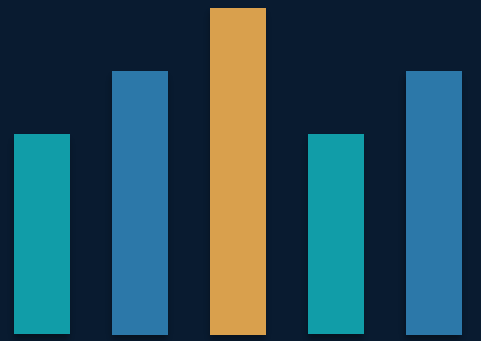
META PORT / PROFESSIONAL OPERATIONS SERIES

JINHAE NEW PORT CONTAINER TERMINAL

Digital Twin • Discrete-Event Simulation • Berth, QC, AGV, Yard & Gate Operations



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EXECUTIVE OVERVIEW

One operating system, six interconnected decisions

A terminal is only as strong as its current bottleneck; local optimization is not system optimization.

BERTH & VESSELS

Which vessel receives which physical berth and when?

QC DISPATCH

How many of the installed quay cranes can be assigned, and where?

AGV & HORIZONTAL FLOW

How will travel, handovers and queueing affect quay productivity?

YARD / SLOT

Which compliant slot receives each container without creating costly future rehandles?

GATE / TRUCKS

How do external truck arrivals, lanes and LSTP allocation shape congestion?

INTEGRATED KPI

Can the proposed plan improve throughput without violating safety or physical limits?

THE ENGINEERING PROMISE | Explain the bottleneck, test the intervention, audit the result.

SCOPE & BOUNDARIES

This publication covers container operations only

The Jinhae New Port demonstration is the reference case; other port services are deliberately excluded.

IN SCOPE

Vessel calls, berth allocation, quay-crane work, AGV/tractor routing, storage slots, yard transport, external trucks and gates.

OUT OF SCOPE

Tanker terminals, liquid-bulk transfers, storage tanks, bunker facilities and greenfield port-investment feasibility.

EVIDENCE RULE

Stage layout, crane and route tests inform the case study; unverified configuration or trial outcomes are never called production facts.

SYSTEM BOUNDARY

Jinhae demonstration: physical operating model

Reference configuration for model verification; site-specific master data supersedes these values.

QUAY SYSTEM

Three berth positions in the reference layout; actual berth geometry and operating limits require CAD confirmation.

QUAY CRANES

A 12-QC fleet cap is used as a reference model acceptance condition; allocation must not count QC13–QC15.

INTERNAL HANDOVER

AGV path: quay crane ↔ WSTP; verify that path nodes and legal transitions exist.

EXTERNAL INTERFACE

Truck flow: main/sub gate ↔ LSTP; external trucks do not assume AGV routes.

STORAGE ZONES

General, Empty, Reefer, Dangerous, Harmful and OOG classes require explicit slot eligibility.

ASSURANCE

A passed visualization is not proof of validated event counts, causal routes or feasible storage allocations.

REFERENCE CONFIGURATION ONLY | Verify the installed asset master and commissioned geometry before an operational claim.

INTEGRATION LOGIC

End-to-end event chain

One disruption must propagate across all connected subsystems.

01	02	03	04	05
VESSEL	**QC**	**AGV**	**YARD**	**GATE**
ETA, berth suitability, start and finish	Gang assignment, moves, crane interference	Dispatch, travel, handover and waiting	WSTP, block, slot, rehandle and retrieval	LSTP, truck queue, exit and SLA

Every event carries a unique ID, timestamp, resource, predecessor and scenario version.

01

Engineering the digital twin

The terminal is a state-changing physical system, not a rendered animation.

REFERENCE MODEL

The six layers of a trustworthy terminal twin

Each layer has a separate evidence contract.

GEOMETRY

CAD-based berth, yard-block, lane, gate, WSTP and LSTP coordinates; defined coordinate transforms.

ENTITY MODEL

Vessel, rotation, container, stowage, QC, AGV, yard machine, truck and physical slot identifiers.

EVENT ENGINE

Arrival, berth assignment, QC lift, handover, stack, rehandle, release, gate transaction.

CONSTRAINT ENGINE

Physical capability, safe segregation, timing, adjacency and equipment-resource limits.

