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# A DECISION-MAKING FRAMEWORK FOR OPTIMIZING HEAVY-EQUIPMENT DELIVERY VIA LANDING CRAFT TANK AT AN INDONESIAN MINING-LOGISTICS COMPANY

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**Abstract**

Heavy-equipment delivery by Landing Craft Tank (LCT) is critical to mining operations in Indonesia's archipelagic regions, yet routing decisions are often made without structured analytical support. This study develops a decision-making framework for optimizing LCT delivery at a mining-logistics company that relies predominantly on single-origin–single-destination (SOSD) voyages. Using a quantitative-dominant single-case design, 55 LCT voyages from 2025 (498 equipment-unit movements) were analysed through voyage-level key performance indicators—load factor, cost per ton, and cost per nautical mile. The Analytic Hierarchy Process (AHP) structured the choice between SOSD and multi-origin–multi-destination (MOMD) routing across six criteria, complemented by thematic analysis of seven expert practitioners and Failure Mode and Effects Analysis (FMEA). The fleet recorded a low mean load factor of 27.7%, with 54 of 55 voyages below 50%. The multi-stop voyages observed in practice were not cheaper than SOSD, indicating that consolidation alone does not guarantee savings. AHP ranked SOSD first (global priority 0.540 versus 0.460). The study contributes a managerially usable, data-driven framework integrating performance measurement, multi-criteria evaluation, and risk assessment to guide LCT routing decisions.

**Keywords:** Analytic Hierarchy Process; Landing Craft Tank; maritime logistics; route consolidation; vessel utilization

## INTRODUCTION

Heavy-equipment logistics is a critical enabler of mining operations. Large, high-value assets such as excavators, bulldozers, graders, and dump trucks must be moved between project sites that are frequently located in remote and archipelagic regions. In Indonesia, where inter-island sea transport accounts for a substantial share of total logistics cost and a large proportion of vessel time is lost to waiting and coordination, the Landing Craft Tank (LCT) is widely used because of its cargo capacity and its shallow-draft access to ports with limited infrastructure (World Bank, 2015). The efficiency with which LCT capacity is planned and utilized therefore has a direct effect on delivery cost and operational reliability.

Despite this importance, routing decisions in practice are often made on the basis of experience rather than structured analysis. The case company, a heavy-equipment mining-logistics operator, relies predominantly on a single-origin–single-destination (SOSD) routing model, in which each voyage serves only one origin and one destination. This pattern is associated with high mobilization cost, underutilized vessel capacity, fragmented planning across project sites, and limited evaluation of routing alternatives. Multi-origin–multi-destination (MOMD) consolidation is, in principle, capable of lowering cost per unit and raising load factor, yet the company's occasional multi-stop voyages have not, on their own, produced such savings—suggesting that the missing element is not consolidation itself but a structured rule for deciding when and how to consolidate.

This study addresses that gap by developing a decision-making framework for optimizing heavy-equipment delivery via LCT. The research is guided by four questions: (1) how can a structured decision-making framework be developed to evaluate alternative LCT delivery strategies; (2) what criteria should be considered when comparing SOSD and MOMD routing; (3) how can voyage-level performance indicators—load factor, cost per ton, and cost per nautical mile—support delivery planning; and (4) what organizational changes are required to implement optimized routing. Correspondingly, the study develops the framework, identifies relevant criteria, evaluates voyage-level performance from 2025 operational records, and recommends the organizational enhancements needed for implementation.

## LITERATURE REVIEW

Decision-making in operational settings typically involves multiple, conflicting criteria such as cost, time, capacity, feasibility, and risk, so that no single alternative dominates on every dimension. Simon (1977) established that managerial choices are made under cognitive and informational limits, favouring structured, satisficing procedures rather than exhaustive optimization. Multi-criteria decision-making (MCDM) methods address this challenge by clarifying trade-offs. Among them, the Analytic Hierarchy Process (AHP) developed by Saaty (1980, 1990) decomposes a decision into a hierarchy of goal, criteria, and alternatives, derives priority weights from pairwise comparisons on a one-to-nine ratio scale, and tests the coherence of judgments through a consistency ratio (CR), with values at or below 0.10 regarded as acceptable. AHP has been applied widely to transport and logistics decisions, including route and mode selection (Saaty, 1995).

