Applying the Prevention through Design (PtD) Framework to Develop a Decision-Matrix for Emerging and Re-emerging Infectious Diseases (EIDs) Preparedness in Maritime Ports

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Abstract

Background: Ports are critical gateways for the movement of people and goods and have a dual role in preventing the import and export of infectious diseases as mandated by the International Health Regulations (2005). Lessons from the COVID-19 pandemic underscored the need for actionable, rapid decision support in port operations.

Objective: To develop a theoretical decision-making matrix for EIDs preparedness for Lembar Port, Lombok, Indonesia, adapting the National Institute for Occupational Safety and Health (NIOSH) Prevention through Design (PtD) framework.

Methods: We adapted the PtD framework from general workplace safety to preparedness against infectious diseases in the port context. Two key epidemiological variables: basic reproduction number (R_o) and case fatality rate (CFR), served as the basis for risk grading. We took four operational steps: (1) initiating early-phase risk reduction actions guided by transmission mode; (2) grading risk using two epidemiological drivers; (3) constructing a decision-making matrix aligning the hierarchy of controls (elimination, substitution, engineering, administrative, and PPE) to risk categories; and (4) engaging key stakeholders to assign shared responsibilities and validate feasibility. A stakeholder consultation was conducted in October 2024 involving the Harbormaster's Office and Port Authority, the Health Quarantine Agency, the Fish/Animal/Plant Quarantine Agency, and port operators (PT Pelindo, PT ASDP).

Results: A decision matrix was developed to guide port authorities on prohibiting, limiting, or modifying activities based on dynamic risk levels. We produced: (i) a set of early-phase risk-reduction actions mapped to six transmission modes (airborne, droplet, fecal-oral, water-borne, vector-borne, and zoonotic); (ii) a three-tier risk-grading instrument using R_o and CFR with illustrative diseases; (iii) a decision-making matrix translating risk categories to specific control measures and port activities (*e.g.*, docking prohibition, passenger flow modification, isolation capacity, paperless processes); and (iv) a task-sharing scheme across stakeholders. The approach emphasizes operational feasibility and rapid implementation

Conclusion: A theoretical decision-making matrix provides a structured and actionable preparedness plan for EIDs in port settings. Conducting a simulation exercise with stakeholders is essential to test, refine, and validate the matrix.

Keywords: *Emerging and re-emerging infectious diseases, ports, hierarchy of controls, preparedness plan, port health, prevention through design.*

INTRODUCTION

The Diamond Princess cruise ship was one of the earliest epicenters of COVID-19 outside mainland China, where a single infected passenger triggered rapid onboard transmission, resulting in the quarantine of thousands of passengers and crew. The early efforts to control the spread were obstructed by limited understanding of the disease characteristics. Ports, as critical gateways, have a dual role in controlling both import and export of infectious diseases under the International Health Regulations (IHR) 2005 [1]. This involves the regulation of the movement of goods and people in the event of a public health emergency [2-6]

As maritime nation, Indonesia has prioritized maritime connectivity, so-called the Sea Toll program [7]. The Port of Lembar, located on Lombok Island, still faces operational gaps and lacks structural decision-making tools, causing delays in the face of health crises.

The National Institute for Occupational Safety and Health developed a tool to minimize occupational hazard in workplace, which can be tailored to specific facilities: Prevention through Design (PtD) framework [8, 9]. Although NIOSH PtD framework is intended for general hazard reduction, its application to the development of preparedness plans for emerging and re-emerging

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infectious diseases in port environment has not yet been explored.

This research aims to propose an operational decision-making matrix for EIDs preparedness, linking epidemiological risk levels to Port-level control measures using the Prevention through Design (PtD) framework.

METHODS

We adopted the NIOSH PtD framework [8] to the operational context of the maritime port. The general characteristic of Emerging and Re-emerging Infectious Diseases (EIDs), a broad-range of the Port activities were integrated and blended into the workflow and control strategies of PtD framework, that produced immediate operational tools for stakeholders/ personnel to mitigate risk [9]. This methodological approach follows the traditional hierarchy of controls, from the hazard elimination and substitution, goes to risk minimization measures: developing engineering controls, administrative control and deciding what, when and how to use personal protective equipment (PPE). The study was conducted from May to December 2024. Ethical approval was obtained from the Ethical Committee of the Faculty of Medicine and Health Science, Mataram University, Indonesia, Ref: 077/UN18.F8/ETIK/2024, dated June 5, 2024.

