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Fumigation Procedures as a Critical Node in Export Logistics Performance: Evidence from Tanjung Perak Port, Surabaya

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ABSTRACT

Fumigation is normally discussed as a phytosanitary compliance activity, but in export operations its duration, documentation, and coordination can directly determine logistics reliability. This study analyzes how fumigation procedures implemented by PT Prana Argentum Corporation in the Tanjung Perak Port logistics environment affect export lead time and contribute to logistics performance. The research used a descriptive qualitative design conducted from February to July 2025. Primary evidence was obtained through field observation and semi-structured interviews with key fumigation and logistics personnel at operational, supervisory, and managerial levels, while secondary evidence was drawn from company documentation and relevant literature. Data were analyzed through qualitative reduction, display, interpretation, and triangulation across interviews, observations, documents, and theoretical perspectives. The findings show that fumigation is an integrated sequence consisting of document and commodity verification, site and equipment preparation, sealing and fumigant application, exposure monitoring, aeration or gas clearance, and certification. The process requires a substantial time allocation and must therefore be embedded in shipment planning before port closing time. Delay risks arise from incomplete documents, schedule changes, weather, limited treatment space and equipment, transporter or port congestion, and weak inter-organizational coordination. Properly planned fumigation reduces cargo rejection and re-treatment risk, supports customs and quarantine document readiness, limits demurrage and storage exposure, and strengthens buyer confidence. The study proposes early scheduling, adequate buffer time, service-level agreements, vendor and resource readiness, routine training, and integrated digital monitoring as practical mechanisms for improving fumigation-integrated export logistics.

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1. INTRODUCTION

International trade links domestic production with global markets and contributes to economic growth by widening market access, generating foreign exchange, creating employment, and encouraging industrial adaptation [1]-[4]. For Indonesia, maritime transport and port-based logistics are particularly important because the country's export flows depend on the continuity of inland transport, cargo handling, port services, documentation, customs, quarantine, and international shipping. The competitiveness of an exported product therefore cannot be separated from the performance of the logistics system that carries the product from the warehouse to the vessel and ultimately to the destination market. The source study places this issue within the broader challenge of ensuring that export growth is accompanied by reliable, timely, and compliant logistics operations.

Tanjung Perak Port in Surabaya is one of the principal gateways for trade in East Java. The source study notes a substantial value of export activity handled through the port and positions Tanjung Perak as an important node for regional distribution and international trade. Its role is not limited to cargo transfer. The port also functions as an interface among exporters, freight forwarders, transporters, terminal operators, customs, quarantine authorities, shipping lines, and specialized service providers. As a result, logistics performance at Tanjung Perak depends on how effectively these actors synchronize physical cargo movement and information. A disruption at one stage can

propagate to subsequent stages, increasing waiting time, storage exposure, and the probability of missing a vessel schedule.

The logistics literature cited in the source manuscript emphasizes that logistics performance is multidimensional. Gani [5] links logistics performance to international trade through service quality, infrastructure, customs processes, and shipment reliability. Harimurti [6] explains logistics as an integrated system that must balance service effectiveness and total cost, while Widiadibrata, as discussed in the thesis, identifies time, cost, capacity, capability, productivity, utilization, and outcomes as practical dimensions of logistics performance. Port-level studies further show that infrastructure, equipment, human resources, licensing, and information technology influence operational efficiency [7], [8]. These perspectives indicate that export performance is not determined by transportation alone, but by the coordination of activities that collectively shape lead time and service reliability.

Lead time is especially important because export logistics operates under fixed deadlines. The source study describes export lead time as an accumulation of waiting time, document-processing time, inspection time, handling time, and vessel-loading time. In container operations, delays can also increase dwell time and generate storage or demurrage charges. The issue becomes more complex when cargo requires regulatory treatment before departure. Such activities cannot always be accelerated because they follow technical and safety standards. Therefore, an activity that is necessary for compliance may also become a bottleneck when it is not integrated into the logistics schedule.
Fumigation is one such activity. It is a pest-control treatment applied to certain commodities or packaging to satisfy quarantine and phytosanitary requirements. The source manuscript explains that fumigation involves exposing cargo to an approved fumigant within a controlled, gas-tight environment, followed by monitoring and aeration. Its purpose is not only to eliminate pests but also to provide evidence that the commodity complies with destination-market requirements. The manuscript also places fumigation within the context of international sanitary and phytosanitary measures, national quarantine regulation, and standards such as ISPM 15 for relevant wood packaging [9]-[12]. Thus, fumigation has a dual function: a technical treatment that protects cargo and a compliance mechanism that facilitates market access.

This dual function creates a managerial tension. A fumigation process that is completed correctly and on time can support smooth export clearance and reduce the risk of rejection at destination. Conversely, incomplete documents, unsuitable treatment conditions, equipment problems, adverse weather, limited fumigation space, lack of competent personnel, or sudden vessel-schedule changes can extend the process and create downstream delays. The source study specifically highlights the relationship between fumigation and logistics indicators such as waiting time, treatment duration, documentation time, logistics cost, regulatory compliance, cargo security, and port productivity. These interactions suggest that fumigation should be analyzed not merely as an external technical service but as an integral component of export-logistics management.