Route optimization originates with the truck dispatching problem (Dantzig & Ramser, 1959), the foundation of the Vehicle Routing Problem (VRP) and its variants (Laporte, 2009; Toth & Vigo, 2014). The Pickup-and-Delivery Problem, in which loads are collected at one or more origins and delivered to one or more destinations, is the closest classical analogue to multi-stop heavy-equipment movement (Berbeglia et al., 2007). In the maritime domain, ship routing and scheduling extends these principles to vessels, cargoes, and ports (Christiansen et al., 2004; Christiansen et al., 2013). Such models can deliver meaningful improvements but are computationally demanding and often abstract away the managerial and coordination realities of field operations.

Shipment consolidation—combining smaller shipments into larger ones—is a well-established lever for lowering cost per unit and improving asset utilization (Ülkü, 2012). Relative to SOSD, MOMD can reduce empty legs, raise load factor, and lower cost per ton. The literature is equally clear, however, that these benefits are conditional on careful coordination of vessel scheduling, cargo readiness, and port availability; without such coordination the theoretical gains are not realized. Performance against cost drivers is monitored through key performance indicators (KPIs)—load factor, cost per ton, and cost per nautical mile being the most relevant at voyage level. Finally, Failure Mode and Effects Analysis (FMEA) provides a structured technique for identifying and prioritizing operational risks through the Risk Priority Number, $RPN = S \times O \times D$ (Stamatis, 2003).

Two gaps emerge. First, most routing research addresses containerized or general freight, with comparatively little attention to heavy-equipment mobilization in mining, where equipment weight, dimensions, and project-specific requirements dominate. Second, few studies offer a managerially usable framework that enables practitioners to compare SOSD and MOMD systematically using voyage-level indicators. This study addresses both by integrating descriptive KPI analysis, AHP, and FMEA into a single decision framework grounded in operational data.

## METHOD

The study adopts a quantitative-dominant single-case study design (Creswell & Creswell, 2018; Yin, 2018). The case is the heavy-equipment delivery operation of PT. Gali Watu Ireng, an Indonesian mining-logistics contractor, examined through its 2025 LCT voyages. The unit of analysis is the LCT voyage. The primary dataset comprises voyage-level records for 55 voyages and 498 equipment-unit movements, including equipment weight and deck area, origin and destination, sailing distance, vessel deadweight capacity (DWT), schedule data, and total chartered cost per voyage. These records form the empirical basis for the performance analysis and for scoring the routing alternatives.

Voyage-level KPIs were computed as load factor (cargo weight ÷ DWT × 100), cost per ton (voyage cost ÷ cargo weight), and cost per nautical mile (voyage cost ÷ distance sailed), and were disaggregated by routing type. The routing choice was structured with AHP across six criteria—cost per ton, cost per nautical mile, schedule adherence, load factor, area utilization, and operational feasibility—comparing the SOSD and MOMD alternatives. Criteria weights were derived using the geometric-mean method and judged for consistency ($CR \leq 0.10$); alternatives were scored directly from the 2025 performance data, with cost-type criteria inverted so that lower cost yields a higher score. Qualitative input was obtained through a structured questionnaire administered to seven experienced logistics practitioners (combined experience exceeding eighty years), analysed using Braun and Clarke's (2006) thematic analysis, and operational risks were assessed using FMEA (Stamatis, 2003).

## RESULTS AND DISCUSSION

### Voyage Performance

The 2025 dataset comprises 55 LCT voyages and 498 equipment-unit movements, with a total chartered cost of approximately USD 2.14 million. As Table 1 shows, fleet performance is dominated by low capacity utilization: the mean load factor is only 27.7%, and 54 of the 55 voyages operated below 50% load factor. This persistent underutilization is the central efficiency problem the framework is designed to address.