Operational Steps

To modify the PtD framework to align with the development of an EIDs preparedness plan specific to port environment, several contextual changes were applied. First, we developed a set of risk reduction strategies in the beginning of an outbreak, grouped by six transmission modes. Second, we constructed a risk grading instrument, utilizing two epidemiological drivers (basic reproductive number and case fatality rate) to classify risk into low, moderate and high. The risk grading was based on a literature review, emphasizing how the disease could potentially become an outbreak. Third, a decision-making matrix was developed to pair NIOSH PtD with risk level and specific activities in a port environment. This step involved a literature review and critical thinking to shift from occupational hazard to infectious disease risks. Fourth, a stakeholder discussion was held to attribute the responsibilities and validate the feasibility of the matrix through a small-group discussion.

Stakeholder Engagement

A small-group discussion was conducted in October 2024 at the Health Quarantine Agency building (Labulia, Lombok), attended by representatives from the Harbormaster's Office and Port Authority, the Health Quarantine Agency, the Fish/Animal/ Plant Quarantine Agency, and the Port Operators (PT. Pelindo and PT. ASDP). Open questions were generated based on a newly developed decision-making matrix. The discussion served to identify roles and secured commitment to collaborate on preparedness planning.

RESULTS

Situation Analysis

Lembar Port lies on the west coast of Lombok Island, facing Padang Bai Port (Bali Island). Two port operators are: PT. ASDP (ferry service) and PT. Pelindo III (cargo and ocean-going passenger services). The port is overseen by a Class I Harbourmaster's Office and Port Authority. In 2019, a new facility, Gili Mas Port, expanded capacity with a 440-meter-long, 26-meter-wide dock and a terminal for up to 1,500 passengers, making it the busiest port in West Nusa Tenggara Province.

Initiate Early-Phase Risk Reduction Actions

In the earliest phase of a potential EIDs event, clusters of travellers and ship's crew of the same ship with flu-like symptoms (*i.e* fever, upper respiratory symptoms, myalgia/arthralgia, rash, gastrointestinal symptoms, restlessness) should trigger immediate consideration of transmission mode [10, 11]. Understanding the mode of transmission should inform infection control and immediate control choices (PPE selection, donning/ doffing, waste handling) and enables immediate measures to limit spread. Notably, transmission modes can evolve from zoonotic to sustained human-to-human transmission, as exemplified by the progression of COVID-19 [12,13].

Table **1** describe how risk-reduction actions are implemented based on transmission modes. Contributing risk in port, including crowded terminals, poor ventilation, inadequate sanitation, and improper food handling, are addressed on a case-by-case basis. In Table **1**, we mapped early actions to six modes: Airborne & droplet: decongest waiting areas; improve ventilation; enhance environmental cleaning; distribute masks; ensure hand sanitizers; implement paperless check-in. Fecal-oral & water-borne: strengthen sanitation and toilet cleaning; enforce food-handler hand hygiene; ensure water-tank

Table 1: Early-phase risk-reduction actions by transmission mode. Finding the mode of transmission, is crucial for taking risk reduction action in Port. PPE=personal protective equipment.

Transmission mode (disease example)	Contributing risk in port and ship	Risk reduction action
Airborne [14] (Tuberculosis, measles, influenza)	Crowded passenger Poor ventilation of waiting room Longer duration of stay in crowded room No passenger selection (health screening) Touching frequently touch surface No PPE use	Provide large waiting room Paperless check in Increase ventilation Environmental cleaning Distribute face-mask Provide hand sanitizer
Droplet [14] (COVID-19, meningococcal meningitis)	Same as airborne Close contact	Prevent close contact
Fecal – oral [15] (Cholera, Norovirus, Hepatitis A)	Water contaminated with fecal material Poor hand hygiene of food handler in port and ship	Regularly toilet cleaning Hand wash timely especially for food handler

Transmission mode (disease example)	Contributing risk in port and ship	Risk reduction action
Water-borne [16] (Salmonellosis, Norovirus, Rotavirus, E. coli, Cryptosporidium sp, Giardia lamblia)	Contaminated water tank in port and ship, during maintenance and repair Poor design water container Back siphonage of water Insufficient residual disinfectant	Water tank cleaning regularly Water pump cleaning
Vector-borne [17] (Malaria, Dengue, Zika, Chikungunya)	Room with open ventilation in an endemic port Sleep without mosquito repellent or net Poor environmental cleaning	Filtered/ netted room ventilation
Zoonotic [18, 19] (Rabies, Nipah, Avian influenza)	Cross-island livestock Transport of storage-leakage frozen food	Special ship for livestock

cleaning, pump maintenance, and residual disinfectant. Vector-borne: net/filtered room ventilation in endemic settings; environmental cleaning; repellents or nets for overnight stays. Zoonotic: safe handling of livestock and cold-chain animal products; dedicated livestock vessels when applicable. Each mode is linked to environmental characteristics or the port's occupant behaviour.

