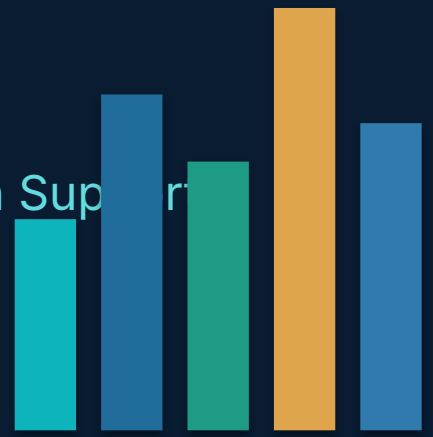
CONTAINER CBM LOAD OPTIMIZATION

3D Packing • Constraint Programming • Digital Simulation • Operational Decision Sup r



PROFESSIONAL TECHNICAL MANUAL | T2L Co., Ltd. / LOGI AI Research Institute | 2026

EXECUTIVE

The decision is not “How much volume fits?”

The true question: what quantity can be loaded, secured, transported and unloaded safely — with an auditable plan?

FEASIBILITY

Container interior geometry, pallet and carton dimensions, allowed orientations, handling clearance.

SAFETY

Payload, floor loading, center of gravity, stack strength, support, lashing and cargo compatibility.

OPERATIONS

Loading sequence, accessibility, discharge order, repacking, labor and execution time.

A 3D animation is evidence only when the underlying feasibility checks and event history can be reproduced.

SCOPE & PRODUCT INTEGRITY

What the current service card proves — and what the pilot must verify

The public-facing card reads “Container CBM · load optimization” and “container · ULD loading and CBM optimization.”

CONFIRMED FROM IMAGE

A named service entry exists with a “Open Service” button.

ENGINEERING METHOD

The following optimization equations and simulation workflow are recommended analytical design.

NOT YET VERIFIED

Live APIs, optimization engine, speed, actual datasets, packing guarantees and UI outputs require direct product audit.

This is an expert technical and adoption manual, not a claim that every described function is already deployed.

01

Understand the loading problem

Units, cargo geometry, load envelopes and the operational objective.

INPUT CONTRACT

Define the loading unit precisely

Do not confuse maritime freight containers with aircraft ULDs; they have different operating and safety constraints.

SEA CONTAINER / CTU

Use approved internal clear dimensions, door aperture, payload, floor-strength and packing/securing plan.

AIRCRAFT ULD

Use an approved ULD type, contour, maximum gross mass, position and aircraft/airline restrictions.

CARGO UNIT

Length, width, height, gross mass, SKU, orientation, stackability, crush limit, hazard class and delivery order.

HANDLING UNIT

Pallet, carton, roll, crate, drum or irregular cargo — each with a defined bounding geometry.

CTU Code and IATA ULDR are separate reference frameworks; never apply a sea-container rule automatically to aircraft ULDs.

MEASUREMENT

Geometric volume and declared CBM

$$V_i = (L_i \times W_i \times H_i) / 10^6 \ [m^3]$$

VARIABLES & UNITS

L, W, H in millimeters; V_i in cubic meters; n_i = unit quantity.

OPERATING DECISION

CBM is a volume descriptor, not proof that an item can physically fit through the door or into the loading envelope.

EXAMPLE | 1,200 × 800 × 1,000 mm → 0.96 m³ MODEL BOUNDARY | Rotate dimensions only among permitted orientations.

UTILIZATION

Nominal volume utilization

$$U_V = \Sigma_i (n_i \times V_i) / V_{usable}$$

VARIABLES & UNITS

V_usable = declared usable interior volume [m³], not always the external or nominal container CBM.

OPERATING DECISION

Use volumetric fill as one KPI after feasibility checks; report denominator provenance.

EXAMPLE | 49 m³ / 58 m³ = 84.5% MODEL BOUNDARY | Irregular shapes, voids, securing space and access reduce achievable packing density.

PAYLOAD

Mass utilization

$$U_M = \Sigma_i (n_i \times m_i) / M_{payload}$$

VARIABLES & UNITS

m_i = gross mass of cargo unit i [kg]; M_payload = allowable payload [kg].

OPERATING DECISION

A volume-rich plan may exceed mass capacity before reaching full CBM.

MODEL BOUNDARY | Use the lesser of equipment, route, carrier, legal and position-specific limits.