Previous studies cited in the thesis address several adjacent issues. Supartini and Fachruli examine export procedures and the role of logistics companies in documentation and transport. Fuadi et al. [13] describe quarantine procedures for agricultural exports and note that fumigation is conducted when required by the destination country. Other studies focus on the commercial side of fumigation services. Rahayu and Lestari [14] analyze service quality and complaint handling in relation to customer satisfaction, while Adiningrum [15] evaluates service quality, price, and promotion in the use of fumigation services. Port and freight-forwarding research, meanwhile, commonly focuses on dwelling time, cargo handling, or general operational performance [7], [8], [16]. What remains less explicitly examined is the operational link between the detailed fumigation sequence and the performance of an export-logistics cycle.

This study addresses that gap by examining fumigation as a critical node connecting compliance, lead time, cost, cargo acceptance, and delivery reliability. The empirical context is PT Prana Argentum Corporation and the export-logistics environment of Tanjung Perak Port, Surabaya. The research has three objectives: to analyze how fumigation procedures influence the completion time of export-logistics activities; to analyze how logistics performance supports the smooth execution of export processes; and to analyze how fumigation contributes to improved logistics performance. The central argument developed from the source evidence is that fumigation does not necessarily reduce logistics efficiency. Rather, its effect depends on whether technical treatment, documentation, resources, and inter-organizational coordination are planned as part of the shipment timeline.

Conceptual Positioning of Fumigation in Export Logistics

The study uses logistics, supply-chain, port-operations, lead-time, logistics-cost, and regulatory-compliance concepts as complementary analytical lenses. Logistics is understood as the planning, execution, and control of goods and information from origin to destination, with the objective of satisfying service requirements at an efficient total cost. Supply-chain thinking adds the need to synchronize material, information, and financial flows across multiple organizations. In the export setting, the port is an interface where these flows converge and where timing errors can have consequences beyond the immediate activity.

Within this framework, fumigation can be positioned between cargo preparation and final port or customs clearance. It consumes processing time and requires resources, but it also reduces biological and compliance risk. The relevant managerial question is therefore not whether fumigation adds time or cost, because any controlled treatment necessarily uses both. The question is whether the required time and cost are predictable, planned, and outweighed by the avoidance of rejection, re-treatment, storage, demurrage, penalties, and reputational damage. This cost-risk-time trade-off is the basis for interpreting the empirical findings.

Table 1. Conceptual lenses used to interpret the role of fumigation in export-logistics performance.

Analytical lens	Core concern	Relevance to fumigation-integrated export logistics
Logistics performance	Time, cost, service reliability, productivity	Treatment must support shipment completion without avoidable delay or cost.
Supply-chain coordination	Synchronization of material and information flows	Exporter, forwarder, transporter, fumigator, port, and quarantine actors must share timely information.
Port operations and lead time	Waiting, handling, documentation, inspection, gate-in and vessel cut-off	Fumigation time must be integrated into the port-bound shipment timeline.
Regulatory compliance	Quarantine and phytosanitary requirements	Treatment and certification protect market access and cargo acceptance.
Risk and total logistics cost	Avoidance of rework, storage, demurrage, penalties and rejection	Effective fumigation can prevent downstream cost even though the treatment itself incurs cost.

2. RESEARCH METHOD

The study adopted a descriptive qualitative design because the research questions focus on how the fumigation process is performed, how operational actors experience its timing and constraints, and how the procedure interacts with logistics performance. The approach is appropriate for examining an operational process that involves technical stages, documents, organizational routines, and coordination among several stakeholders. Rather than testing a causal model statistically, the study seeks to construct an evidence-based explanation of the mechanisms through which fumigation can either support or disrupt export operations.

The research was conducted at PT Prana Argentum Corporation in Surabaya, East Java, with attention to fumigation services connected to cargo moving through Tanjung Perak Port. The data-collection period was February to July 2025. The researcher also had prior field exposure through an internship at the company, which helped provide contextual understanding of the operational setting. In the paper, this field familiarity is treated as contextual knowledge and is complemented by formal observation, interviews, and documentation rather than being used as a substitute for evidence.

Primary data were gathered through direct observation and semi-structured interviews. The interview instrument was organized according to the responsibilities of operational, supervisory, and managerial personnel in both fumigation and logistics. This role-based design allowed the study to compare the technical view of fumigation with the scheduling, cost, documentation, and strategic views of logistics. The evidence represented six key roles: fumigation operational staff, fumigation supervisor, fumigation manager, logistics staff, logistics supervisor, and logistics manager. This structure provided vertical coverage from field execution to managerial policy and horizontal coverage across the two operational functions most relevant to the research problem.

The fumigation interviews addressed the sequence of preparation, sealing, fumigant application, exposure, monitoring, aeration, safety verification, certification, operational constraints, compliance, and improvement needs. The logistics interviews addressed cargo receipt, stuffing, export documentation, shipment-cycle time, fumigation scheduling, port gate-in, performance indicators, cost exposure, vendor coordination, digital systems, and improvement strategies. The source material also contains detailed responses from key fumigation personnel, including operational and supervisory informants, and from logistics personnel responsible for day-to-day control and performance evaluation.