Categorized and Grade Risks Based on Epidemiological Drivers

SARS-CoV-2 transmission in the household and community close to the epidemiological driver is the basic reproduction number (R_o). Knock *et al.* (2021) discovered that by the implementation of national lockdown, R_o fell below 1, and the case fatality rate decreased from 1.00% to 0.79% indicating improvement of care [20].

Another study compared the basic reproduction number (R_o) among SARS-CoV-2 strains: Alpha 3.0%, Delta 2.1%, wildtype 1.2%, and Omicron 0.7% [21]. These differences show that in one episode of EIDs, the case fatality rate dynamically changes, especially with a long-circulating pathogen in the community.

Risk metrics are the combination of probability and the magnitude/severity of consequences [22], and in infectious diseases, the available epidemiological drivers are transmission rate and case fatality rate.

Transmission Rate/ Basic Reproduction Number (R_o) and The Case Fatality Rate (CFR)

The transmission rate is quantified by the number of people that can be infected by single infected person. $R_o>1$ means an outbreak continues and ends if $R_o<1$ [23]. In EIDs, the risk is stratified into three categories: low transmissibility ($R_o<1.5$; limited outbreak potential); moderate transmissibility (R_o 1.5-3.0; higher chance of significant spread); and high transmissibility ($R_o>3$; potential for a public health emergency of international concern or pandemic). The value of R_o could be affected by multifactorial: reservoir, mode of transmission, length of time asymptomatic infectivity, number of susceptibility people and medical intervention. The calculated R_o of an infectious disease in the past does not reflect the R_o of the same disease today [23-25].

Table 2: Risk grading using R_o and CFR (traffic-light categorization). Example of diseases is also mentioned. CFR=case fatality rate; Low CFR=mild symptom; Moderate CFR= moderate symptom or causing long-term sequelae; High CFR= severe symptoms or systemic effect; R_o=basic reproduction number /transmission rate. Red color=highest risk; yellow color=moderate risk; green color=low risk. N/A=not applicable.

-	$R_o<1.5$	R_o 1.5-3.0	$R_o>3.0$
Low CFR	Hantavirus [30] Seasonal influenzae [31]	Norovirus [32]	Measles [33]
Moderate CFR	MERS-CoV [34]	Ebola [35] SARS-CoV-1 [36] SARS-CoV-2 [36]	Monkeypox 2022 outbreak [37] SARS-CoV-2 [36]
High CFR	H5N1 Avian Influenza [38]	Marburg virus [39] Some Ebola strains [32]	N/A

The case fatality rate is an important epidemiological driver in the prevention and control of infectious disease transmission. Stricter isolation and close monitoring of the infected person needs to be implemented for a higher CFR. A higher CFR reflects increased morbidity and mortality, often demanding higher health care facilities, prolonged hospital stays, extended antibiotic therapy. In the context of EIDs, a high CFR can significantly disrupt containment and deluge healthcare systems [26].

A practical tool for risk grading is presented in Table **2**, using a three-color traffic-light system: red for high risk, yellow for moderate risk, and green for low risk, a format widely recognized for visual risk communication. The "R_o < 1.5" category is scored as 1, "R_o 1.5-3.0" as 2, and "R_o > 3.0" as 3. Similarly, a low case fatality rate (CFR) is scored as 1, a moderate CFR as 2, and a high CFR as 3.

The overall risk score is calculated by multiplying the R_o score by the CFR score, producing a graded scale:

- High risk (red): score 6-9
- Moderate risk (yellow): score 3-4
- Low risk (green): score 1-2

This method follows approaches used in previous studies [27-29]. The placement of each selected disease in the appropriate category was based on published references, beginning with a review of reported R_o values and then an analysis of the case fatality rate data.

The simplified risk model prioritizing R_o and CFR was adopted because these two parameters are consistently stable and universally reported in early emerging infectious disease events. Other parameters, such as the incubation period, asymptomatic transmission rate, and healthcare capacity, often vary widely, are setting-dependent, are rarely available in real time, and have limited operational utility for rapid decision-making during early EIDs detection [12, 24]. WHO emphasizes that ports and points of entry require rapid operational tools

Table 3: Translation of PtD framework and EID operational definition into Port activities.