DENSITY

Cargo density screen

$$\rho_i = m_i / V_i \quad [kg/m^3]$$

VARIABLES & UNITS

m_i in kg; V_i in m^3; use gross package values when screening handling demand.

OPERATING DECISION

Identify heavy/compact items likely to constrain weight distribution before pure volume fill.

MODEL BOUNDARY | Density alone is not sufficient to determine floor loading or stackability.

OPERATING WORKFLOW

Preflight an optimization run

Agree the input contract before selecting an algorithm.

01	02	03	04	05	06
IMPORT	**VALIDATE**	**CLASSIFY**	**BOUND**	**SOLVE**	**APPROVE**
Load manifest; enforce IDs, dimensions, mass and units.	Check duplicate records, zero dimensions, missing rotations.	Group cargo by loading unit and constraints.	Calculate lower bounds and feasibility screens.	Generate and test placement alternatives.	Review evidence; release a supervised loading plan.

A missing cargo mass or unknown safety parameter is a HOLD or explicitly flagged estimate, never silently zero.

02

Mathematical optimization

Formal placement variables, objective functions and hard constraints.

MATHEMATICAL MODEL

Container selection variables

$$y_k \in \{0,1\};\ x_{ik} \in \{0,1\};\ \Sigma_k x_{ik} = 1$$

VARIABLES & UNITS

x_ik = 1 if item i is assigned to load unit k; y_k = 1 if k is used.

OPERATING DECISION

Model multi-container load plans and avoid losing or double-allocating cargo units.

MODEL BOUNDARY | Constraints enforce x_ik ≤ y_k; special partial-shipment rules must be explicit.

MATHEMATICAL MODEL

Load-count minimization

$$\text{Minimize } \Sigma_k c_k \times y_k + \lambda \times \text{HandlingPenalty}$$

VARIABLES & UNITS

c_k = all-in cost of unit k; λ = declared operational penalty weight.

OPERATING DECISION

Optimize total plan cost rather than only minimizing the container count.

MODEL BOUNDARY | Penalty coefficients should be normalized and approved by the customer.

MATHEMATICAL MODEL

Orientation selection

$$r_{io} \in \{0,1\};\ \Sigma_o r_{io} = 1$$

VARIABLES & UNITS

o indexes allowed orientations; geometry rotates with orientation selection.

OPERATING DECISION

Constrain carton “this side up”, fragile, liquid or equipment-specific restrictions.

MODEL BOUNDARY | Not every 90° rotation is physically or commercially permissible.

3D PLACEMENT

Container envelope

$$0 \le X_i \le L - l_i \; ; \; 0 \le Y_i \le W - w_i \; ; \; 0 \le Z_i \le H - h_i$$

VARIABLES & UNITS

(X_i, Y_i, Z_i) = placement origin; l, w, h = oriented package dimensions.

OPERATING DECISION

Establish geometric containment for every placement.

MODEL BOUNDARY | Use effective interior/door/contour envelopes and handling clearance, not just a perfect rectangular box.

3D PLACEMENT

Non-overlap disjunction

For i ≠ j: one axis must separate i and j

VARIABLES & UNITS

Either $X_i+l_i \le X_j$, $X_j+l_j \le X_i$, $Y_i+w_i \le Y_j$, $Y_j+w_j \le Y_i$, $Z_i+h_i \le Z_j$, or $Z_j+h_j \le Z_i$.

OPERATING DECISION

Prevent impossible placements that visually intersect; MILP uses big-M disjunctive binaries or a CP-SAT NoOverlap formulation.

MODEL BOUNDARY | Numerical tolerances and clearances must be specified.

PHYSICAL SAFETY

Payload feasibility

$$\Sigma_i m_i x_{ik} \leq Payload_k \times y_k$$

VARIABLES & UNITS

All masses and limits in kg.

OPERATING DECISION

Reject overweight plans even when geometric fit is excellent.

MODEL BOUNDARY | ULD gross-mass limits can be position-specific; cargo + device tare must be handled consistently.

PHYSICAL SAFETY

Longitudinal center of gravity

$$x_{CG} = [\Sigma_i m_i (X_i + l_i/2)] / \Sigma_i m_i$$

VARIABLES & UNITS

X_i is measured from a documented container datum [m]; m_i is item gross mass.

OPERATING DECISION

Detect imbalanced fore/aft loading; similarly compute y_{CG} and z_{CG}.

MODEL BOUNDARY | Acceptable range must come from the relevant equipment/transport instruction; do not invent a universal threshold.