Secondary data were obtained from documents, operational records, company information, and literature used in the thesis. Documentary evidence was important because the research questions involve process sequence and compliance. Documents help verify whether the descriptions obtained from interviews are consistent with the procedural and administrative requirements used in operations. The study therefore did not rely on interview statements alone.

Data analysis used descriptive qualitative procedures. Evidence was first organized according to the research questions and recurring operational themes. The material was then reduced to the most relevant information concerning process sequence, lead time, delay sources, documentation, cost and risk, compliance, performance indicators, and coordination. The organized findings were displayed in narrative and tabular form before conclusions were drawn. The thesis explicitly applies triangulation of data, methods, and theory: interview evidence is compared with observations and documents, and the resulting patterns are interpreted using logistics, fumigation, and related theoretical perspectives.

The analytical unit in this paper is the fumigation-integrated export process rather than an individual employee. Interview responses are therefore used to reconstruct the process and identify converging or diverging operational perspectives. For example, the source material contains a minimum 48-hour estimate for a complete fumigation cycle from the fumigation side, while logistics respondents describe an allocation of approximately 24-48 hours within an overall export cycle of four to five days. Instead of forcing these statements into one number, the analysis treats them as evidence that duration depends on what activities are included, the commodity and fumigant, and the operating conditions. This distinction is important for credible logistics planning.

Table 2. Role-based structure of the qualitative evidence used in the study.

Informant role	Operational focus	Main evidence contribution	Connection to research objective
Fumigation operational staff	Execution and safety	Detailed treatment stages, exposure, aeration, equipment, delay causes	Procedure and lead-time effects
Fumigation supervisor	Quality and compliance control	Verification, timing control, coordination, quality assurance	Efficiency and regulatory performance
Fumigation manager	Policy and external coordination	Regulatory adaptation, technology, strategic service management	Strategic logistics contribution
Logistics staff	Daily cargo flow	Warehouse-to-vessel process, shipment-cycle time, documentation, operational systems	Export-flow integration
Logistics supervisor	Performance and problem solving	KPIs, buffer time, SLA, bottleneck analysis, vendor management	Operational logistics performance
Logistics manager	Cost, risk and competitiveness	Cost-to-export, schedule policy, compliance risk, digital integration	Strategic performance and competitiveness

3. RESULTS AND DISCUSSION

Operational Context of PT Prana Argentum Corporation

PT Prana Argentum Corporation operates in fumigation, gas clearance, inspection, and related cargo-support services. The source manuscript describes the company as serving export-import activities in Surabaya and emphasizes its role in protecting cargo integrity and meeting international requirements. For the present analysis, the important point is that the company is positioned at the boundary between specialized technical treatment and the broader logistics chain. Its work begins before the container enters the final port process and ends only when the treatment, safety verification, and required documentation have been completed.

This positioning creates dependence in both directions. The fumigation team depends on the exporter and logistics side for accurate cargo information, document readiness, container availability, treatment space, and schedule visibility. The logistics side, in turn, depends on the fumigation provider to complete treatment and certification within the shipment window. The evidence repeatedly shows that neither function can optimize performance independently. A technically correct treatment delivered too late can still cause a logistics failure, while a fast logistics schedule that does not allow sufficient treatment time can threaten technical compliance and safety.

Fumigation Procedure as a Multi-Stage Logistics Node

The process reconstructed from observation and interviews consists of four broad phases: preparation, fumigation execution, aeration or gas clearance, and certification. Preparation begins with verification of export documents and cargo information. Documents such as the packing list and other shipping information must be consistent with the commodity, quantity, packaging, and destination requirements. The cargo is identified to determine the appropriate treatment method and fumigant dose, and the potential pest risk is considered in relation to the destination market. A treatment site is then selected and checked for safety, ventilation, and the ability to maintain the required gas-tight condition.

Equipment and materials are also prepared at this stage. The source material lists fumigants such as phosphine-based products and methyl bromide in the operational discussion, alongside protective equipment, gas-detection instruments, sealing materials, and temperature or humidity measurement tools. The logistics implication of this preparation is significant. If the equipment is unavailable, not functioning properly, or not calibrated, the treatment may be delayed or fail. If the treatment area is overloaded, a container may wait before the process even begins. Therefore, capacity planning for fumigation space and equipment is part of export capacity planning.
During execution, the commodity is arranged to support gas circulation, the container or treatment enclosure is sealed, warning signs are installed, and the fumigant is applied according to the required dose. Gas concentration and environmental conditions are monitored during the exposure period. The source material notes that exposure time varies according to fumigant, dose, temperature, and pest target. It also indicates that some treatments can require an exposure period within a broad 24-72 hour range. This technical variability is one reason why a fixed last-minute logistics schedule is risky. Even when a company has standard operating procedures, the actual treatment window must still accommodate the characteristics of the shipment.

