.

(3) An EFA (exploratory factor analysis) was used to identify underlying constructs and reduce the dimensionality of the factors influencing transport mode choice [47].

(4) Reliability analysis used Cronbach's alpha to assess the internal consistency of the measurement scales [48].

(5) Comparative analysis used t-tests and ANOVA to identify significant differences in perceptions between barge and feeder vessel transport [49].

(6) A correlation analysis was also used to explore relationships between different factors and overall assessments of efficiency and sustainability. The statistical package for the social sciences (SPSS-Version 28) was used for data analysis.

4. RESULTS

The results of this study provide comprehensive insights into the factors influencing the choice between barge and feeder vessel transport for container shipping to Bangkok Port, as well as stakeholders' perceptions of their relative efficiency and sustainability. This section presents the findings from our statistical analyses, organized to address our research questions and hypotheses.

4.1 Descriptive statistics

Four hundred questionnaires were distributed for this study, of which 387 valid responses were collected, amounting to a 96.75% response rate. The respondents belonged to various stakeholders in the maritime and logistics sectors. Shipping lines and agents were the largest constituent group (25.1%, 97), closely followed by freight forwarders and logistics service providers (24.8%, 96). Port operators and terminal managers accounted for 19.9% (77) of the respondents, and government agencies and regulators for 15.0% (58). The balance of 15.2% (59) comprised other relevant stakeholders. The respondents had a mean industry experience of 9.3 years (SD=4.70). The generally high level of participant experience suggests that the sample is suitably reflective of the expertise in the industry, thereby increasing the certainty and depth of the data collected.

4.2 Factor analysis

In order to examine the latent factors that influence stakeholders' preference for barges and feeder vessels for intermodal transport, an EFA was adopted [47]. EFA was used because it tries to discover the latent constructs underlying the items, identifies factor structure, and imposes no such structure on the outcome [50].

Before the analysis, two tests were used to check the suitability of the dataset for factorial analysis. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy output values=0.873, exceeding the recommended minimum of 0.80, indicating that the samples were adequate for factor analysis [51]. In addition, Bartlett's test of sphericity was significant ($\chi^2(136)=3578.92$, $p<.001$), showing that the correlation matrix was not an identity matrix and that the variables were

sufficiently correlated to provide a reasonable basis for factor analysis [51].

We used principal component analysis (PCA) with varimax rotation, retaining factors with eigenvalues >1 to ensure interpretability [52]. We also assessed the results by examining the screen plot. Five independent factors were extracted, explaining 74.6% of the total variance. This indicates that the model explains much of the stakeholder preference variance. The factor loadings of all variables were higher than 0.70, with all variables that loaded onto the factors not having cross-loadings, indicating that there was no ambiguity associated with an item loading onto more than one factor. Accordingly, no items were eliminated from the analysis. Thus, all the measurement scales were confirmed.

Each of the five identified factors reflects a distinct dimension of the transport mode choice decision. Cost-effectiveness (factor 1) captures the extent to which stakeholders prioritize low transportation expenditure and cost-efficiency [8, 9]. Environmental impact (factor 2) captures the priority attached to minimizing carbon emissions and promoting environmentally sustainable practices [5, 53-56].

Operational flexibility (factor 3) reflects flexible logistics solutions accommodating diverse operational conditions and demand patterns [7]. Transit time (factor 4) reflects the priority of speed and time-sensitive delivery [20]. Infrastructure availability (factor 5) captures the existence of sufficient supporting facilities and amenities for effective transportation operations [3-6, 57].

Cronbach's alpha was used to determine the internal consistency of each factor [48]. All factors had values of more than 0.80 (Table 1), indicating excellent reliability. Cost-effectiveness (α=0.91) had the highest internal consistency, suggesting respondents referred to financial implications consistently when selecting a transport mode. Environmental impact (α=0.88), transit time (α=0.87), operational flexibility (α=0.85), and availability of infrastructure (α=0.83) were also shown to have stable and reliable measurement scales.

The EFA provides a statistically strong framework (Table 1) for determining the key factors affecting choices between barge and feeder vessels' transport modes. The model's strength is depicted by significant factor loadings, a high proportion of explained variance, and high internal reliability, thus further validating these factors and capturing the logic of stakeholders' preferences. This is an important foundation for the subsequent MRAs on the main factors' relative significance on the transport mode choice preference [46].