Hierarchy of control [37]	Operational definition on Infectious diseases and risk level [39]	Translation in Port activities
Elimination [physically remove the hazard]	Prevent pathogen to infect health people High-risk of EIDs is applied	prohibit docking of ships from high-risk areas; restrict access to screened personnel and passengers only; automate off-loading to prevent person-to-person contact; secure infectious-waste handling.
Substitution [replace the hazard]	Health care worker taking care of sick person with minimal contact – non contact High-risk of EIDs is applied	transition from paper to paperless processes; deploy robotics where feasible; implement containment and quarantine procedures as appropriate.
Engineering control [isolate people from hazard]	Treatment room modification that inhibits pathogen spread fit to mode of transmission Moderate risk of EIDs is applied	install physical barriers at counters; increase mechanical/natural ventilation; provide isolation rooms; add touchless hand-washing stations; reduce passenger capacity.
Administrative control [change the way people work]	Implement standard procedures in screening, diagnosis and treatment of the patient Low risk of EIDs is applied	shorten contact time *via* scheduling; conduct training; establish screening criteria and officer medical checks; temperature checks; restrict access to certain areas; signage for distancing; modify flows; define PPE selection and donning/doffing procedures; apply restrictions for susceptible staff; enhance environmental cleaning/sanitation; tighten passenger data collection and pre-departure requirements.
PPE [protect the worker with personal protective equipment]	Select appropriate PPE based on the transmission mode High, medium and low risk of EIDs is applied	PPE supply chain; distinct-able uniform; life-vest and helmet; personal hand sanitizer

based on readily available epidemiologic parameters rather than complex parameters [4, 11].

Decision-Making Matrix Aligned to PtD and Port Needs

The NIOSH hierarchy of controls comprises five levels: elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE) [40]. As a foundation for determining actions and policies at the maritime port, this matrix requires mapping Port activities to the corresponding control levels. Two main steps were undertaken in formulating this decision-making matrix.

First, it was necessary to assess whether all control levels were applicable in the Port setting. According to Gambatese (2019), not all levels in the hierarchy can be generally applied across all workplaces [41]. In particular, the top two levels, elimination and substitution, are considered highly effective but costly. From the literature review, it was found that within the context of infectious diseases, “elimination” has two interpretations: (1) the complete eradication of a pathogen from an infected individual, and (2) the strategy in interrupting disease transmission in a certain area, like the Port or vessel [42]. Given that Ports serve as points of arrival and departure for travellers, the second definition is more relevant. Therefore, all five control levels were considered applicable in this context.

Second, the PtD framework was translated into corresponding infectious disease control levels, then the Port activities were fitted to those control levels (**Table 3**).

The highest level of pathogen risk is operationally defined as a situation in which a minimal infective dose is sufficient to cause severe disease [43, 44]. During an outbreak, this risk is further escalated when effective treatment is not yet available, and the mode of transmission remains unknown during the emergence of new infectious diseases. Under these circumstances, the highest control level needs to be implemented to prevent pathogen entry at the port. Elimination and substitution are the most effective control strategies for reducing exposure to high-risk pathogens. The port activities described above illustrate how direct contact with people or goods arriving from abroad (as shown in Table **3**) can be either eliminated (elimination) or minimised (substitution).

Cost considerations strongly influence the choice between elimination and substitution at the port level, as these two top-tier measures are typically associated with high operational impact. The high-risk classifications in Table **4** align with Step 3 of the Strategic Toolkit for Assessing Risk [28], which characterizes high-risk events by greater severity, stronger penetration into vulnerable populations, and limited coping capacity in

Table 4: Decision-making matrix; hierarchy of controls x representative port activities. Colors determined based on risk category (**Table 2**). Red color=high risk; yellow color=moderate risk; green color=low risk.

Control level	Port activities	High risk	Moderate risk	Low risk
Elimination	Prohibit docking of ships from high-risk areas			
	restrict access to screened personnel and passengers only			
	automate off-loading to prevent person-to-person contact			
	secure infectious-waste handling			
Substitution	Transition from paper to paperless processes			
	Deploy robotic where feasible			
	Implement containment and quarantine procedures as appropriate			

Control level	Port activities	High risk	Moderate risk	Low risk
Engineering control	Install physical barrier at counters			
	Increase mechanical/ natural ventilation			
	Provide isolation rooms			
	Add touchless hand-washing stations			
	Reduce passenger capacity			
Administrative control	shorten contact time *via* scheduling			
	Conduct training on infectious diseases protocols			
	establish screening criteria			
	Officer medical checks			
	Temperature checks			
	restrict access to certain areas			
	Signage for distancing *etc.*			
	Modify (passenger and officer) flows			
	Define PPE selection and donning/ doffing procedure			
	apply restrictions for susceptible staff			
	Environmental cleaning/sanitation			
	Tightened passenger data collection			
	Pre-departure requirement			
PPE	PPE supply chain			
	Life-vest and helmet			
	Personal hand sanitizer			

Note: To interpret Table **4**, a risk grading result of red (high risk) from Table **3** signals that the Port must consider implementing all five levels of control measures. The selection of specific Port activities within each control level—for example, the three options listed under the elimination level—should be guided by the mode of transmission outlined in Table **1**. For instance, if the disease is transmitted *via* the airborne route, the Port may need to restrict cruise ships from docking entirely or allow only temporary docking for logistical resupply without disembarkation of passengers.

areas surrounding the port, all of which contribute to more serious consequences.