After exposure, the process enters aeration or gas clearance. The enclosure is opened under controlled conditions, and gas concentration is monitored until the area is safe. The source study describes gas clearance as a required safety stage, not a discretionary waiting period. Only after safety has been verified can the cargo proceed normally. Certification then records the treatment information and supports the export document package. The certificate contains treatment details and, where applicable, must align with phytosanitary requirements. The sequence shows why the process should be managed as one integrated operational package. Preparation, exposure, aeration, and certification are sequentially dependent, so a delay in an early stage affects all later stages.

Table 3. Fumigation stages and their direct logistics implications.

Stage	Key activities	Potential failure or delay	Logistics consequence
Preparation	Document and cargo verification; site, equipment and fumigant readiness	Incomplete data, unsuitable site, equipment unavailability	Late treatment start and schedule compression
Treatment	Sealing, fumigant application, exposure and monitoring	Leakage, technical failure, unsuitable weather or exposure conditions	Extended treatment or repeat work
Aeration / gas clearance	Controlled opening and residual-gas measurement	Slow gas release, unsafe concentration	Cargo cannot be released to next logistics stage
Certification	Completion and verification of treatment records and certificate	Missing supporting documents or slow verification	Customs/quarantine paperwork and gate-in can be delayed

Lead-Time Structure and the Need for Early Scheduling

The most direct effect of fumigation on logistics performance is its contribution to lead time. The source study reports a minimum complete-process duration of approximately 48 hours from the fumigation side, covering preparation, treatment, aeration, monitoring, documentation, and certification. Logistics personnel describe a typical export cycle of around four to five days, with roughly 24-48 hours allocated to fumigation. These statements are not necessarily contradictory because the interviews refer to different operational scopes. A logistics schedule may refer to the window reserved for the treatment within a broader shipment process, whereas the fumigation side may count the complete technical and administrative sequence.

This difference itself is a managerial finding. When two functions define the same activity with different time boundaries, the risk of schedule mismatch increases. Effective planning therefore requires a common definition of when fumigation starts and when it is considered complete. If the logistics team counts only the gas-exposure period while the fumigator includes document verification, site preparation, aeration, monitoring, and certificate release, the planned buffer may be insufficient. The study supports the use of milestone-based scheduling in which each stage has a target time and clear completion criterion.

The source evidence emphasizes that the fumigation process cannot be accelerated arbitrarily. Technical exposure and safety requirements set minimum conditions that must be satisfied regardless of vessel pressure. This makes schedule discipline more important than emergency acceleration. Respondents repeatedly recommend early scheduling of stuffing and fumigation, planning at the beginning of the week, and completing treatment well before vessel closing time. The thesis specifically describes a 36-48 hour buffer before closing time as a practical safeguard against congestion, equipment problems, extreme weather, vessel delay, port omission, or late trucking. From a logistics perspective, the buffer is not idle time; it is risk capacity. It absorbs uncertainty without forcing the shipment to miss the vessel. The same principle is widely used in resilient supply chains: time buffers reduce the propagation of local disruptions into system-wide failure. In this study, the buffer is particularly important because the treatment has sequential and safety-sensitive stages. Once fumigation has started, a change in vessel schedule or container plan can create re-planning costs that are more difficult to absorb than ordinary administrative delay.

Sources of Delay: Documents, Weather, Capacity, and Schedule Volatility

Document readiness is one of the most consistent delay factors in the study. The fumigation team requires accurate commodity information and supporting export documents before treatment can be properly specified and recorded. Logistics respondents similarly report delays in shipping instructions, invoices, and other documentation as recurring operational constraints. When documents are late, the treatment may start late; when treatment records are incomplete, certification may be delayed. The result is a chain effect on customs or quarantine processing, terminal gate-in, and vessel connection.

Weather is another source of uncertainty. The source study describes heavy rain and strong winds as problematic for treatments using tarpaulin or other sealing arrangements. Temperature and humidity can also affect fumigant behavior and the duration required to achieve effective treatment or safe gas clearance. In this context, weather does not merely influence transport conditions; it can directly influence a technical compliance activity. This broadens the conventional understanding of weather risk in port logistics.

Capacity constraints arise from limited treatment areas, equipment availability, maintenance, competent personnel, trucking, and cargo-handling resources. The fumigation operational interview describes treatment-area overload and crane maintenance as examples that can prevent containers from being positioned on time. Logistics respondents add queueing for heavy equipment, congestion, and transporter dependence. These factors show that treatment capacity and logistics capacity are linked. Adding export volume without expanding the supporting treatment or handling capacity can create a bottleneck even if the shipping line itself has available space.

Schedule volatility is particularly difficult because it originates outside the treatment process but directly affects it. Sudden vessel rescheduling, port omission, late container arrival, or a change in cargo readiness can require the fumigation sequence to be adjusted. Because exposure and gas-clearance stages cannot always be shortened, the operational response must rely on earlier planning, alternative capacity, and rapid communication rather than simple time compression. Respondents therefore stress proactive information sharing among shipper, forwarder, transporter, fumigator, port, and other stakeholders.

