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Concentration, Capacity and Constraint: A Mixed-Methods Evaluation of Cargo Handling Performance at Ciwandan Port, Banten, Indonesia

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A B S T R A C T

Multipurpose ports in emerging economies handle heterogeneous cargo across shared berths, yet the operational literature remains dominated by container terminals. This study evaluates cargo handling performance at Ciwandan Port, Banten, operated by PT Pelabuhan Indonesia Regional 2, and identifies the constraints that impede it. A convergent mixed-methods design was employed, combining descriptive analysis of 289 vessel calls recorded between January and September 2025 with field observation and semi-structured interviews conducted between May and November 2025. The vessel-call data comprise a total throughput of 2,626,613 tonnes. Analysis reveals a pronounced concentration of activity: the three sub-berths of Berth 05 together account for 70.8% of throughput, while Berth 04 absorbs 22.5% of all calls yet contributes only 7.9% of tonnage. Mean parcel size varies almost sevenfold across berths, from 3,192 to 21,870 tonnes per call.

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INTRODUCTION

Seaports constitute critical nodes linking maritime transport to inland logistics networks, and the efficiency with which they transfer cargo between these modes exerts a direct influence upon national economic competitiveness. In Indonesia, where logistics costs have historically represented a substantial share of gross domestic product, the operational performance of ports carries particular significance for industrial development (Amin et al., 2021; Santoso et al., 2025). Ciwandan Port, operated by PT Pelabuhan Indonesia Regional 2 Banten and situated in Ciwandan District, Cilegon, serves the industrial hinterland of Banten Province, encompassing Cilegon, the western and eastern zones of Serang, Balaraja, and western Tangerang. Inaugurated in 1988 with a terrestrial working area of 62.27 hectares and an associated water area of approximately 4,100 hectares, the port was reclassified from Class II to Main Class status in 2017 in recognition of growth in throughput and revenue.

Ciwandan is a multipurpose facility. It handles liquid bulk, dry bulk, general cargo, and roll-on/roll-off vehicle traffic across a common set of berths, and provides ancillary services including berthing and anchorage, warehousing, and terminal operations. This heterogeneity distinguishes it from the container terminals that dominate the port performance literature. Research on terminal optimisation has concentrated overwhelmingly upon containerised operations, with studies of non-containerised terminals in developing economies remaining comparatively scarce (Soimun et al., 2025). The distinction is consequential: whereas container terminals achieve productivity through standardisation and the repetitive execution of a single handling cycle, multipurpose terminals must reconfigure equipment, labour, and storage between successive calls of dissimilar cargo, and their performance is therefore governed by a different set of constraints.

The measurement of port performance rests upon a well-established family of indicators encompassing throughput, service time, and facility utilisation ratios. Empirical work has demonstrated strong associations between vessel numbers handled, output per hook per shift, and total traffic, together with a pronounced negative association between idle time at berth and productivity. Comparative studies employing stochastic frontier analysis and data envelopment analysis have quantified efficiency differentials across terminals and operators (Lopez-Bermudez et al., 2019; Danladi et al., 2024), while more recent contributions have derived performance indicators directly from vessel movement data (Chen et al., 2016). Efficiency at berth is not merely an operational concern: Rodseth et al. (2019) demonstrated that improvements in technical efficiency translate into substantial gains in environmental productivity by reducing the time vessels spend emitting at berth.

Notwithstanding this analytical apparatus, the diagnosis of performance shortfalls at individual multipurpose ports remains underdeveloped. Aggregate efficiency scores identify that a terminal underperforms but seldom disclose why. Studies of dry bulk operations in Indonesia and elsewhere have begun to address this gap by cataloguing operational constraints directly, identifying equipment malfunction, truck circulation, weather, and fleet availability as recurrent sources of delay (Parman et al., 2025). Yet such studies typically rely upon expert judgement alone, without triangulation against operational records, and consequently cannot establish whether the constraints reported by practitioners correspond to the patterns evident in throughput data.

This study addresses that gap by evaluating cargo handling performance at Ciwandan Port through a convergent mixed-methods design. Two research questions guide the enquiry. First, how is cargo handling activity distributed across the port's berths, and what does that distribution reveal about the utilisation of installed capacity? Second, what operational constraints impede the execution of cargo handling, and how do these constraints relate to the observed distribution of activity? The contribution of the study lies in coupling a quantitative account of 289 vessel calls with practitioner testimony, thereby permitting the identification of which reported constraints are corroborated by the operational record and which represent perceptions not yet visible in throughput data.