These factors explain why the highest-risk items are marked in red and placed at the highest control levels of the hierarchy.

A moderate risk of pathogens requires a higher infecting dose and a lower disease severity. At times, somehow, we can tolerate these pathogens becoming naturally circulating in our environment. Immediate measures for the acute phase need to be addressed: do we have the cure/ vaccines, or is control of transmission possible? In the end, the circulating pathogen will shape human civilization [45]. Every hazard-reduction effort involving structural modifications to Port buildings and their surroundings is included in the engineering control level. The engineering control level is appropriate for moderate-risk pathogens.

Low-risk pathogens require less control than moderate-risk pathogens [45]. By developing procedures, such as establishing screening procedures and temperature checks, they are considered sufficient to control the spread. Administrative controls are used for low-risk pathogens.

Engage Port Stakeholder: Assign Shared Responsibilities and Tasks

A discussion with stakeholders of Lembar Port was conducted to clarify shared tasks and responsibilities among the involved agencies: the Harbormaster's Office and Port Authority (KSOP), the Health Quarantine Agency (Badan Kekarantinaan Kesehatan), the Fish, Animal, and Plant Quarantine Agency (Badan Karantina Ikan, Hewan, dan Tumbuhan), PT Pelindo and PT ASDP as port operators, and the research team from the Maritime Medicine Specialist Program, who served as facilitators. The meeting took place at the Health Quarantine Agency building in Labulia, Lombok, on October 8, 2024.

Stakeholder responsibilities were identified through a focus group discussion (FGD) designed in three sessions: opening, discussion, and closing.

In the opening session, the research team explained the study procedures and obtained informed consent. Participants were then divided into two groups based on managerial level: top- and middle-level managers and executive managers.

The closing session included collecting feedback from participants and delivering closing remarks.

For the FGD, we prepared instruments comprising open-ended questions tailored to managerial levels, focusing on the detailed port activities listed in Table **5**. Examples of question styles included:

- "Have you ever heard about …?" (Executive managers)
- "Have you ever been instructed to …?" (Executive and middle managers)
- "Have you ever been told to coordinate with … regarding …?" (Middle managers)

Table 5: Shared responsibilities among stakeholder. X mark= the chosen mark for tasks and responsibilities.

Control level	Port activities	Shared responsibilities			
		Harbormaster's Office and Port Authority	Health Quarantine Agency & Quarantine of fish, animal and plant agency	Port operator (PT ASDP, PT Pelindo)	Ship operator
Elimination	Prohibit docking of ships from high-risk areas	X			X
	restrict access to screened personnel and passengers only	X		X	X
	automate off-loading to prevent person-to-person contact	X	X	X	X
	secure infectious-waste handling		X	X	X
Substitution	Transition from paper to paperless processes	X	X	X	X
	Deploy robotic where feasible			X	X
	Implement containment and quarantine procedures as appropriate	X	X	X	X
Engineering control	Install physical barrier at counters	X	X	X	X
	Increase mechanical/ natural ventilation	X	X	X	X
	Provide isolation rooms		X	X	X
	Add touchless hand-washing stations	X	X	X	X
	Reduce passenger capacity			X	X
Administrative control	shorten contact time *via* scheduling		X	X	X
	Conduct training on infectious diseases protocols	X	X	X	X
	establish screening criteria	X	X	X	X
	Officer medical checks	X	X	X	X
	Temperature checks	X	X	X	X
	restrict access to certain areas			X	X
	Signage for distancing *etc.*	X	X	X	X
	Modify (passenger and officer) flows		X	X	X
	Define PPE selection and donning/ doffing procedure	X	X	X	X
	apply restrictions for susceptible staff	X	X	X	X
	Environmental cleaning/sanitation	X	X	X	X
	Tightened passenger data collection		X	X	X
	Pre-departure requirement	X	X	X	X
PPE	PPE supply chain	X	X	X	X
	Life-vest and helmet	X	X	X	X
	Personal hand sanitizer	X	X	X	X

- "Do you understand your organization's main duties and how these listed activities become part of your agency's responsibilities?" (Top managers)

Any activity for which a top manager confirmed "yes" was categorized as part of that stakeholder's responsibility.