Table 1. Factor loadings

Factor/Items	Factor Loadings	Cronbach's α
Cost-effectiveness (4)	0.78-0.89	0.91
Environmental impact (4)	0.75-0.86	0.88
Operational flexibility (3)	0.72-0.84	0.85
Transit time (3)	0.79-0.88	0.87
Infrastructure availability (3)	0.71-0.83	0.83

4.3 Multiple regression analysis (MRA)

Before conducting the multiple regression analyses, the underlying assumptions were tested. Normality was assessed using histogram and Q-Q plots, which indicated that residuals were approximately normally distributed. Multicollinearity was checked using Variance Inflation Factors (VIF), all below 2, suggesting no serious multicollinearity. Linearity and homoscedasticity were confirmed by examining scatterplots of standardized residuals versus predicted values. These diagnostic checks confirm that the assumptions for multiple regression were met, thereby validating the use of this method.

The study used MRA to evaluate the importance of factors influencing the choice between barge and feeder vessel transport and perceptions of their efficiency and sustainability (Table 2). Results showed the MRA was statistically significant, explaining 56.2% of the variance in transport mode choice (Table 2). Cost-effectiveness emerged as the strongest predictor (β=0.389, p<.001), followed by environmental impact (β=0.261, p <.001).

Table 2. MRA results for transport mode

Factor	B	SE B	β	t	*p*
Cost-effectiveness	0.41	0.05	0.39	8.58	<.001
Environmental impact	0.29	0.05	0.26	5.52	<.001
Operational flexibility	0.20	0.06	0.17	3.60	<.001
Transit time	0.156	0.050	0.14	3.12	.002
Infrastructure availability	0.09	0.05	0.08	1.89	.059

Notes: R^2=0.562, Adjusted R^2=0.556, F(5, 381)=97.654, p<.001

Table 3's MRA model for perceived efficiency was also statistically significant, explaining 53.1% of the variance. Cost-effectiveness was the strongest predictor (β=0.352, p<.001), followed by operational flexibility (β=0.267, p<.001).

Table 3. MRA results for perceived efficiency

Factor	B	SE B	β	t	*p*
Cost-effectiveness	0.38	0.05	0.35	7.41	<.001
Operational flexibility	0.30	0.05	0.27	5.70	<.001
Transit time	0.25	0.05	0.23	5.00	<.001
Infrastructure availability	0.16	0.05	0.15	3.25	.001
Environmental impact	0.10	0.05	0.09	1.96	.051

Notes: R^2=0.531, Adjusted R^2=0.524, F(5, 381)=86.213, p<.001

The MRA model for perceived sustainability was statistically significant, explaining 58.9% of the variance (Table 4). Environmental impact was the strongest predictor (β=0.467, p<.001), followed by cost-effectiveness (β=0.208, p<.001).

Table 4. MRA results for perceived sustainability

Factor	B	SE B	β	t	*p*
Environmental impact	0.50	0.05	0.47	10.60	<.001
Cost-effectiveness	0.23	0.05	0.21	4.44	<.001
Operational flexibility	0.19	0.05	0.16	3.46	.001
Infrastructure availability	0.13	0.05	0.12	2.74	.007
Transit time	0.08	0.05	0.07	1.49	.137

Notes: R^2=0.59, Adjusted R^2=0.58, F(5, 381)=109.18, p<.001

4.4 Comparative analysis

To compare the perceptions of barge and feeder vessel transport, paired-sample t-tests were conducted for each factor and overall assessments of efficiency and sustainability (Table 5). Significant differences were found in barge and feeder vessel transport perceptions across all factors and overall assessments. Barge transport was perceived as more environmentally friendly and operationally flexible, while feeder vessels were seen as more cost-effective and time-efficient. Feeder vessels were also perceived as having better infrastructure availability (Table 5).

To enhance the interpretation of the results, we categorized

the effect sizes using Cohen's d, where d=0.20 indicates a small effect, d=0.50 is a medium effect, and d=0.80 a large effect [58]. In this study, transit time (d=0.85) and environmental impact (d=0.74) demonstrated large effect sizes, indicating that respondents perceived substantial differences between feeder vessels and barges in these dimensions.

Table 5. Barge and feeder vessel comparative analysis

Factor	Barge Mean (SD)	Feeder Mean (SD)	t	*p*	Cohen's d	Effect Size
Cost-effectiveness	3.82 (0.91)	4.15 (0.83)	-5.87	<.001	0.38	Small to medium effect
Environmental impact	4.28 (0.79)	3.65 (0.92)	10.24	<.001	0.74	Large effect
Operational flexibility	4.05 (0.88)	3.78 (0.95)	4.62	<.001	0.30	Small to medium effect
Transit time	3.45 (1.02)	4.22 (0.80)	-12.54	<.001	0.85	Large effect
Infrastructure availability	3.68 (0.97)	4.08 (0.86)	-6.73	<.001	0.43	Medium effect
Overall efficiency	3.75 (0.94)	4.12 (0.85)	-6.25	<.001	0.41	Medium effect
Overall sustainability	4.18 (0.82)	3.72 (0.90)	8.76	<.001	0.54	Medium to large effect

Cost-effectiveness (d=0.38), infrastructure availability (d=0.43), and overall efficiency (d=0.41) showed medium effect sizes, suggesting meaningful but more moderate distinctions. Operational flexibility (d=0.30) reflected a small-to-medium effect, still indicating a consistent preference for barges in that category. Lastly, overall sustainability (d=0.54) was interpreted as a medium effect size, reinforcing the practical relevance of barge transport's environmental advantages.