LITERATURE REVIEW

Cargo Handling Operations and Performance Indicators

Cargo handling at a conventional port comprises three sequential activities. Stevedoring denotes the transfer of cargo between the vessel's hold and the quay; cargodoring, or quay transfer, denotes the movement of cargo from the quay to warehouse or stacking yard; and receiving or delivery denotes the transfer of cargo between the storage area and inland transport. The productivity of the overall operation is determined not by the fastest of these activities but by the slowest, since an imbalance between stevedoring and cargodoring rates produces accumulation at the quay and eventual suspension of discharge.

International practice employs four families of indicator to characterise this process. Cargo flow indicators measure tonnage handled and are disaggregated into berth output, ship output, and gang output, the last measuring tonnage handled by a single gang per working hour. Service time indicators measure the interval between a vessel's arrival within port limits and its departure. Facility utilisation ratios express the proportion of available berth, shed, or yard capacity consumed within a given period, and are conventionally reported as the berth occupancy ratio, shed occupancy ratio, and yard occupancy ratio. Finally, equipment utilisation indicators capture the availability and productivity of mechanical handling plant.

Delovic (2020) analysed net berth productivity in dry bulk handling and systematised the groups of influential factors that determine its value, noting that research addressing this metric specifically for dry bulk operations remains limited relative to its practical importance. Contemporary work has extended measurement practice in two directions. Gulmez et al. (2025) developed a neural network model predicting cargo handling and berthing times in bulk terminals from vessel particulars, cargo type, weather, and equipment data, generating inputs for berth occupancy calculation and berth planning. Praharsi et al. (2025) developed key performance indicators tailored to the Indonesian port context, addressing the mismatch between generic international metrics and the operational realities of national ports.

Berth Allocation and Capacity Utilisation

The allocation of vessels to berths constitutes one of the most extensively studied problems in port operations research. Rodrigues and Agra (2022) surveyed the berth allocation and quay crane assignment problem under uncertainty and documented the proliferation of formulations addressing stochastic arrival times, handling rates, and equipment availability. The practical significance of this literature for multipurpose ports lies in its demonstration that berth productivity is jointly determined by allocation policy and by the equipment assigned to each berth, rather than by quay length alone.

Empirical studies of berth utilisation in Indonesian ports report berth occupancy ratios approaching or exceeding the thresholds at which queueing becomes significant. Soimun et al. (2025) analysed stevedoring activity and berth occupancy at Jamrud Terminal, Tanjung Perak, and forecast a berth occupancy ratio of 85% alongside general cargo and dry bulk handling performance falling below international standards. Santoso et al. (2025) demonstrated at a land-constrained Indonesian container terminal that capacity in excess of nominal design could be achieved through agile and lean operational reform, without capital expansion, while maintaining acceptable berth and yard occupancy ratios. These findings suggest that in the Indonesian context the marginal return to operational reform may exceed that to infrastructure investment.

Equipment Reliability and Operational Disruption

Mechanical handling equipment constitutes the principal determinant of cargo handling rate at conventional berths, and its unavailability is a recurrent source of disruption. Rosca et al. (2025) assessed the influence of equipment reliability upon terminal activity through discrete-event simulation and quantified the propagation of individual equipment failures into terminal-level performance loss. Lv et al. (2025) addressed the same problem in bulk cargo ports through a dual strategy combining dynamic berth replanning with equipment maintenance, optimised by reinforcement learning, and demonstrated material reductions in downtime.

Predictive approaches to equipment management have advanced considerably. Tian et al. (2024) proposed a high-level feature fusion deep learning model for fault detection in dry bulk port handling equipment, achieving prediction accuracy exceeding 86% while explicitly addressing the high configuration and maintenance cost of sensor-based monitoring in bulk terminals. Crespo Del Castillo et al. (2023) developed a data-driven asset health index for quay cranes, and Aslam et al. (2025) demonstrated machine learning-based predictive maintenance using Internet of Things sensor data at smart ports. Collectively this work indicates that equipment reliability is increasingly amenable to systematic management, but also that such management presupposes data collection infrastructure that many multipurpose terminals in emerging economies do not possess.