KPI ENGINE

Time-weighted occupancy, queue waiting, vessel completion, QC and vehicle utilization, throughput.

EVIDENCE ENGINE

Inputs, hashes, scenarios, run IDs, errors, versions, seeds and reviewed decisions.

SIMULATION MATHEMATICS

Discrete-event state transition

$$S(t+) = F[S(t-), e, R(t), C]$$

VARIABLES & UNITS

S = system state; e = event; R(t) = resource availability; C = fixed and dynamic operating constraints.

WHY THE DECISION CHANGES

Any delayed lift, blocked slot or unavailable AGV updates queues and downstream resource demand.

MODEL BOUNDARY | The actual deployed scheduler and state schema require code-level audit.

EVENT CONTROLLER

How a simulation clock advances

Activities are driven by the next feasible event, not by frame count.

01	02	03	04	05
POP EVENT	**TEST**	**ALLOCATE**	**UPDATE**	**LOG**
Extract earliest admissible timestamp.	Validate resource and physical eligibility.	Lock assigned resource and location.	Change queue, inventory and resource state.	Persist event and accumulate time-weighted KPI.

Require deterministic replays for the same snapshot, configuration, random seed and code version.

SIMULATION MATHEMATICS

Time-weighted yard occupancy

$$U_y = (1/T) \int_{[0,T]} N_{occupied}(t)/C_{effective}(t)\, dt$$

VARIABLES & UNITS

N_occupied(t) = occupied eligible slots; C_effective = operational available slots; T in hours.

WHY THE DECISION CHANGES

Avoid interpreting a single screenshot as average yard utilization over the simulation period.

MODEL BOUNDARY | Capacity denominators must exclude disabled or ineligible locations; report the chosen definition.

MODEL CONTRACT

What an auditable run must preserve

Export minimum provenance with every result.

INPUT CONTRACT

Snapshot ID, source dates, units, record counts and authoritative vs estimated values.

LAYOUT CONTRACT

CAD file hashes, accepted transform, node geometry and reachable routes.

RULE CONTRACT

Slot eligibility, QC limit, resource calendars and movement precedence.

OUTPUT CONTRACT

Event log, rejection reasons, final state and KPI series with numerical units.

A moving icon cannot substitute for physical path validity or event consistency.

02

Berth & quay-crane planning

Feasible berth windows, crane assignment and vessel completion are modeled together.

OPERATING PROCEDURE

Vessel arrival-to-departure procedure

The operations manager should be able to reproduce each transition.

01	02	03	04	05
SCREEN	**ASSIGN**	**RESOURCE**	**SIMULATE**	**REVIEW**
Check ETA, LOA, draft, berth clearance and cargo volume.	Reject unsuitable berths; calculate feasible start window.	Allocate available QCs and gangs within the fleet limit.	Advance lifts, handovers, interruptions and completion.	Inspect late vessels, QC bottlenecks and evidence.

Exception record: unavailable QC, berth conflict, overlong vessel, tide-window failure or invalid sequence.

BERTH MATHEMATICS

Compatible berth utilization

$$U_b = \Sigma_i T_{berth,i} / \Sigma_b H_{available,b}$$

VARIABLES & UNITS

$T_{berth,i}$ = occupied berth hours for vessel i; $H_{available,b}$ = usable hours for berth b.

WHY THE DECISION CHANGES

High utilization may indicate little recovery capacity; compare delay distribution and vessel conflicts.

ILLUSTRATIVE | 3 identical berths × 168 h = 504 nominal berth-hours/week.

MODEL BOUNDARY | An aggregate denominator is valid only for compatible berths and consistent study horizons.

BERTH MATHEMATICS

Vessel waiting and turnaround

$$W_i = \max(0, t_{berth,i} - t_{arrival,i}) \; ; \; TAT_i = t_{departure,i} - t_{arrival,i}$$

VARIABLES & UNITS

W = anchorage or berth waiting [h]; TAT = total port turnaround [h], with consistent event definitions.

WHY THE DECISION CHANGES

Identify whether late departure originates in berth conflict, QC capacity or yard backpressure.

ILLUSTRATIVE | Arrival 08:00, start 13:30 → waiting 5.5 h.

MODEL BOUNDARY | Distinguish port-arrival timestamps from pilot station or planned ETA.