Furthermore, when presented with scenarios involving short-distance transport (<100 km), 68% of the respondents said they would prefer barge transport, citing less road congestion and a minor environmental impact as key reasons. Concerning future potential, 73% of the respondents expected that using barges for container transport to BKP would increase over the next five years, citing technological advancements and environmental regulations as reasons.

When asked about infrastructure development, 82% stated they would be more likely to choose barge transport if waterway infrastructure improved. Meanwhile, 76% identified better integration of barge transport with other modes (e.g., railways, road) as essential for better logistics efficiency.

The results give a comprehensive overview of the determinants of choice for barge transport and feeder vessel transport to Bangkok Port and stakeholders' perceptions of the relative efficiency and sustainability of barge transport and feeder vessel transport. The study also characterizes how the two modes of transport are assessed, clarifying the similarities and discrepancies between the current findings.

5. DISCUSSION

This study examined the efficiency and sustainability of barge and feeder vessel transport to BKP, identifying five key determinants influencing mode choice: cost-effectiveness, environmental performance, operational policy flexibility, transit time, and infrastructure availability. Cost-effectiveness emerged as the most influential factor (β=0.389, p<.001), confirming the dominance of economic considerations. Environmental performance ranked second (β=0.261, p<.001), indicating a growing emphasis on sustainability in logistics decision-making [5, 59-63].

Respondents rated barge transport as more environmentally friendly and operationally flexible than feeder vessels [31]. A notable 68% considered barges more effective than road transport for short distances (<100 km), reinforcing their potential to reduce congestion and emissions. However, feeder vessels remain preferred for their long-standing use and economic convenience in provincial port connections.

Infrastructure limitations were seen as the primary barrier to greater barge use. Over 80% of respondents indicated a willingness to adopt barge transport if infrastructure were improved, aligning with prior research on the decisive role of physical logistics capacity. These insights support Thailand's Integrated Logistics and Intermodal Transport (ILIT) Plan, prioritizing multimodal connectivity and inland dry port development.

Finally, the findings reinforce the practical importance of synchromodality. A majority (76%) valued better integration across barge, rail, and road modes as essential for global logistics efficiency—highlighting the potential of hybrid solutions that optimize the strengths of each mode.

5.1 Cost-effectiveness and transit time

The most important variable used when choosing the transport mode was cost-effectiveness, followed by transit time. This finding is similar to Arencibia et al. [20], who suggested that economic factors are important in deciding the freight transport mode. Moreover, although feeder vessels are more cost-effective than barge transport and were suggested as the less time-consuming mode overall, the respondents preferred barge transport in the short-distance scenarios. Therefore, the respondents' perception of cost-effectiveness contrasts with the calculated rates, considering other cost-effectiveness determinants, such as road congestion and last-mile delivery costs [64-66].

Feeder vessels scoring higher on the transit time dimension is perhaps attributable to the same reasons highlighted by Bruzzone et al. [66] who contended that feeder schedule reliability is of greater significance for shippers. On the other hand, the prospect of barges reducing road congestion in a metropolitan city like Bangkok raises the intriguing possibility that (port–port) transit time (Table 4) may not be an appropriate measure of transport service efficiency; instead, the efficiency of (door–door) transport should be ascertained.

5.2 Environmental impact and sustainability

The intense focus on the environmental impact, especially the perception of sustainability, proves the high significance of the green logistics approach in the maritime industry. This finding aligns with the study by Zhang et al. [30] pointing to the environmental advantages of inland waterway transport. A considerably higher evaluation of the environmental friendliness of the barge points to the fact that stakeholders perceive this mode with the potential to create more sustainable

logistics practices.

However, compared to cost-effectiveness, environmental impact received a relatively lower score in influencing the overall modal choice of transport modes could indicate a possible misalignment between sustainability aspirations and present decision-making. The economic-environmental tension is consistent with Esser et al. [26], who studies the effects of environmental regulation on ship practices.

5.3 Critical comparison with past studies

The results of this study partially align with prior European research, particularly in the strong role that environmental impact and cost-effectiveness play in shaping modal choice [10, 11, 67]. However, unlike European contexts where institutional support and infrastructure maturity favor inland waterways, our findings reveal that infrastructure availability remains a critical barrier to increased barge use in Bangkok.