The discussion agreed on two things: understanding their shared tasks and responsibilities, and a commitment to work together to develop the EIDs' preparedness plan based on a set of decision matrices (**Tables 1, 2, 4,** and **5**).

A tailored preparedness plan based on the specific type of EIDs needed should be prepared and led by the Health Quarantine Agency (BKK). The following experts developed the specific preparedness plan: clinical epidemiologist, epidemiologist, entomologist, clinical microbiologist, microbiologist, maritime medicine specialist, aviation medicine specialist, clinical laboratory expert, related clinicians, and the decision-maker on Port (*i.e.*, Ministry of Transportation). It should be noted that external stakeholders outside the port play essential roles during the pandemic, which was not covered in this study.

DISCUSSION

A clear example of implementing of a Public Health Emergency Contingency Plan (PHECP) was seen in Greek ports during the COVID-19 pandemic. In this set up, the Ministry of Maritime Affairs and the Ministry of Health collaborated closely with local stakeholders, including port authorities, regional health directorates, and the Coast Guard. This collaboration resulted in the establishment of a Local Coordination Task Force responsible for health screening, case reporting, and enforcement of port-level health protocols. The inclusion of external agencies, such as emergency medical services, immigration authorities, and the Ministry of Tourism, further strengthened this multisectoral response, demonstrating the value of structured interagency coordination in enhancing port preparedness during public health emergencies [46].

By contrast, PHECP implementation at Lembar Port remains highly centralized, with operational decisions largely dependent on directives from respective head offices. The Port Health Quarantine Agency serves as the lead authority for health-related functions, including screening, surveillance, infection prevention and control, and public health education. However, interagency coordination has been limited, partly due to operational constraints imposed by social distancing experienced during the pandemic. Nevertheless, stakeholder discussions indicated growing awareness of the importance of shared responsibility and stronger collaboration. In this context, our proposed decision-making matrix provides a practical approach to streamline coordination, clarify each roles, and support timely, and consistent responses to future emerging infectious disease (EIDs) threats.

The proposed decision-making matrix represents an application of the PtD framework tailored specifically to the context of port operations and emerging infectious diseases (EIDs). However, several challenges and limitations should be anticipated by port stakeholders in the future implementation [47], as follows:

1. **Economic considerations in PtD implementation.** The financial justification for prosecuting the PtD approach may be questioned, as decision-making within commercial organizations often prioritize cost-efficiency. Consequently, the hierarchy of controls may favor low-cost measures. To secure adoption, the PtD implementation must demonstrate a clear return on investment and operational feasibility within port operations.
2. **Relevance of design elements to infectious disease causality.** A critical issue lies in determining whether the proposed matrix components are directly relevant to EIDs transmission dynamics. Given the diverse and evolving characteristics of infectious diseases, periodic redesign and contextual adaptation of the matrix may be necessary to maintain its applicability
3. **Technical and infrastructural requirements.** Effective EIDs detection and surveillance demand advanced diagnostic infrastructure (*i.e.* polymerase chain reaction (PCR) machines and genomic sequencing instruments) and optimization of sampling protocols (including specimen type, collection site, and timing). These requirements may present logistical and financial challenges for port authorities.
4. **Interactions among humans, machines, and the environment.** Seize behavioral and operational interactions between workers, equipment, and the environment remains a significant challenge. In the context of EIDs, factors such as hand hygiene compliance, adherence to standard operating procedures, environmental sanitation, and infection-prevention awareness are critical, given the inherently high-risk nature of port environments.
5. **Diffusion and institutionalization of the matrix innovation.** Sustained communication strategies are essential for long-term adoption, including continuous dissemination of guidance materials. A strong occupational safety culture served as key enabler for embedding the PtD integration into port operations. Commitment from top management, including appointing PtD officers within each division, is vital [47]. Furthermore, fostering engagement through solidarity, transparency, and acknowledgement of uncertainty can create internal demand for improved safety practices among port personnel [48].

Technical Aspects of the Decision-Making Process

Within the five elements of the NIOSH hierarchy of controls, assigning specific measures in the decision-making matrix to particular control levels is inevitable, as each aspect carries distinct economic, political, operational, and communication implications within the port environment.

The elimination element focuses on preventing the importation of infectious diseases from other regions. While this measure is the most effective, it also incurs the highest economic cost, as it may restrict core port operations, in which creating a dilemma between health protection and business continuity. The substitution element involves replacing or minimizing contact with materials originating from external sources. Although potentially effective, substitution can be costly, alter work processes, and disrupt established communication patterns.