BERTH CONSTRAINTS

Non-overlap and vessel compatibility

$$x_{ib} \in \{0,1\};\ \Sigma_b x_{ib}=1;\ \ [s_i,e_i] \cap [s_j,e_j]=\emptyset$$

VARIABLES & UNITS

x_ib = vessel i assigned to berth b; s,e = occupied start/end times for vessels sharing space.

WHY THE DECISION CHANGES

Filter invalid berth candidates before comparing turnaround objectives.

MODEL BOUNDARY | Along-quay simultaneous positioning may require a spatial interval model, not simple one-ship-one-berth.

QC MATHEMATICS

Quay-crane work duration

$$T_{QC} \approx M_{total} / (n_{QC} \times P_{net}) + T_{nonproductive}$$

VARIABLES & UNITS

M_total = container moves; n_QC = noninterfering available cranes; P_net = effective moves/QC-hour.

WHY THE DECISION CHANGES

Estimate completion and assess changes in number of QCs, breakdowns and work-sequence policy.

ILLUSTRATIVE | 1,800 moves ÷ (6×25 moves/h) = 12 h before additional overhead.

MODEL BOUNDARY | Productivity cannot be assumed linear when cranes interfere or workload is unbalanced.

QC MATHEMATICS

Effective crane productivity

$$P_{net} = M_{completed} / \Sigma_q H_{working,q}$$

VARIABLES & UNITS

M_completed = actual successful lifts; H_working,q = available working hours using a declared time base.

WHY THE DECISION CHANGES

Separate productive time, waiting on AGV/yard, downtime and shift change for intervention selection.

MODEL BOUNDARY | Gross vessel moves/h is not the same as per-QC net moves/h.

QC CONSTRAINTS

Fleet and assignment conservation

$$\Sigma_v x_{(q,v,t)} \leq 1; \quad \Sigma_q \text{Active}(q,t) \leq 12$$

VARIABLES & UNITS

$x_{(q,v,t)} = 1$ if QC q serves vessel v at time t; 12 = reference Jinhae test fleet cap.

WHY THE DECISION CHANGES

Detect phantom cranes and simultaneous double assignment before ranking schedules.

MODEL BOUNDARY | QC-12 cap is a project validation criterion, not a claim about every future installation.

QC SIMULATION

Four controlled crane-dispatch experiments

Use one cargo workload, vessel sequence, equipment fleet and random-seed set.

MINIMUM WAIT

Prioritize vessel start delay subject to physical feasibility.

MAXIMUM OUTPUT

Allocate QCs toward maximizing terminal moves within the horizon.

BALANCED RESOURCE

Reduce equipment idle time and harmful yard/AGV congestion.

ROBUSTNESS-FIRST

Limit tail waiting and restore service under delays or breakdowns.

The exact deployed policy/solver must be confirmed against the current source code.

BERTH / QC CASE

Illustrative scenario: one crane becomes unavailable

Option	Operational consequence	Check before approval
Baseline: six QCs	Expected work duration uses six cranes	Confirm noninterference and AGV support
Disruption: five QCs	Nominal handling duration rises	Verify yard and crew response
Reallocate crane	Other vessels lose assigned QC capacity	Compare full terminal waiting
Change berth sequence	Different arrival and work windows	Inspect berthing feasibility

Illustrative mechanisms only; no claim of measured Jinhae time or productivity.

03

AGV & internal transport

The quay-to-yard link must obey real road geometry, handover capacity and dispatch rules.

AGV STANDARD PROCEDURE

QC ↔ WSTP cycle

Every trip has a legal destination and recorded handover.

01	02	03	04	05
READY	**PICK UP**	**TRAVEL**	**TRANSFER**	**RETURN**
Release container and verify compatible vehicle.	Travel to QC, queue and load.	Follow connected legal nodes to WSTP.	Wait for handover equipment and unload.	Travel safely to next dispatch point.

AGV flow is distinct from external truck Gate ↔ LSTP flow.

AGV MATHEMATICS

Transport cycle time

$$T_{cycle} = T_{empty} + T_{QCwait} + T_{load} + T_{loaded} + T_{WSTPwait} + T_{unload}$$

VARIABLES & UNITS

All times in minutes/trip; define whether repositioning and recovery are included.

WHY THE DECISION CHANGES

Long QC waits may be caused by vehicle scarcity or WSTP congestion rather than QC inefficiency.