This contrasts with research by Knatz et al. [68], who observed higher modal integration in ports like Rotterdam and Antwerp. Moreover, while previous Thai studies focused mainly on highway congestion or rail investment [67], Tachaudomdach et al. [69] highlight the often-overlooked role of inland water transport in urban freight resilience. Thus, our results extend the Southeast Asian logistics literature by positioning barges as viable sustainability tools in complex megacity environments.

5.4 Policy implications

These findings imply that policymakers should prioritize targeted upgrades to barge-supporting infrastructure at Bangkok Port, including dock modernization, waterway dredging, and smart traffic routing. Public-private partnerships (PPPs), as used in Vietnam's Cat Lai expansion, offer one implementation model. Fiscal tools—such as carbon credit systems or tax deductions for low-emission vessels—could incentivize the adoption of green fleets. Industry stakeholders, including logistics firms and port operators, are encouraged to adopt digital solutions like AI-powered barge scheduling platforms, which have been piloted in Singapore and are linked to measurable gains in berth efficiency and cargo handling time. Integrating these elements into Thailand's ILIT strategy could help unlock barge transport's environmental and congestion-reducing potential [60].

5.5 Theoretical integration

We have explicitly mapped our findings to the underlying frameworks of modal choice theory and synchro modality to enhance theoretical integration. The strong influence of cost-effectiveness, environmental impact, and operational flexibility on transport mode choice supports classical modal choice models, emphasizing both 'hard' factors (cost, time) and 'soft' factors (flexibility, sustainability) in shaping logistics decisions.

Furthermore, the finding that 76% of respondents identified intermodal integration as key to improved logistics efficiency is consistent with the principles of synchromodality, which advocate dynamic, real-time switching between transport modes based on network conditions. It is also consistent with a recent International Transport Forum study stating that Thai respondents strongly emphasized reducing intermodal and border delays more than the other countries surveyed [43].

Moreover, this study's stakeholders preferred barge use on short routes, especially under improved infrastructure scenarios, reflecting a synchromodal logic in practice—where barges serve as adaptive, eco-efficient alternatives within a broader multimodal system.

5.6 Operational flexibility and infrastructure availability

The higher ranking of barges on operational flexibility, especially in short-distance cases, corresponds to synchromodality [61]. Stakeholders recognize a potential for barges to complement other modes of transport in a flexible, time-saving, integrated logistics system.

However, the reduced average score for the availability of infrastructure suggests that this is a significant impediment to the greater use of barges. This is consistent with previous work [24], which has identified that infrastructure quality is a key factor in the viability of barge transport. The interest in infrastructure expressed by respondents is an encouraging sign that there is some recognition of the problem and possible scope for targeted investment to improve the competitiveness of barge vis-à-vis road/rail transport. Finally, Dirman et al. [70] have stated that the strong interest in infrastructure development and the recognition of environmental benefits associated with barge transport provide clear directions for policy interventions. This is in line with other studies highlighting the role of port authorities in facilitating sustainable hinterland transport [71].

It is also recommended that the development of PPPs be considered for the modernization of barge terminal infrastructure at Bangkok Port, modeled on Vietnam’s Cat Lai Port PPP, where joint public-private funding improved barge services and reduced road dependency [29].

Second, the Thai government could introduce targeted tax incentives or carbon credit schemes to encourage logistics firms to adopt cleaner, low-emission barge fleets [72], similar to initiatives seen in Cambodia's Phnom Penh Autonomous Port upgrade [53].

Third, integrating artificial intelligence (AI)-powered barge scheduling systems, already piloted in Singapore's Jurong Port, could help optimize waterway traffic flow and reduce waiting times. These contextually relevant interventions would align Thailand's barge sector with broader ASEAN trends toward sustainable and smart port logistics.

6. CONCLUSIONS

This study investigated the influences on the choice of transport mode between barge and feeder vessels for the shipment of containers to Bangkok Port. Using survey data from 387 industry stakeholders between October and December 2024, the study highlights the conflict between economic and sustainability logic that characterizes logistics operators’ decisions to send containers.

Although feeder vessels still hold the upper hand because of their economical operation and speed, barge transport is developing as a viable mode for short-distance transportation. It offers several benefits regarding environmental performance and higher operational flexibility. However, insufficient infrastructure remains the main barrier to increased barge adoption, indicating the need for strategic investment and intermodal coordination.

Immediate action is needed: investment in barge infrastructure, fiscal incentives for green fleets, and adoption of smart port systems. Without this, Bangkok risks lagging

behind more advanced ASEAN logistics hubs. To align this study with emerging trends in smart logistics, it is important to note that advancements such as AI-driven route optimization and autonomous barge navigation systems are already being piloted in Southeast Asia. For example, Singapore's Jurong Port has begun testing automated barge scheduling platforms, and Vietnam has initiated feasibility studies for uncrewed inland vessels. These technologies can further enhance barge transport's operational efficiency and environmental performance in urban port contexts like Bangkok.

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