Table 4. Main delay sources identified in the qualitative evidence.

Delay source	Observed mechanism	Immediate effect	Recommended control
Incomplete or late documents	Treatment or certificate cannot be initiated/verified	Late fumigation and late clearance	Pre-document checklist and cut-off for document completion
Weather and environmental conditions	Sealing, exposure or aeration becomes difficult	Longer treatment or safety verification	Weather-aware scheduling and contingency time
Treatment-space/equipment constraints	Containers wait for area, tools, crane or competent staff	Queueing before treatment	Capacity planning, maintenance and vendor alternatives
Transport/port congestion	Late arrival at depot/TPS or slow handling	Compressed remaining schedule	Earlier dispatch and shared schedule visibility
Vessel schedule changes	Treatment plan no longer matches cut-off	Rescheduling and possible missed vessel	Flexible booking, buffer time and escalation protocol
Weak coordination	Different actors work with incomplete or delayed information	Cumulative delay across stages	Integrated communication, daily coordination and SLA

The Role of Logistics Performance in Export Continuity

The logistics interviews show that smooth export execution depends on a sequence beginning with cargo receipt and document checking at the warehouse. Goods are inspected, prepared, packed, and stuffed into containers. Where fumigation is required, the treatment is performed before the container is finally sealed and moved toward the port. After treatment and certificate readiness, the container is scheduled for transport to Tanjung Perak, entered into the terminal system, and prepared for vessel loading. The source study reports that this overall cycle typically takes around four to five days in the observed context.

Performance is evaluated through both operational and managerial indicators. Logistics staff emphasize on-time delivery, absence of document-related rejection, low demurrage or storage cost, and minimal complaints from buyers or shipping lines. Supervisory personnel refer to on-time shipment rate, average logistics cycle time, number of deviations, document accuracy, and additional costs. At the managerial level, cost-to-export ratio, actual versus target delivery time, gate-in success relative to vessel schedule, customer complaints, and adaptability to regulatory change are also considered. Together, these indicators provide a broader picture of performance than any single measure.

The importance of documentation appears throughout these indicators. A shipment may be physically ready but still fail operationally if documents are incomplete. Conversely, correct documentation can accelerate the handover between fumigation, quarantine, customs, terminal, and shipping processes. In this sense, document quality is a logistics capability. It reduces uncertainty, shortens waiting, and enables downstream actors to make decisions without repeated clarification. This finding is consistent with the source literature on freight forwarding, in which document handling is a central service function [16].

The study also demonstrates that logistics performance has a reputational dimension. Buyers and shipping lines evaluate reliability through the consistency of delivery, cargo quality, and documentation. Repeated delays or rejection can therefore affect future business relationships even if the immediate financial loss is limited. This explains why interviewees connect fumigation compliance and logistics discipline with buyer trust. In B2B export operations, trust is partly built through predictable execution.

Fumigation as a Compliance and Market-Access Mechanism

The source manuscript treats fumigation as a prerequisite for compliance when the commodity or destination market requires phytosanitary treatment. This is a crucial distinction because the economic value of the process is not limited to the treatment itself. It also lies in enabling the cargo to continue through the export chain. A technically successful fumigation that is properly documented reduces the probability that cargo will be rejected, quarantined again, or required to undergo additional treatment after arrival.

The role of phytosanitary requirements is supported by the literature cited in the thesis. Muslimah and Latifah [10] discuss the relationship between international trade and environmental protection under the WTO framework. Nugroho et al. [11] examine the influence of food-safety standards on exports, while Kapoh [12] discusses Indonesia's quarantine framework for animal, fish, and plant products. Fuadi et al. [13] show that agricultural export processes can include fumigation when required by destination-country conditions. Together, these studies support the argument that compliance requirements are part of the logistics environment rather than external to it.

The practical implication is that regulatory knowledge must be embedded in operational planning. Destination requirements can influence the choice of treatment, documentation, and timing. A logistics plan that ignores those requirements may appear efficient at the warehouse stage but fail later during inspection or clearance. The manager's task is therefore to convert regulatory requirements into operational milestones before the cargo reaches the critical port window.

Risk Mitigation and Total Logistics Cost

Fumigation adds a direct service cost, but the study indicates that its larger financial significance lies in the costs it can prevent. Failure or non-compliance may lead to cargo rejection, re-treatment, return shipment, penalties, product deterioration, additional storage, and demurrage. These are classic examples of total-logistics-cost trade-offs: minimizing the cost or time of one activity without considering downstream risk can increase total cost. Respondents therefore evaluate fumigation performance in relation to avoidance of unplanned cost. If a treatment is completed on time and the certificate is accepted, the container can proceed without avoidable interruption. If the process is late, the company may face extra storage or miss the vessel. If the treatment is technically inadequate, the potential cost is even greater because the failure may only become visible at destination. The cost-control role of fumigation is thus preventive rather than merely transactional.