MODEL BOUNDARY | Use path travel time from graph edges and observed speed profiles, not Euclidean distance.

AGV MATHEMATICS

Fleet transport capacity

$$Q_{AGV} \leq 60 \times N_{eff} / E[T_{cycle}]$$

VARIABLES & UNITS

Q_AGV [moves/h]; N_eff = available vehicles; E[T_cycle] in minutes.

WHY THE DECISION CHANGES

Test how many vehicles are required to sustain assigned quay-crane productivity.

ILLUSTRATIVE | 24 AGVs, mean 15-min cycle → nominal upper bound 96 moves/h.

MODEL BOUNDARY | Upper-bound approximation; directional conflicts and dispatch variability need discrete-event simulation.

ROUTING MATHEMATICS

Shortest legal travel route

$$d^*(u,v) = \min_{p \in P_{legal}} \sum_{(a,b) \in p} d_{ab}$$

VARIABLES & UNITS

P_legal = graph paths respecting one-way, no-go and terminal lane restrictions.

WHY THE DECISION CHANGES

Compute realistic travel and identify high-load crossings before adding vehicles.

MODEL BOUNDARY | An unmatched path node must be flagged, not connected by an arbitrary straight line.

TRAFFIC MATHEMATICS

Lane demand-to-capacity ratio

$$v/c = q_{vehicles} / q_{sustainable}$$

VARIABLES & UNITS

q_vehicles = vehicle flow demand [vehicles/h]; q_sustainable = conflict-aware sustainable route throughput.

WHY THE DECISION CHANGES

Locate choke points and determine whether route control beats adding fleet size.

MODEL BOUNDARY | Sustainable traffic capacity must be estimated or calibrated for the actual road layout.

SPATIAL QA

CAD alignment is an engineering acceptance gate

The displayed route must correspond to a registered coordinate system.

SOURCE GEOMETRY

Preserve original CAD source and file hash; do not silently modify it.

COORDINATE TRANSFORM

Document scale, rotation, translation and residual alignment error.

GRAPH COVERAGE

All AGV trips resolve to legal graph nodes and connected edges.

COLLISION CHECK

Physical conflicts, turn radii and pedestrian/operational restrictions require review.

Current local-to-CAD overlays are QA candidates until approved and registered.

AGV EXCEPTION HANDLING

Route defects: classify before running

Finding	What it means	Required action
UNMATCHED node	Route point has no registered layout node	HOLD path validity; inspect mapping
Broken connection	From/to endpoints are not graph-connected	Repair graph or input contract
Forbidden segment	Direction or restriction not respected	Reject trip or route alternative
Unreasonable travel	Speed/distance/clock inconsistencies	Reconcile coordinates, units and event time
Excess crossing	Safety or congestion exposure	Test revised circulation control

Earlier Stage unmatched-route counts were diagnostic, not a license to interpolate missing physical paths.

04

Yard storage & rehandling

Slot feasibility first; accessibility, rehandles and yard machinery second.

STORAGE POLICY

The six storage classes must remain distinguishable

Never optimize away cargo segregation or operational restrictions.

GENERAL

Standard units under stacking, weight and access policy.

EMPTY

Empty-unit blocks and stacking-height rules.

REEFER

Power availability, monitoring and plug capacity.

DANGEROUS

Regulated segregation, compatibility and exclusion limits.

HARMFUL

Separate classification and verified terminal-specific restrictions.

OOG

Out-of-gauge clearance, handling envelope and special equipment.

YARD MATHEMATICS

Nominal and effective storage capacity

$$C_{eff} = \Sigma_b C_{design,b} \times \eta_{usable,b}$$

VARIABLES & UNITS

$C_{design,b}$ = designed slots for block b; $\eta_{usable,b}$ = operational availability after exclusions.

WHY THE DECISION CHANGES

Separate geometric block capacity from physically enabled, eligible and reachable slots.

MODEL BOUNDARY | Do not double-apply factors already embedded in effective slot masters.

YARD MATHEMATICS

Occupancy and the bottleneck block

$$U_{b(t)} = N_{occupied,b(t)} / C_{effective,b(t)}$$

VARIABLES & UNITS

b = yard block; N_occupied = units occupying available eligible slots.

WHY THE DECISION CHANGES

A whole-yard average can hide locally full reefer, DG or general blocks.