Engineering controls aim to reduce exposure by preventing the spread of infectious agents among individuals, while administrative controls modify work practices and enhance awareness through training, standard operating procedures, and targeted communication. These two elements are typically easier to integrate into daily port operations because they closely align with existing routines and management systems. The utility of personal protective equipment (PPE) is adjusted to a specific EIDs. As example the needs for protective clothing, powered air-purifying respirators (PAPRs) provides the final barrier to safeguard workers from exposure of airborne pathogen [49].

Managing personnel during the implementation of the matrix also involves managing emotions. The introduction of a new decision-making matrix may evoke stress or resistance among port workers, as it requires adaptation to unfamiliar procedures and responsibilities [50]. Nevertheless, changes in workplace practices during infectious disease threats are essential to protect

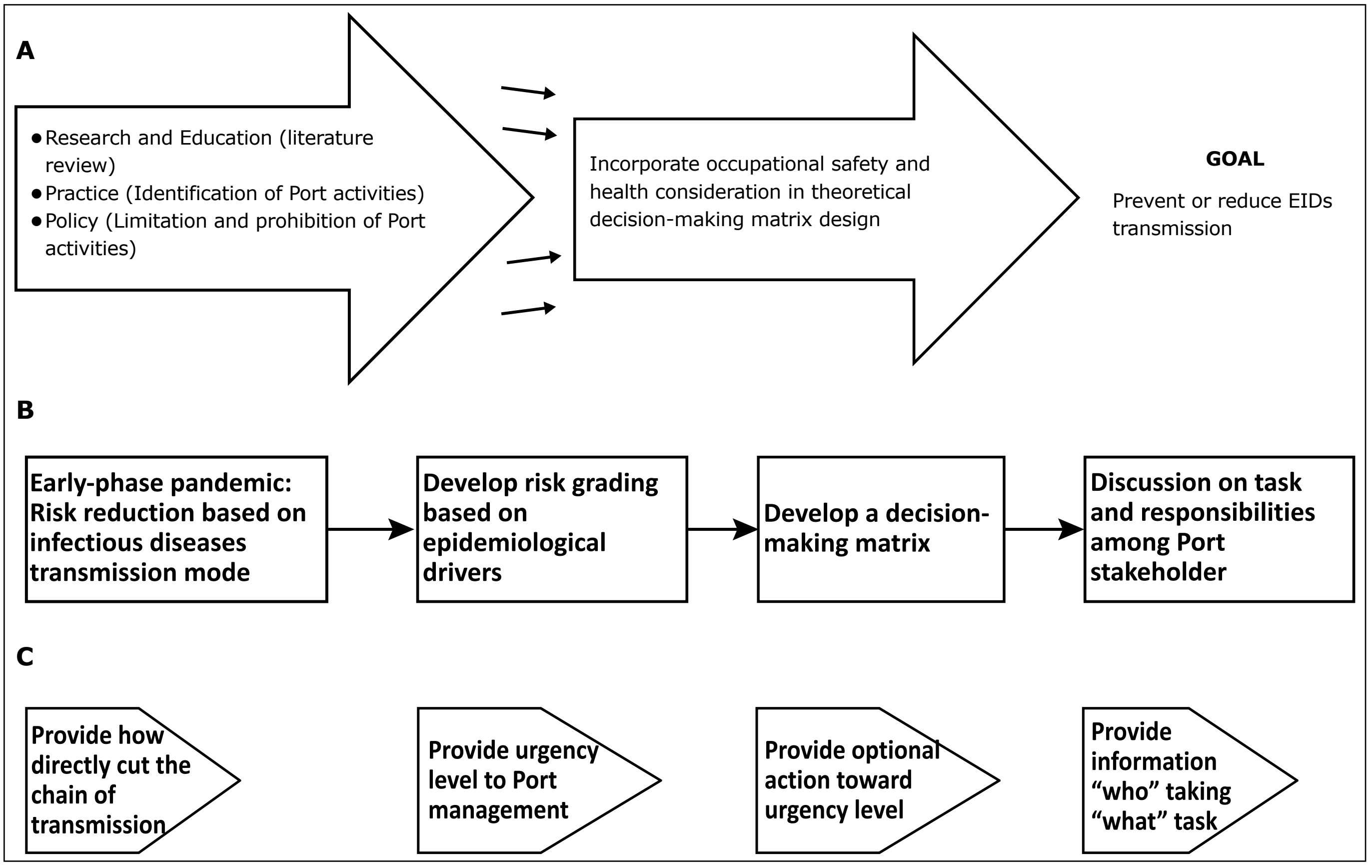

Fig. (1): Development EIDs preparedness plan in Port based on PtD strategic planning and implementation design; **A.** PtD framework of the National Initiative focus in strategic planning and implementation (modified from Fig. **1** Reference 8); **B.** PtD framework alignment in EIDs preparedness plan in this study; **C.** Goal description according to each box of this study.

not only the workers themselves but also their families and the broader community [51].