This perspective also explains the value of multiple verified vendors and contractual SLAs. A single-vendor dependency may reduce flexibility during a volume surge or operational disruption. Diversification can increase administrative complexity, but it also creates capacity resilience. Similarly, an SLA that specifies response time, treatment timing, documentation, escalation, and quality expectations converts informal coordination into a measurable service arrangement. The source interviews explicitly recommend both approaches.

Coordination, Service-Level Agreements, and Operational Governance

Coordination is the recurring mechanism linking all other findings. The fumigation process requires information from the logistics side, while logistics needs confirmation of treatment status and certificate readiness. The study reports the use of shared weekly schedules, operational communication groups, email, daily coordination, and escalation to management. Supervisory respondents also recommend SLAs with fumigation providers to define treatment and certificate targets. These mechanisms are valuable because they reduce ambiguity about responsibility and timing. A useful governance principle emerging from the study is that exceptions should be made visible early. If a document is missing, if the container is late, if the treatment area is full, or if the vessel schedule changes, the relevant actors need immediate notification. Waiting until the original cut-off is no longer achievable converts a manageable deviation into a shipment failure. Consequently, operational governance should combine routine planning with explicit exception-management rules.

The source evidence also suggests that coordination quality depends on standardization. Common checklists, standardized documentation requirements, agreed definitions of treatment start and completion, and shared escalation procedures can reduce variation across shipments. Training is therefore not limited to fumigator technical competence. Logistics staff also need sufficient knowledge of treatment requirements, and fumigation staff need visibility into shipping deadlines. Cross-functional understanding reduces the risk that one team optimizes its own activity at the expense of the total process.

Digital Integration and Information Visibility

Digital systems appear in the interviews as enablers of coordination. Logistics personnel report the use of internal software, ERP-based information, spreadsheets, and electronic connections with port systems to monitor cargo status and shipment schedules. The fumigation side also describes the development or use of digital access and reporting mechanisms. The common recommendation is deeper integration so that treatment requests, progress, completion status, certificate readiness, and shipping deadlines can be observed by the relevant actors in near real time.

The benefit of integration is not automation for its own sake. Its value lies in reducing information latency and human error. When all parties work from the same shipment status, the logistics team can adjust trucking or port timing, the fumigation team can prioritize workloads, and management can intervene when a milestone is at risk. Digital visibility can also provide historical data for evaluating vendor performance, recurrent bottlenecks, treatment duration, and the relationship between fumigation events and logistics cost.

However, the findings caution against a purely technological interpretation. Digital monitoring cannot solve limited treatment space, insufficient equipment, lack of competent personnel, extreme weather, or unrealistic schedules. Technology is therefore one component of a broader capability that includes resources, SOPs, training, vendor governance, and contingency planning. This finding is consistent with the port-technology literature cited in the thesis, which treats technology as an enabler of operational efficiency rather than a substitute for management [7].

Table 5. Logistics performance indicators and their relationship with fumigation.

Performance dimension	Indicator found in the study	Fumigation linkage	Managerial use
Time	On-time shipment; actual vs target cycle time; gate-in against vessel schedule	Treatment and certificate completion affect remaining shipment window	Detect schedule risk and define buffer
Cost	Cost-to-export; demurrage; storage; penalties	Delay or re-treatment creates additional cost	Evaluate total cost, not only fumigation fee
Quality/compliance	Document accuracy; rejection events; treatment conformity	Fumigation protects phytosanitary acceptance	Monitor compliance and vendor quality

Performance dimension	Indicator found in the study	Fumigation linkage	Managerial use
Reliability	Number of deviations and re-scheduling events	Weather, capacity and coordination create exceptions	Prioritize recurring bottlenecks
Customer outcome	Buyer/shipping-line complaints and confidence	Consistent treatment and delivery reinforce reliability	Link operations to service reputation

Managerial Framework for Fumigation-Integrated Export Logistics

Synthesizing the evidence produces five managerial principles. First, plan early. Fumigation should appear in the shipment timeline at the same time as stuffing, trucking, document preparation, and port cut-off. Second, protect compliance. Commodity information, treatment requirements, and supporting documents should be checked before treatment begins. Third, build time resilience. A buffer should be maintained between treatment completion and vessel closing time so that external disruptions can be absorbed. Fourth, control capacity and service quality through trained personnel, functioning equipment, verified vendors, and SLAs. Fifth, integrate information so that all parties can see the status of cargo, treatment, documents, and schedule milestones.

These principles change the managerial meaning of fumigation. Under a reactive model, fumigation is requested when the container is nearly ready to depart, and any problem becomes an emergency. Under an integrated model, fumigation is treated as a planned node with defined inputs, processing time, output documents, capacity requirements, and escalation rules. The integrated model is more consistent with the source study's conclusion that efficiency results from the synergy of technical management, resource readiness, and coordinated communication.

Table 6. Proposed managerial framework derived from the qualitative findings.