MODEL BOUNDARY | Compare TEU, container units and slot positions using consistent denominators.

YARD MATHEMATICS

Rehandle ratio

$$R_{move} = N_{rehandle_moves} / N_{target_retrievals}$$

VARIABLES & UNITS

N_rehandle_moves = additional physical relocation moves;
N_target_retrievals = requested retrievals.

WHY THE DECISION CHANGES

Monitor stacking efficiency and avoid reporting rehandled containers as total rehandle moves.

MODEL BOUNDARY | Count only traceable movement events with valid from/to slots and event time.

YARD MATHEMATICS

Expected space demand: Little's law

$$E[N] = \lambda \times E[W]$$

VARIABLES & UNITS

λ = arrival rate [containers/day]; E[W] = mean dwell [days]; E[N] = average inventory.

WHY THE DECISION CHANGES

Estimate baseline yard demand and test reduced dwell vs new storage capacity.

ILLUSTRATIVE | 1,200 units/day × 5 days = 6,000 average units.

MODEL BOUNDARY | Steady-state relationship; peak inventory and class-specific blocks need stochastic simulation.

SLOT ELIGIBILITY

Physical slot assignment constraint

$$\text{Eligible}(c,s) = \text{Size} \wedge \text{Class} \wedge \text{Weight} \wedge \text{Height} \wedge \text{Access} \wedge \text{Safety}$$

VARIABLES & UNITS

c = container, s = slot; all conjunctive constraints must be true.

WHY THE DECISION CHANGES

Only physically and operationally eligible slots enter candidate rankings.

MODEL BOUNDARY | Unknown slot capability must not be treated as safe or available.

INVENTORY INTEGRITY

State invariants that every placement must pass

The digital twin needs both event-level and final-slot proof.

EXACTLY ONE POSITION

A container is in one valid current slot or explicit in-transit state.

NO DOUBLE BOOKING

Two containers never occupy the same slot in the same time interval.

REHANDLE CHAIN

Each rehandle has source, destination, time, triggering retrieval and moved-container ID.

MASTER POLICY

Disabled slots and incompatible cargo classes never silently pass eligibility.

The difference between cargo-rule conflicts and physically disabled/unknown slots must remain visible.

YARD QA

Acceptance matrix for placement outcomes

Status	Interpretation	Disposition
PRIMARY_SLOT_MATCH	Eligible planned final slot selected	PASS after event trace
CARGO_RULE_CONFLICT	Cargo class or slot policy violated	HOLD assignment
PHYSICAL_DISABLED_OR_UNKNOWN	Slot disabled, unreachable or unknown	HOLD capacity claim
REHANDLE_EVENT	Valid movement linked to retrieval demand	Audit count and final state

These labels represent Stage classification logic; exact live routing must be verified.

05

External trucks & gate control

LSTP assignments, appointment peaks and road constraints define landside service reliability.

LANDSIDE PROCEDURE

Gate ↔ LSTP truck transaction

Do not route external trucks through AGV-only QC/WSTP operations.

01	02	03	04	05
ARRIVE	**GATE**	**DRIVE**	**HANDOVER**	**EXIT**
Timestamp and validate external truck request.	Select open lane; process documents and appointment.	Follow permitted gate-to-LSTP road graph.	Wait for yard machine and complete transaction.	Log gate-out, turnaround and exceptions.

Use independently measured truck timestamps when calibrating turnaround and service time.

QUEUE MATHEMATICS

Gate lane utilization

$$\rho_{gate} = \lambda / (c \times \mu)$$

VARIABLES & UNITS

λ = truck arrivals [trucks/h]; c = available lanes; μ = per-lane service rate [trucks/h].

WHY THE DECISION CHANGES

Show why small lane outages can trigger disproportionate queueing when ρ approaches 1.

ILLUSTRATIVE | 220 trucks/h, 5 × 55/h lanes → ρ = 0.80.

MODEL BOUNDARY | Assumes comparable parallel lanes; appointments, peaks and finite capacity need DES.

QUEUE MATHEMATICS

Truck waiting and turnaround

$$W_{q,i} = t_{service_start,i} - t_{arrival,i}$$

VARIABLES & UNITS

$W_{q,i}$ = queue waiting [min]; gate/terminal turnaround includes all relevant dwell intervals.