Landside Interface and External Constraints

Port performance is bounded not only by quayside capacity but by the landside interface through which cargo enters and leaves. Neagoe et al. (2021) compared congestion management initiatives at a bulk cargo marine terminal through discrete-event simulation and found that terminal appointment systems reduced truck turnaround times by up to 65% and idling emissions by up to 80%, with the benefits of infrastructure expansion rivalling those of appointment systems only under high throughput scenarios. Cheng et al. (2025) addressed the complementary problem of internal truck scheduling through a graph-theoretic reinforcement learning approach, reducing crane waiting times and improving vehicle utilisation.

Weather represents a further external constraint of demonstrable economic consequence. Garcia-Alonso et al. (2020) quantified the effect of weather conditions upon port technical efficiency, and Verschuur et al. (2023) documented systemic risks arising from climate-related disruption at ports. For bulk commodities sensitive to moisture, adverse weather necessitates suspension of operations, converting meteorological variability directly into lost berth time. Labour availability constitutes a third constraint: Ozder and Gumus (2023) addressed sustainable staff scheduling in dock terminals, and the coordination of dockworker shifts with vessel arrival patterns remains a persistent operational challenge at ports where labour is supplied through cooperative arrangements. Finally, Brunila et al. (2021) identified the organisational and technical impediments to port digitalisation, which conditions the feasibility of the appointment systems and scheduling reforms that the literature recommends.

Research Gap

Three observations follow from this review. First, the operational literature remains oriented towards container terminals, and the specific dynamics of multipurpose terminals handling heterogeneous cargo across shared berths are comparatively unexamined. Second, studies of operational constraints in dry bulk and general cargo handling rely predominantly upon expert elicitation, without corroboration against throughput records. Third, evidence from the Indonesian context suggests that operational reform may dominate capital expansion in cost-effectiveness, but the diagnosis required to direct such reform at a specific port has rarely been performed. The present study addresses these gaps through a berth-level analysis of vessel call records triangulated against practitioner accounts of operational constraint.

METHODOLOGY

Research Design and Setting

This study employed a convergent mixed-methods design in which quantitative and qualitative data were collected in parallel and integrated at the interpretive stage. The research site was Ciwandan Port, Cilegon, Banten Province, operated by PT Pelabuhan Indonesia Regional 2 Banten. Fieldwork was conducted between May and November 2025 in the course of a community engagement programme, which afforded sustained access to port personnel and operational areas.

Data Sources

Quantitative data comprised the port's vessel call register for the period January to September 2025. Each record identifies the calendar month, vessel name, berth of assignment, consignee or shipper, commodity description, and cargo volume in tonnes. After exclusion of records with incomplete berth or volume fields, 289 vessel calls were available for analysis, representing an aggregate throughput of 2,626,613 tonnes. Qualitative data were obtained through direct observation of cargo handling operations at the berths, warehouses, and stacking yards, and through semi-structured interviews with operational personnel of PT Pelabuhan Indonesia Regional 2 Banten. Photographic documentation of equipment and operational areas supplemented these sources. Secondary data comprised the port's equipment register and applicable national regulations governing cargo handling tariffs and the conduct of loading and unloading operations.

Analytical Procedure

Quantitative analysis proceeded by descriptive aggregation. Vessel calls were grouped by berth of assignment in order to establish the distribution of throughput and call frequency across the facility, and mean parcel size per call was computed for each berth as the ratio of aggregate tonnage to number of calls. Commodities were classified into four groups, namely dry bulk coal, other dry bulk, liquid bulk, and general cargo including steel products, with residual records assigned to an unclassified category. This classification permits assessment of the heterogeneity of the cargo mix, which conditions the equipment configuration required at each berth. Qualitative analysis followed the standard sequence of data reduction, data display, and conclusion drawing with verification. Interview and observational material was coded thematically to identify recurrent constraints, and the resulting categories were compared against the patterns evident in the quantitative distribution in order to establish where the two data sources corroborated or diverged from one another.

Limitations of the Data

Two limitations of the quantitative data warrant statement at the outset. First, the vessel call register records tonnage and berth assignment but does not record berthing and unberthing timestamps, and it is therefore not possible to compute berth occupancy ratios, service times, or gang outputs directly. The analysis presented here consequently characterises the distribution of activity rather than the rate at which it was performed. Second, records for May, August, October, November, and December were not available within the dataset obtained, and the nine-month window analysed may therefore not capture the full seasonal profile of the port's traffic. These constraints are acknowledged in the interpretation of results.