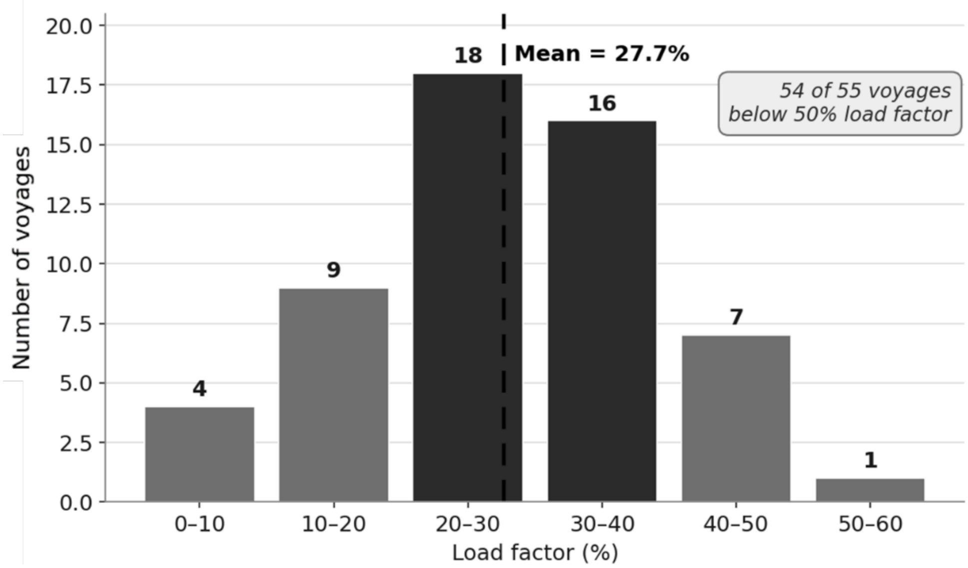


**Image 1.** Distribution of voyage load factor across the 2025 fleet (n = 55)

**Table 1.** Fleet-wide voyage performance indicators, 2025

| Indicator | Value |
|---|---|
| Voyages analysed | 55 |
| Equipment-unit movements | 498 |
| Total LCT spend | USD 2,140,505 |
| Mean load factor | 27.7% |
| Load-factor range | 3.6% – 58.7% |
| Voyages below 50% load factor | 54 of 55 |
| Weighted cost per ton | USD 76.4 |
| Median cost per ton | USD 65.9 |
| Median cost per nautical mile | USD 89.6 |

### SOSD versus MOMD

Contrary to the expectation that consolidation lowers cost, the multi-stop (MOMD) voyages observed in 2025 were not cheaper than SOSD voyages. As Table 2 shows, MOMD recorded a higher median cost per ton (USD 73.36 versus 57.19) and a higher median cost per nautical mile (USD 106.14 versus 86.77), while load factor was essentially tied (27.50% versus 27.74%). This indicates that consolidation as currently practised—without a structured rule governing cargo readiness and scheduling—does not by itself capture the efficiency gains predicted by theory.

**Table 2**. Performance comparison: SOSD versus existing MOMD voyages, 2025

| Metric | SOSD (n=36) | MOMD (n=19) |
|---|---|---|
| Median cost per ton (USD) | 57.19 | 73.36 |
| Median cost per nautical mile (USD) | 86.77 | 106.14 |
| Mean load factor (%) | 27.74 | 27.50 |

### Multi-Criteria Evaluation (AHP)

The routing decision was structured through AHP using six criteria. Cost-related criteria carried the greatest weight (cost per ton 0.327; cost per nautical mile 0.188), followed by schedule adherence (0.188), with load factor, area utilization, and operational feasibility at 0.099 each; the criteria judgments were highly consistent (CR = 0.002). Synthesizing the criteria weights with alternative scores derived from the 2025 data, SOSD obtained a global priority of 0.540 against 0.460 for MOMD (Table 3). A sensitivity analysis confirmed that SOSD remained preferred across the full range of cost-criteria weightings, so the recommendation is robust.

**Table 3.** AHP criteria weights and global priorities (CR = 0.002)

| Criterion | Weight | SOSD | MOMD |
|---|---|---|---|
| Cost per ton | 0.327 | 0.565 | 0.435 |
| Cost per nautical mile | 0.188 | 0.545 | 0.455 |
| Schedule adherence | 0.188 | 0.500 | 0.500 |
| Load factor | 0.099 | 0.500 | 0.500 |
| Area utilization | 0.099 | 0.500 | 0.500 |
| Operational feasibility | 0.099 | 0.600 | 0.400 |
| Global priority | 1.000 | 0.540 | 0.460 |
| Rank | | 1 | 2 |