WHY THE DECISION CHANGES

Distinguish pre-gate line, transaction wait, internal travel and LSTP service.

MODEL BOUNDARY | Use the same time basis and sign conventions across all truck records.

QUEUE MATHEMATICS

Percentile service level

$$SLA_{95} = percentile_{95}(T_{turnaround,i})$$

VARIABLES & UNITS

T_turnaround = defined gate-in to gate-out, or alternative agreed terminal interval [min].

WHY THE DECISION CHANGES

Control long-tail service failures, not only the mean turnaround time.

MODEL BOUNDARY | Always report sample size, time window, truck mix and interpolation method.

GATE EXCEPTIONS

Landside route and transaction failure controls

Failure mode	Detection	Action
Missing LSTP mapping	No valid handover point for request	HOLD transaction
Incorrect gate type	Truck enters incompatible route	Reject or redirect
Peak saturation	Queue exceeds agreed threshold	Appointment and staffing scenario
Ambiguous turnaround	Missing gate-in or out timestamp	Exclude from validated SLA

Separate operational delay from incomplete data; do not hide missing visits from KPI denominators.

06

Integrated scenario experiments

Same input demand, same constraints, transparent objectives, comparable uncertainty.

EXPERIMENT DESIGN

Every scenario changes a defined lever

No simulation result can be called an improvement without a comparable baseline.

BASELINE

Reproduce known vessel workload, layout, asset availability and dispatch policy.

BERTH / QC

Change vessel order, permitted start, crane count or crane priority.

AGV

Alter dispatch priority, legal routing and effective vehicle count.

YARD

Change compliant placement rule, access sequence or occupied blocks.

GATE

Modify appointment arrival profile or lane staffing.

ROBUSTNESS

Apply delays, equipment downtime and demand bursts under matched conditions.

SCENARIO COMPARISON

Paired scenario difference

$$\Delta KPI_r = KPI_{option,r} - KPI_{baseline,r}$$

VARIABLES & UNITS

r = matched replication using common random numbers and the same initial state.

WHY THE DECISION CHANGES

Estimate effect of a specific decision while reducing noise from stochastic arrivals.

MODEL BOUNDARY | Sign of Δ must be defined per metric: lower waiting is good, higher throughput often good.

MODEL VALIDATION

Absolute error against observed performance

$$MAE = (1/n)\ \Sigma_i\ |y_{sim,i} - y_{obs,i}|$$

VARIABLES & UNITS

n = matched observations; y = KPI values with identical time bounds and units.

WHY THE DECISION CHANGES

Use historical replay to calibrate waiting, turnaround, volume and equipment use before recommendations.

MODEL BOUNDARY | MAE alone does not prove causal validity or correct event ordering.

UNCERTAINTY

Confidence interval for mean KPI

$$CI_{95} \approx \bar{x} \pm t_{(0.975,R-1)} \times s/\sqrt{R}$$

VARIABLES & UNITS

R = independent replications; s = replication standard deviation.

WHY THE DECISION CHANGES

Differentiate genuine scenario effect from random simulation variation.

MODEL BOUNDARY | Small samples and skewed tails need robust interval methods.

RISK CONTROL

Constraint violation rate

$$P_{violation} = N_{failed_replications} / R$$

VARIABLES & UNITS

Failed replication = any precisely defined violation event, such as invalid slot or breached service SLA.

WHY THE DECISION CHANGES

Rank only physically feasible options, and report reliability under peak stress.

MODEL BOUNDARY | Physical impossibility should trigger a hard reject; not a low-weight optimization penalty.

ILLUSTRATIVE OPERATIONS

A six-hour vessel delay—what changes first?

Demonstration case, not a measured Jinhae outcome.

01 ARRIVAL

Vessel A is 6 hours late; scheduled calls B and C retain planned arrival times.

02 BERTH PLAN

Calculate occupied windows, compatible berth alternatives and downstream conflicts.

03 QC FLEET

Reassign only approved QC01–QC12, preserving active-shift limits.

04 VEHICLE / YARD

Recalculate AGV WSTP wait, eligible slot demand and potential rehandle chains.

05 GATE

Track yard release and external LSTP queue changes.

06 DECISION

Compare vessel delays, QC hours, yard conflicts and total service reliability.