RESEARCH RESULT

Cargo Handling Procedure

Observation established that cargo handling at Ciwandan follows the conventional three-stage sequence. Stevedoring is performed using ship's gear or shore cranes according to vessel type and commodity, with liquid bulk transferred through pipeline connections and dry bulk handled through grabs and hoppers. Cargodoring is executed principally by forklift, with units drawing cargo from the discharge point at the ship's side once released from the sling and transferring it to the stacking area. Receiving and delivery involves the loading of cargo from warehouse or yard onto road vehicles for onward carriage to consignees within the industrial hinterland. Interviews confirmed that the productivity of the cargodoring stage is governed by two variables: the haulage distance between berth and storage area, and the transfer cycle time of the forklift fleet, defined as the interval between successive pick-ups at the discharge point.

Distribution of Throughput Across Berths

Analysis of the 289 vessel calls reveals a pronounced concentration of activity. Aggregate results by berth are presented in Table 1 and visualised in Figure 1.

Table 1. Distribution of Vessel Calls and throughput By Berth, January to September 2025

Berth	Vessel calls	Share of calls (%)	Throughput (tonnes)	Share of throughput (%)	Mean parcel size (tonnes/call)
05 A	90	31.1	735,178	28.0	8,169
05 B	27	9.3	590,479	22.5	21,870
05 C	30	10.4	533,854	20.3	17,795
07	43	14.9	327,976	12.5	7,627
02	33	11.4	231,227	8.8	7,007

Berth	Vessel calls	Share of calls (%)	Throughput (tonnes)	Share of throughput (%)	Mean parcel size (tonnes/call)
04	65	22.5	207,484	7.9	3,192
06	1	0.3	415	0.0	415
Total	289	100.0	2,626,613	100.0	9,089

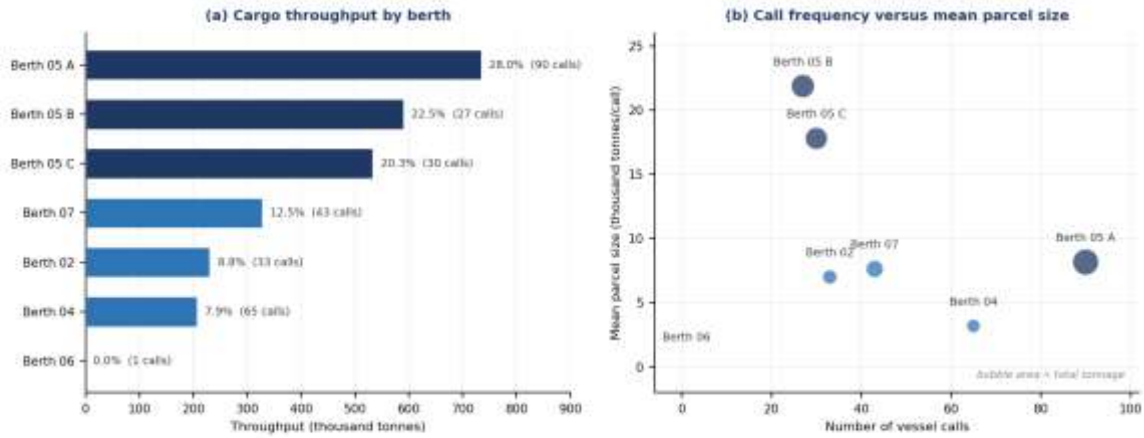

Figure 1. Cargo throughput By Berth and the Relationship Between Call Frequency And Mean Parcel Size

The three sub-berths comprising Berth 05 together handled 1,859,511 tonnes, equivalent to 70.8% of total throughput, from 147 calls representing 50.9% of all vessel movements. Berth 05 A alone received 90 calls, the highest frequency in the dataset, and handled 735,178 tonnes or 28.0% of throughput. Berths 05 B and 05 C, by contrast, received only 27 and 30 calls respectively yet handled 590,479 and 533,854 tonnes, indicating their assignment to substantially larger parcels.