Illustrative Development of a Theoretical Decision-Making Matrix for EIDs Preparedness in Ports

The PtD flow typically begins with stakeholder input, followed by strategic planning and implementation. In this study, the stakeholder input stage was omitted because EIDs hazards are not part of the core functions and responsibilities of port operations. Instead of stakeholder input, it was replaced by a literature study.

As illustrated in Fig. **(1)**, part A depicts the adoption of the PtD framework in this study. Research and educational processes were informed by an extensive literature review, focusing on infection control practices relevant to EIDs transmission. Port activities were systematically identified to determine how top management could implement preventive policies by limiting or prohibiting activities, with the ultimate goal of reducing EIDs transmission.

Part B of the figure outlines the decision-making process for port stakeholders in managing the potential occurrence of EIDs, based on the stage of disease onset. In the early phase of a pandemic, risk-reduction measures are determined by the mode of transmission. If the EIDs persists, stakeholders are required to assess its severity through risk grading, which in this study utilized two key epidemiological indicators: the basic reproduction number (R_O) and the case fatality rate (CFR). Once the risk level is established, appropriate actions can be executed based on the decision-making matrix. These actions involve multiple port stakeholders, with each actor's tasks and responsibilities aligned with their institutional roles.

Part C summarizes the overall objectives of these sequential steps, emphasizing the integration of the PtD framework into a coordinated and operationally feasible preparedness plan for port settings.

STUDY LIMITATION

The simulation of the proposed decision matrix by port stakeholders has not yet been conducted. The validation activity feasibly undertaken in this study was a structured stakeholder discussion rather than an operational simulation. Several obstacles were identified. First, each port stakeholder organization has its own internal affairs in adopting the matrix, while our approach was multi-stakeholder. Second, obtaining a local port permit is challenging without the central port authority's clearance. Finally, the costs of conducting a simulation are potentially high, as every disruption of Port activities means economic loss. Operational simulation is recommended as a next-phase activity, as shown in recent port public health preparedness studies [3, 46], where simulation-based evaluation improves workflow coordination, bottleneck identification, and emergency response performance.

The authors acknowledge that the risk grading of EIDs in the port context may represent a simplified approach, as it relies solely on two epidemiological drivers: the basic reproduction number (R_O) and the case fatality rate (CFR). This selection was based on two considerations: (1) these parameters are the most representative indicators of disease severity, and (2) they have been demonstrated to be effective in assessing the risk of COVID-19, which persisted for more than three years. Other epidemiological variables are considered too complex to be operationalized in the port setting. Nevertheless, this simplified risk-grading framework provides a practical tool for port authorities to guide an immediate response to EIDs, cutting unnecessary meetings that potentially postpone initial effective action. When necessary, consultations with infectious disease experts can be sought to support the interpretation and refinement of the assessment.

CONCLUSION

A theoretical decision-making matrix provides a structured and actionable preparedness plan for EIDs in port settings. Conducting a simulation exercise with stakeholders is essential to test, refine, and validate the matrix.

ETHICS APPROVAL

Ethical approval was obtained from the Ethical Committee of the Faculty of Medicine and Health Science, Mataram University, Indonesia, Ref: 077/UN18.F8/ETIK/2024, dated June 5, 2024. All procedures performed in studies involving human participants were conducted in accordance with the ethical standards of the institutional and/or national research committee and the Helsinki Declaration.

CONSENT FOR PUBLICATION

Informed consent was obtained from the participants.

AVAILABILITY OF DATA

The data utilized in this study are freely accessible through the sources cited in the reference list. This study did not involve any private, confidential, or otherwise restricted datasets.

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CONFLICT OF INTEREST

Authors declare no conflict of interest.

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Declared none.

AUTHORS' CONTRIBUTION

EHW conceptualization, study design, data analysis, finalized the manuscript, RN, NMSGD, DAP, NDAPP, IAEW, WSA, BTD, PSS, YPS, DY: data analysis and manuscript drafting. All authors reviewed and approved the final manuscript.

GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work the authors limitedly used ChatGPT (GPT-4, OpenAI) to get language suggestions and do minor proofreading in some parts of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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