Principle	Operational action	Primary risk addressed	Expected effect
Early scheduling	Plan stuffing and fumigation together; reserve treatment capacity	Late treatment start	Higher probability of meeting vessel cut-off
Compliance readiness	Complete documents and confirm destination requirements before treatment	Certification delay and rejection	Faster release and lower rework risk
Time resilience	Maintain 36-48 hour buffer where operationally feasible	Weather, congestion, equipment or vessel changes	Reduced propagation of disruptions
Capacity and SLA control	Maintain equipment, train personnel, diversify verified vendors and set service targets	Overload, equipment failure, response delay	More predictable capacity and quality
Integrated information	Track cargo, treatment and certificate status in shared digital workflow	Information gaps and late escalation	Faster decisions and lower human error

Discussion in Relation to Previous Studies

The findings extend the previous research summarized in the thesis in several ways. Export-procedure studies show that freight forwarders and logistics companies are important in document handling and transportation, but the present study demonstrates how a specialized treatment provider becomes part of the same operational chain. The fumigation provider cannot be considered an isolated vendor because its work determines when the container becomes technically and administratively ready for the next stage.

The findings also complement the fumigation-service literature. Rahayu and Lestari [14] and Adiningrum [15] focus on service quality, customer satisfaction, price, and service-choice factors. Those dimensions remain important, but the present study identifies an additional B2B operational value: the ability to protect the shipment schedule and reduce downstream compliance risk. Service quality in this context therefore includes not only responsiveness and customer handling but also treatment reliability, schedule adherence, certificate readiness, and coordination with the logistics chain.

Port-performance research cited in the thesis emphasizes infrastructure, equipment, technology, and management as determinants of efficiency [7], [8]. The source evidence supports these factors but shows that specialized compliance activities create additional dependencies. A container terminal may have adequate infrastructure, yet the shipment can still be delayed because treatment space is unavailable, documents are incomplete, or the fumigation window was not included in the schedule. Therefore, performance analysis should extend beyond the terminal boundary to include pre-gate compliance processes that influence cargo readiness. Finally, the study provides a practical interpretation of total logistics cost. A company may attempt to minimize fumigation expense or reserve the service as late as possible, but such local optimization can increase the probability of missing a vessel or facing destination rejection. The more appropriate objective is to minimize the combined cost of treatment, time, delay risk, and compliance failure. This interpretation is consistent with the source manuscript's emphasis on time, cost, compliance, cargo security, and port productivity as interrelated logistics indicators.

Practical Implications

For fumigation companies, the main implication is the need to manage service capacity as part of the customer's logistics timeline. This includes predictable booking procedures, equipment maintenance, competent fumigators, clear treatment milestones, fast documentation, and proactive notification when deviations occur. Operational performance should be measured not only by successful pest treatment but also by turnaround time and schedule reliability. For exporters and freight forwarders, fumigation requirements should be confirmed before cargo is fully packed or the final vessel window is selected. Documents and commodity data should be ready early, and the shipping plan should contain an explicit treatment and certification buffer. Exporters should also maintain alternative arrangements for periods of high volume or capacity constraint, especially when the cargo is time-sensitive.
For port and regulatory stakeholders, the study suggests value in improving information interoperability and simplifying the handover of treatment documentation. The objective is not to reduce control, but to reduce avoidable waiting caused by repeated data entry, unclear status, or inconsistent information. Where possible, shared digital visibility between treatment providers, logistics companies, and relevant authorities can support faster exception management.

At the managerial level, the most important recommendation is to evaluate fumigation through integrated KPIs. A shipment-level dashboard could combine planned and actual treatment start, treatment completion, certificate release, gate-in, vessel cut-off, extra storage cost, and reason for delay. Such data would allow management to identify whether recurring problems originate from documents, vendor capacity, weather, equipment, transporter performance, or schedule design.

OPERATIONAL INTEGRATION ACROSS THE EXPORT CYCLE

A closer reading of the interview evidence shows that the export process can be understood as a chain of operational handovers. The first handover occurs when the cargo moves from warehouse preparation into stuffing and treatment readiness. The second occurs when the fumigation team accepts the container and supporting information. The third occurs after treatment, when gas clearance and documentation determine whether the cargo can return to the logistics flow. The final handovers involve transport to the port, terminal gate-in, and vessel loading. Each handover requires a specific combination of physical readiness and information readiness. A container that is physically available but lacks complete documents is not operationally ready, just as a complete document package cannot compensate for a container that has not completed the required treatment.

This handover perspective helps explain why coordination problems produce cumulative rather than isolated delay. For example, a late shipping instruction may postpone fumigation preparation. A late treatment start then reduces the remaining buffer before gate-in. If the port or transporter also experiences congestion, the shipment may lose the vessel even though none of the individual delays appears severe when viewed separately. The source study therefore supports an end-to-end interpretation of export performance. Managers should measure the elapsed time between milestones and the waiting time at each handover, because waiting frequently reveals coordination failure more clearly than treatment duration itself.

The evidence also suggests that the export cycle contains two types of time. The first is value-adding or compliance-required processing time, such as cargo preparation, stuffing, fumigation exposure, aeration, and formal verification. The second is avoidable waiting caused by missing information, unavailable equipment, queueing, re-scheduling, or delayed decisions. The objective of process improvement should not be to remove technically required time. Instead, it should reduce avoidable waiting and protect the required processing window. This distinction is important because pressure to shorten the wrong activity can create safety or compliance risk while leaving the actual source of inefficiency unchanged.