The disparity in mean parcel size across berths is the most striking feature of the distribution. Berth 05 B recorded a mean of 21,870 tonnes per call and Berth 05 C a mean of 17,795 tonnes, whereas Berth 04 recorded 3,192 tonnes, a ratio approaching seven to one between the extremes. Berth 04 absorbed 65 calls, or 22.5% of all vessel movements, yet contributed only 207,484 tonnes, equivalent to 7.9% of throughput. Berth 06 appears once in the dataset with 415 tonnes and is effectively dormant across the observation window. Panel (b) of Figure 1 displays this relationship, with berths distributed along an inverse gradient between call frequency and parcel size.

Composition of the Cargo Mix

Classification of the commodity descriptions confirms the multipurpose character of the facility. The composition of throughput by commodity group is presented in Table 2.

Table 2. Composition of Throughput By Commodity Group

Commodity group	Vessel calls	Throughput (tonnes)	Share of throughput (%)
Dry bulk other than coal (wheat, minerals)	52	786,625	29.9
General cargo (steel products)	63	619,276	23.6
Unclassified / mixed	41	476,757	18.2
Dry bulk coal	54	416,530	15.9
Liquid bulk (fuel, chemicals, asphalt)	79	327,425	12.5
Total	289	2,626,613	100.0

No single commodity group accounts for as much as one third of throughput. Dry bulk commodities other than coal, principally wheat and mineral products, constitute the largest group at 29.9%, followed by general cargo in the form of steel products at 23.6%, coal at 15.9%, and liquid bulk at 12.5%. The remaining 18.2% comprises commodities not falling within these categories. Liquid bulk accounts for the largest number of calls at 79, or 27.3% of vessel movements, but the smallest share of tonnage among the classified groups, reflecting the comparatively modest parcel sizes of tanker and barge traffic serving the petrochemical and fuel distribution sectors of the hinterland.

Operational Constraints

Interviews and observation identified five recurrent constraints upon cargo handling performance. These are summarised in Table 3 together with the mitigating measures reported by port personnel.

Table 3. Operational Constraints Identified and Mitigating Measures Reported

Constraint	Manifestation reported	Mitigating measure reported
Equipment availability and reliability	Cranes, hoppers and conveyors require unscheduled maintenance or are insufficient in number during peak traffic, producing vessel queueing and extended berth stay	Intensified preventive maintenance; replacement of units beyond reliable service life
Landside access and connectivity	Congestion on access roads during peak hours and when truck volumes rise, slowing cargo distribution	Coordination of truck movement; adjustment of gate operating patterns

Constraint	Manifestation reported	Mitigating measure reported
Scheduling coordination	Discrepancies in information on readiness of vessels, equipment or labour among operators, service users and the port authority	Synchronisation of schedules and improved inter-party communication
Weather and environment	Strong winds and heavy rainfall interrupt handling, particularly for moisture-sensitive bulk commodities	Suspension of operations to preserve safety and cargo quality; weather monitoring
Dockworker availability	Uneven distribution of registered dockworkers across shifts during concentrated vessel arrival	Shift adjustment; coordination with the dockworker cooperative

The constraint reported most consistently concerned the availability and reliability of mechanical handling equipment. Cranes, hoppers, and conveyors were described as periodically requiring unscheduled maintenance or as being insufficient in number during periods of elevated traffic, producing vessel queueing and extended berth stay. Examination of the port's equipment register substantiates the concern regarding equipment age: of the forklift fleet, two three-tonne and two five-tonne units date from 2018, three ten-tonne units from 2015, one fifteen-tonne unit from 2016, and one twenty-three-tonne unit from 2019, while the rough terrain crane and mobile crane both date from 2014. At the time of observation the principal lifting plant was therefore between six and eleven years old.

Personnel further reported that the discharge rate achieved at the ship's side frequently exceeded the rate at which the forklift fleet could clear cargo from the quay, producing accumulation at the berth and, in extreme cases, suspension of discharge. This imbalance was attributed to forklift downtime arising from breakdown at moments of peak demand. The remaining constraints concerned the landside interface, where congestion on access roads during peak hours slowed the distribution of cargo; coordination among vessel operators, service users, and the port authority, where discrepancies in information regarding the readiness of vessels, equipment, or labour produced delay; adverse weather, which necessitated suspension of operations for moisture-sensitive bulk commodities; and the availability of registered dockworkers, whose distribution across shifts was reported as insufficiently flexible during periods of concentrated vessel arrival.