Require event logs, reproducibility and feasibility evidence for all alternatives.

KPI DASHBOARD

Recommended executive scorecard

Metric	Definition	Interpretation
Berth utilization	Occupied berth-hours / available berth-hours	Need arrival/queue context
QC utilization	Productive QC time / declared available time	Separate idle and wait
Mean vessel waiting	Mean of valid berth-start minus arrival	Show P95 as well
Yard occupancy	Occupied eligible slots / effective slots	Break down by class/block
Gate throughput	Completed truck transactions / hour	Align transaction cut-off
AGV cycle	Travel + wait + handling per trip	Use legal route graph

Never reduce a terminal to a single aggregated percentage or an unvalidated animation.

07

Shift operating handbook

A repeatable control-room procedure for daily planning, monitoring, exception response and sign-off.

DAILY CONTROL

Before the morning shift

Give operators a finite checklist rather than another dashboard.

01	02	03	04	05
FREEZE	**RECONCILE**	**VERIFY**	**RUN**	**REVIEW**
Snapshot vessel calls, moves, yard inventory and asset availability.	Check shipment uniqueness, event keys, timestamps and slot capacity.	Check CAD graph, QC fleet, zone rules and gate service calendars.	Execute baseline and alternatives using versioned controls.	Approve human decision and retain exceptions.

Every run should have scenario ID, data hash, software version, random seed and responsible reviewer.

ALARM PHILOSOPHY

Operational alarms must be explainable

An alarm is an actionable finding with a cause and owner.

HARD HOLD

Physical infeasibility, duplicate slot occupancy, illegal route, missing critical geometry, crane fleet exceeded.

QUALITY WARNING

Estimated unit rate, incomplete truck record, unknown cargo classification or uncertain timestamps.

PERFORMANCE WARNING

Rising ship wait, QC starving, AGV congestion, yard near-capacity or gate P95 deterioration.

RELEASE GATE

Operations reviewer confirms scope, exceptions and service-risk trade-offs before dispatch.

Missing is not zero; unknown route is not a straight line; estimated KPI is not a measured outcome.

OPERATING SOP

Who does what—and what evidence remains

Role	Daily responsibility	Recorded evidence
Berth planner	Approve vessel/berth windows	Berth plan and conflicts
QC dispatcher	Apply crane/shift allocation	Active fleet and moves
Yard controller	Accept zone/slot plan	Slot eligibility and event chain
AGV controller	Validate legal routes and dispatch	Route graph and vehicle cycles
Gate supervisor	Set lanes and truck flow policy	Turnaround / queue records
Model reviewer	Check KPIs, fit and assumptions	Scenario report and sign-off

Actual role permissions and authorizations must be defined by the terminal operator.

EXCEPTION RESPONSE

Five-stage anomaly procedure

Never hide a failed constraint inside a KPI average.

01	02	03	04	05
DETECT	**CLASSIFY**	**ISOLATE**	**CORRECT**	**REPLAY**
Identify invalid state, count, event or source.	Separate safety/physical hold from data gap or metric warning.	Preserve source and stop infeasible candidate ranking.	Apply authorized source/master/rule repair in a controlled Stage.	Re-run same scenario and document reconciliation.

Leave production code, operating master data and public demos untouched until acceptance gates pass.

ACCEPTANCE

Jinhae pilot: example engineering acceptance gates

Gate	Evidence	Go / hold criterion
QC resource cap	QC identities never exceed configured fleet	HOLD if > QC12 in reference case
AGV route coverage	All path nodes matched to approved graph	HOLD unmatched/illegal paths
Yard safety	No invalid container/slot class placements	HOLD conflict candidates
Slot inventory	Event movement trace equals final slot status	HOLD unexplained mismatch
Gate/LSTP contract	Every truck transaction maps correctly	HOLD missing reference links
Reproducibility	Same scenario repeats same KPIs within rules	Investigate divergence

These are proposed verification gates, not certification that the current platform has passed all of them.

DATA INPUT

Minimum data needed for a credible deployment

A pilot begins with data ownership, not a sales promise.

VESSELS

ETA/ATA, berth windows, LOA, draft, cargo moves, gang and completion records.

EQUIPMENT

QC/AGV/yard machine masters, schedules, breakdowns, speeds and productivity logs.

YARD

Block, bay, row, tier, capacity, container class, stowage and movement histories.