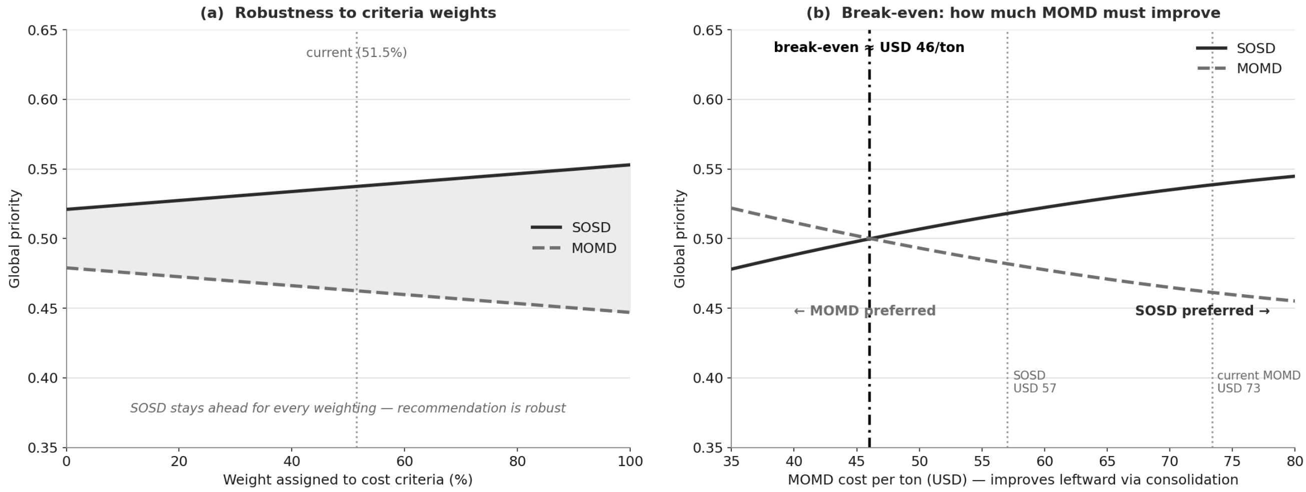


**Image 2.** AHP sensitivity analysis — (a) robustness to criteria weights and (b) break-even for MOMD cost per ton

### Risk Assessment (FMEA)

FMEA ranked operational risks by Risk Priority Number (RPN = S × O × D). As Table 4 shows, the highest-priority risk is equipment not being ready at the vessel's scheduled departure (RPN 192), followed by adverse weather and wave conditions (RPN 168). The prominence of the readiness–schedule mismatch reinforces the central finding: because consolidation depends on synchronized cargo readiness, the absence of a structured scheduling rule is both the principal efficiency loss and the principal operational risk.

**Table 4.** FMEA of LCT delivery risks (top risks by RPN)

| Failure mode | RPN |
|---|---|
| Equipment not ready at vessel schedule | 192 |
| Adverse weather / high waves | 168 |
| Low water depth / tidal constraints | 150 |
| Port congestion / berth queue | 150 |
| Vessel unavailability / breakdown | 112 |

### Discussion

Taken together, the results show that the company's efficiency problem is not the absence of consolidation but the absence of a structured decision rule. SOSD is currently preferred because the multi-stop voyages undertaken without coordinated planning carry higher unit costs and the same low utilization. The framework's contribution is to make this judgment explicit and repeatable: voyage-level KPIs establish the performance baseline, AHP converts criteria and performance into a transparent ranking, and FMEA incorporates risk. The managerial implication is that MOMD should be adopted selectively—only when a defined consolidation threshold (cargo readiness, compatible schedules, and a cost-per-ton improvement beyond an identified break-even) is met—supported by cross-team coordination between head office and site teams.

## CONCLUSION

This study developed a structured, data-driven framework for optimizing heavy-equipment delivery via LCT. Analysis of 55 voyages from 2025 revealed a low mean load factor of 27.7% and showed that the multi-stop voyages observed in practice were not cheaper than single-stop voyages. Using AHP across six criteria, SOSD ranked first (global priority 0.540 versus 0.460), a result that proved robust under sensitivity analysis, while FMEA identified the readiness–schedule mismatch as the dominant risk. The framework answers the research questions by integrating performance measurement, multi-criteria evaluation, and risk assessment into a single managerially usable tool. Practically, the company should retain SOSD as the default while adopting MOMD selectively under a defined consolidation rule, supported by improved cross-team scheduling. Future work could extend the framework with a larger expert panel and full area-utilization data, and validate it across additional operating periods.

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