DISCUSSION

Concentration of Activity and Its Implications

The concentration of 70.8% of throughput upon a single berth complex carries two implications. The first concerns resilience. Where the majority of cargo passes across three contiguous sub-berths, the failure of equipment serving that complex propagates immediately into aggregate port performance, and the redundancy that a multi-berth facility might in principle provide is not realised in practice. Rosca et al. (2025) demonstrated through simulation that equipment reliability exerts a disproportionate influence upon terminal activity precisely under such conditions of concentration, and Lv et al. (2025) accordingly coupled berth replanning with maintenance scheduling rather than treating the two as separate decisions. The evidence from Ciwandan indicates that this coupling is operationally warranted.

The second implication concerns the interpretation of the underutilised berths. Berth 04 receives 22.5% of calls yet contributes 7.9% of tonnage, and Berth 06 is effectively dormant. On one reading this pattern signals surplus capacity; on another it signals a mismatch between the physical characteristics of these berths and the parcel sizes of the traffic offered. The predominance of liquid bulk calls, which are numerous but individually small, at berths equipped for that trade suggests the latter interpretation. If so, the addition of quay length would not relieve the pressure upon Berth 05, since the constraint is not the availability of berth space in aggregate but the availability of berth space equipped to receive large dry bulk and general cargo parcels.

This reading is consistent with the finding of Santoso et al. (2025) that a land-constrained Indonesian terminal achieved throughput exceeding nominal design capacity through operational reform rather than capital expansion, and with the broader observation of Soimun et al. (2025) that handling performance at Indonesian non-container terminals falls below international standards even where berth occupancy is high. High occupancy accompanied by low productivity indicates that berths are occupied for longer than the cargo requires, which directs attention to handling rate rather than to berth supply.

The Equipment Constraint as the Binding Constraint

The convergence between the quantitative and qualitative strands is most instructive in relation to equipment. Practitioners identified equipment availability as the foremost constraint, and the equipment register corroborates that the principal lifting plant is between six and eleven years old. The reported imbalance between stevedoring and cargodoring rates provides the mechanism by which this ageing translates into performance loss: when forklift availability falls below the level required to clear cargo at the rate discharged, the quay becomes a buffer of finite capacity and discharge must eventually cease. The productivity of the operation is therefore determined by the reliability of the cargodoring fleet rather than by the capability of the stevedoring gear.

This diagnosis has a direct bearing upon the allocation of investment. Rodrigues and Agra (2022) noted in surveying berth allocation under uncertainty that equipment availability constitutes a principal source of the stochasticity that allocation models must accommodate; reducing that stochasticity at source is therefore preferable to accommodating it in scheduling. The predictive maintenance literature offers established means of doing so. Tian et al. (2024) achieved fault detection accuracy exceeding 86% in dry bulk port handling equipment using a model designed explicitly to function without the sensor infrastructure whose cost is prohibitive in such terminals, and Crespo Del Castillo et al. (2023) demonstrated the construction of asset health indices from operational data already routinely collected. Aslam et al. (2025) extended this to Internet of Things sensor deployments at smart ports. For Ciwandan, the practical implication is that a structured condition monitoring regime, coupled with a replacement programme for units beyond their reliable service life, addresses the binding constraint more directly than any adjustment to berth allocation policy.

The Landside Interface

The constraints reported in relation to road access, scheduling coordination, and truck circulation locate a second bottleneck at the interface between quay and hinterland. This finding accords closely with the simulation evidence of Neagoe et al. (2021), who established at a bulk cargo terminal that appointment systems reduced truck turnaround times by up to 65% while infrastructure expansion delivered comparable benefit only under high throughput conditions. The relevance to Ciwandan is direct: the port serves a dense industrial hinterland along a road network shared with general traffic, and the marginal benefit of coordinating truck arrival is likely to exceed that of expanding road capacity, which in any event lies beyond the port's control.

Realising such coordination presupposes information exchange among the port, operators, and service users of a kind that the reported discrepancies in readiness information indicate is not presently achieved. Brunila et al. (2021) identified the organisational and technical impediments that commonly obstruct port digitalisation, and their findings suggest that the introduction of an appointment system at Ciwandan would encounter adoption barriers as much as technical ones. Cheng et al. (2025) addressed the complementary problem of internal vehicle scheduling and demonstrated that coordinated allocation reduces crane waiting time, indicating that gains are available on both sides of the gate.