In operational terms, the study supports milestone control from cargo readiness to vessel departure. A practical control sequence would include: document readiness, container readiness, treatment booking, treatment start, exposure completion, gas clearance, certificate readiness, dispatch to port, gate-in, and vessel cut-off. Each milestone can be assigned a planned time, an actual time, a responsible actor, and an escalation threshold. Such a structure would make the fumigation process visible within the same performance system used by logistics personnel. It would also make it easier to distinguish whether a late shipment resulted from the treatment itself or from an upstream or downstream delay.

Table 7. Suggested milestone control for integrating fumigation into the export shipment cycle.

Milestone	Readiness evidence	Main owner/interface	Escalation trigger
Cargo/document ready	Commodity details and supporting export documents complete	Exporter / logistics	Missing data near planned treatment slot
Treatment booked	Confirmed time, site, equipment and fumigator availability	Logistics / fumigation provider	Capacity unavailable or booking not confirmed
Treatment completed	Exposure and monitoring requirements satisfied	Fumigation team	Technical deviation or completion beyond target
Gas clearance/certificate ready	Safe gas level and complete treatment record	Fumigation / quarantine interface	Certificate not ready within shipment buffer
Port gate-in	Container dispatched and accepted before cut-off	Transporter / terminal	Traffic, queue or terminal delay threatens vessel connection

RESEARCH CONTRIBUTION

The main contribution of the study is the operational reframing of fumigation. The source thesis begins from the practical question of whether fumigation supports or constrains logistics performance. The combined evidence suggests that the answer depends on process integration. Fumigation is beneficial when the required inputs are ready, the treatment window is protected, and the output certificate reaches the next process on time. It becomes a bottleneck when those conditions are absent. This conditional interpretation is more useful for management than describing fumigation simply as either a cost or a regulatory burden.

A second contribution is the identification of coordination as the mechanism connecting technical compliance with logistics outcomes. Existing literature in the source document discusses logistics performance, port efficiency, quarantine, and fumigation service quality separately [5]-[8], [12]-[16]. The present analysis brings these elements together by showing how a compliance activity changes lead time, cost exposure, reliability, and buyer confidence through the quality of inter-organizational coordination. The result is an applied framework that can be used for process improvement even without a complex statistical model.

A third contribution is the distinction between treatment time and avoidable delay. The technical process requires exposure, monitoring, aeration, and safety verification. Those activities should not be interpreted automatically as inefficiency. Inefficiency arises when the required time is not anticipated, when inputs are incomplete, or when the handover to the next logistics stage is delayed. This distinction can improve performance evaluation because it prevents managers from setting unrealistic targets that conflict with treatment quality or safety. It also directs improvement efforts toward documents, capacity, information flow, and schedule design, which are the recurring sources of avoidable delay in the source evidence.

Study Limitations and Future Research

The study has several limitations that should be considered when interpreting the findings. First, the empirical setting is one company and one port environment. The findings describe the mechanisms observed in that context and should not automatically be generalized to all commodities, ports, or fumigation providers. Second, the research is qualitative. The reported duration and performance figures are operational descriptions from the study context rather than statistical estimates for a broader population. Third, different informants use different time boundaries when discussing fumigation duration, highlighting the need for more standardized process measurement.

Future research can address these limitations by collecting shipment-level timestamps across multiple companies and ports. Quantitative studies could test the effect of fumigation-related variables on total export lead time, demurrage, missed-vessel frequency, or rejection risk. Comparative research could examine differences by commodity, destination country, fumigant, season, and port. Another useful direction would be to evaluate the

economic value of digital integration by comparing logistics performance before and after implementation of shared treatment and documentation tracking.

4. CONCLUSION

This study shows that fumigation is a critical operational node in export logistics at Tanjung Perak Port. Its effect on logistics performance arises because treatment is both a technical requirement and a time-sensitive process. Preparation, application, monitoring, aeration, safety verification, and certification form a sequential chain that must be completed before the shipment can proceed normally. The source evidence indicates that the process can require approximately 24-48 hours or a minimum complete-cycle window of around 48 hours depending on how duration is defined and on operational conditions. This time requirement must therefore be planned rather than treated as an emergency activity. Fumigation contributes positively to logistics performance when it is integrated with shipment planning. Its benefits include supporting compliance and market access, reducing the risk of cargo rejection or re-treatment, improving documentation readiness, protecting the vessel schedule, limiting additional storage or demurrage exposure, and strengthening buyer confidence. The principal risks are incomplete documents, schedule volatility, weather, treatment-space or equipment constraints, congestion, and weak coordination among logistics and fumigation actors. The study concludes that effective fumigation-integrated logistics requires five managerial practices: early scheduling, compliance readiness, sufficient time buffer, capacity and SLA control, and integrated information visibility. These practices shift fumigation from a stand-alone technical service to a managed component of the export supply chain. In practical terms, the objective is not to eliminate the time required for fumigation, but to make that time predictable, compliant, and synchronized with the broader logistics process.

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