ROADS / GATES

CAD layout, nodes, route permissions, truck appointments, lanes and timestamps.

SOURCE CONTROL

Unit system, file hashes, privacy approvals, estimate flags and data owners.

OPERATING TARGETS

Berth waiting SLA, turnaround, congestion, safety and approval thresholds.

08

Engineering verification & teaching cases

Measure what a port manager must be able to explain, not merely which buttons were pressed.

MODEL ASSURANCE

Historical model validation

Separate verification of code from validation against real operations.

01	02	03	04	05
VERIFY	**REPLAY**	**COMPARE**	**CALIBRATE**	**HOLDOUT**
Check conservation, feasibility and event-order invariants.	Reconstruct a defined historical vessel and gate period.	Calculate KPI errors using identical data definitions.	Investigate bias and change only documented assumptions.	Validate on unused events before presenting decision evidence.

Acceptance tolerances require agreement with the port operator; do not invent accuracy claims.

PRACTICAL EXERCISE

Training exercise: three decisions under pressure

Situation	Learner action	What is assessed
QC outage	Reassign work inside 12-QC cap	Resource feasibility
Yard block near full	Find compliant alternative slots	Safety and accessibility
Peak truck wave	Compare appointment/lane plans	Queue tail and transaction quality
AGV path disconnected	Report HOLD and root cause	Physical route integrity
Late vessel	Compare original vs revised berth sequence	Global KPI trade-off

Discussion question: which intervention truly improves the entire terminal instead of one local number?

PRESENTER DISCIPLINE

How to show the system to an authority

The demonstration sequence should make the mechanism and evidence visible.

SHOW THE PHYSICAL WORLD

First establish berth/yard geometry, vehicles and the source of every displayed movement.

CHANGE ONE DECISION

QC count, berth order, dispatch or yard rule—not multiple variables at once.

SHOW THE CAUSAL RESPONSE

Replay queues, movement, occupancy and time-to-completion under matched conditions.

SHOW THE DECISION RECORD

Report KPI comparison, physical constraints, assumptions, uncertainty and review status.

A smooth GIF is useful for communication; it is not a substitute for executable simulation evidence.

CUSTOMER DEMONSTRATION

30-minute operator-focused live demonstration

Select a fully verified module and keep a pre-run replay as contingency.

01	02	03	04	05
0–5 MIN	5–11 MIN	11–19 MIN	19–25 MIN	25–30 MIN
Business challenge and Jinhae reference layout.	Integrated vessel → QC → AGV → yard → gate model.	Change a crane/berth scenario, replay event and compare KPIs.	Show formulas, constraints, conflicts and audit trail.	Agree pilot data scope, success tests and owner.

Declare whether the screen is live execution, historical replay or illustrative model output.

CONSULTING ENGAGEMENT

Pilot deliverables a terminal authority can procure

A bounded, verifiable engagement is more credible than a generic productivity promise.

DIGITAL REFERENCE MODEL

CAD/asset graph, container/vehicle/vessel entities and documented source mapping.

REPRODUCIBLE BASELINE

Historical event replay with calibration summary and unresolved-source inventory.

SCENARIO TEST PACK

Berth, QC, AGV, yard and gate alternatives under equal workload and seed conditions.

OPERATIONAL DECISION REPORT

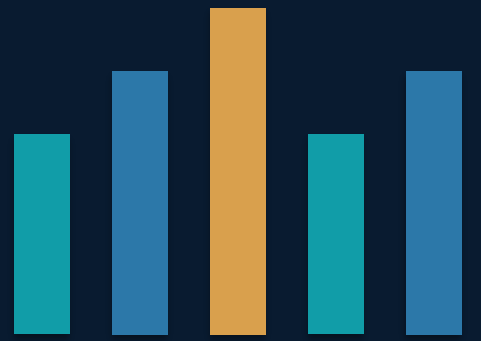
KPI definitions, uncertainty intervals, constraints, recommendation trade-offs and reviewer sign-off.

Commercial procurement and final go-live are subject to customer data access, technical validation and acceptance.

META PORT / PROFESSIONAL OPERATIONS SERIES

TEST THE REAL TERMINAL BEFORE CHANGING THE PLAN

A trustworthy digital twin joins physical constraints, event causality and explainable operating decisions.



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