Weather and Labour

The suspension of operations during adverse weather, reported by personnel in relation to moisture-sensitive bulk commodities, is consistent with the quantified effect of weather upon port technical efficiency established by Garcia-Alonso et al. (2020) and with the systemic climate-related risks documented by Verschuur et al. (2023). Given that dry bulk commodities other than coal constitute the largest single group in the Ciwandan cargo mix at 29.9%, exposure to this constraint is material. Covered handling arrangements and weather-informed berth scheduling, of the kind contemplated in the predictive berthing models of Gulmez et al. (2025), represent proportionate responses.

Labour availability during demand peaks reflects the structural characteristics of dockworker supply through cooperative arrangements, in which shift allocation is negotiated rather than centrally scheduled. Ozder and Gumus (2023) addressed the corresponding scheduling problem in semi-automated terminals, and their formulation is transferable in principle, though its application at Ciwandan would require the same information infrastructure upon which truck appointment scheduling depends. The three landside constraints of road congestion, coordination failure, and labour distribution are thus not independent, but share a common dependence upon the port's capacity to plan and communicate ahead of vessel arrival.

Limitations

Several limitations qualify these findings. The absence of berthing timestamps in the vessel call register precludes computation of berth occupancy ratios, service times, and gang outputs, and the analysis therefore characterises the distribution of activity rather than the rate at which it was achieved; conclusions regarding productivity rest upon practitioner testimony rather than upon measured handling rates. The nine-month observation window omits several months and may not capture the full seasonal profile of traffic. The qualitative strand draws upon interviews with port personnel and does not incorporate the perspectives of shipping agents, cargo owners, or dockworkers, whose accounts of the same constraints might differ. Finally, the study examines a single port, and the extent to which its findings generalise to other Indonesian multipurpose terminals requires comparative investigation.

CONCLUSIONS AND RECOMMENDATIONS

This study evaluated cargo handling performance at Ciwandan Port through the analysis of 289 vessel calls comprising 2,626,613 tonnes, triangulated against field observation and interviews with operational personnel. Cargo handling follows the conventional sequence of stevedoring, cargodoring, and receiving or delivery, and activity is heavily concentrated: the three sub-berths of Berth 05 handle 70.8% of throughput, while Berth 04 absorbs 22.5% of calls for 7.9% of tonnage and Berth 06 is effectively dormant. Mean parcel size varies almost sevenfold across berths. The cargo mix is genuinely heterogeneous, with no commodity group exceeding 30% of throughput. Five operational constraints were identified, of which the availability and reliability of mechanical handling equipment emerged as the most consequential, corroborated by an equipment register showing principal lifting plant between six and eleven years old.

Four recommendations follow. First, the operator should implement a structured condition monitoring and preventive maintenance regime for handling equipment, and should establish a replacement programme for units that have passed their reliable service life, since equipment reliability rather than quay length constitutes the binding constraint upon throughput. Second, the capacity of the cargodoring fleet should be synchronised with achievable stevedoring rates, whether through fleet augmentation or through the scheduling of discharge to match clearance capacity, in order to prevent the accumulation at the quay that currently interrupts operations. Third, the port should pursue coordination of truck arrival through an appointment or slot system, together with improved information exchange with operators and service users regarding the readiness of vessels, equipment, and labour. Fourth, berth allocation policy should be reviewed in the light of the observed mismatch between berth capability and offered parcel size, with a view to relieving pressure upon Berth 05 by equipping underutilised berths to receive larger parcels.

ADVANCED RESEARCH

Four directions for further research are indicated. First, the collection of berthing and unberthing timestamps would permit computation of berth occupancy ratios, service times, and gang outputs, and thereby enable the productivity diagnosis that the present dataset could not support. Second, discrete-event simulation of the Ciwandan quay and landside system, following the approach of Neagoe et al. (2021) and Rosca et al. (2025), would allow the relative benefit of equipment renewal, fleet augmentation, and appointment scheduling to be compared quantitatively before investment is committed. Third, comparative analysis across several Indonesian multipurpose ports using data envelopment or stochastic frontier methods would establish whether the constraint structure identified here is characteristic of the class or specific to this facility. Fourth, the feasibility of low-cost predictive maintenance at terminals lacking sensor infrastructure, along the lines developed by Tian et al. (2024), merits direct trial in the Indonesian context.

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