PHYSICAL SAFETY

Floor contact pressure

$$p_i = (m_i \times g) / A_{contact,i} \ [Pa]$$

VARIABLES & UNITS

g = 9.81 m/s²; A_contact is effective supported contact area [m²].

OPERATING DECISION

Identify local concentrated loads requiring spreaders, dunnage or rejection.

MODEL BOUNDARY | Actual floor and wheel/point-load limits depend on equipment; average floor pressure is not enough.

STACKING

Support and crush-load check

$$F_{supported,i} \leq F_{allowable,i}$$

VARIABLES & UNITS

F_supported = downward load transferred to item i; F_allowable from package strength/safety factor.

OPERATING DECISION

Avoid placing heavy cargo on fragile or insufficiently supported packages.

MODEL BOUNDARY | Support area, load transfer path and dynamic effects must be modeled; gross mass alone is insufficient.

CARGO SECURING

Simplified inertial load screening

$$F_d = m \times a_{design}$$

VARIABLES & UNITS

m = cargo mass; a_design = transport-mode/design-direction acceleration [m/s²].

OPERATING DECISION

Translate transport accelerations into securing demand during engineering checks.

MODEL BOUNDARY | Never treat this expression as a complete lashing design; use applicable CTU guidance and engineering verification.

SEQUENCE

Accessibility and discharge order

$$t_{load,i} < t_{load,j} \Rightarrow \text{precedence constraints}$$

VARIABLES & UNITS

Delivery order, stop sequence and access corridors may impose precedence between cargo units.

OPERATING DECISION

A geometrically feasible plan can still fail because earlier-destination cargo is buried.

MODEL BOUNDARY | Precedence logic differs for rear-door, side-door and ULD handling contexts.

03

Simulation before deployment

Turn static placement into a repeatable loading, handling and unloading experiment.

DIGITAL SIMULATION

Event-driven model of a load plan

Simulation checks actions, dependencies and interruptions, not just a colorful 3D snapshot.

01	02	03	04	05	06
SELECT	**CHECK**	**MOVE**	**PLACE**	**SECURE**	**TRACE**
Read next cargo and planned position.	Validate corridor, orientation and support.	Reserve equipment and travel path.	Update remaining geometry and center of mass.	Add restraint and inspection events.	Store time, action, resource, result and reason.

Replay requires run ID, data version, model version, unit ID, event time and random seed where stochastic inputs exist.

SIMULATION STATE

Discrete-event transition

$$S(t^{+}) = F[S(t^{-}), \text{event}, \text{rules}, \text{resources}]$$

VARIABLES & UNITS

S = occupied geometry, mass/CG, resources, queues, loading sequence and state of securing.

OPERATING DECISION

An item placement must propagate into subsequent free-space and handling feasibility.

MODEL BOUNDARY | Evidence of a real simulation requires event logs, not merely a pre-recorded movement animation.

SIMULATION CLOCK

Simulation event timing

$$t_{(k+1)} = \min \{ t_e : \text{event } e \text{ is admissible} \}$$

VARIABLES & UNITS

The event queue contains handling start/end, move, place, inspect, reject and unload.

OPERATING DECISION

Quantify total build time, queue delays and rework under different staffing and equipment choices.

MODEL BOUNDARY | A simulation step may advance at nonuniform intervals; video frame count is not its time base.

LABOR AND HANDLING

Total loading time

$$T_{total} = T_{setup} + \Sigma_i T_{handle,i} + T_{wait} + T_{secure} + T_{inspect}$$

VARIABLES & UNITS

Units are minutes or hours; each term must have a defined event boundary.

OPERATING DECISION

Compare a fast but unstable packing order with one that reduces handling conflicts.

MODEL BOUNDARY | Do not double-count concurrent handling activities; use event-based makespan if parallel.

STOCHASTIC EVALUATION

Expected KPI over replications

$$\hat{\mu}_{KPI} = \frac{1}{R} \sum_{r=1}^{R} KPI_r$$

VARIABLES & UNITS

R = number of independent replications using documented seed sets.

OPERATING DECISION

Use repeated simulation for variable handling time, defects, congestion and delays.

MODEL BOUNDARY | Replications must share comparable assumptions when alternatives are ranked.

STATISTICAL ASSURANCE

Approximate confidence interval

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

VARIABLES & UNITS

s = replication standard deviation; use Student-t critical value for finite R.

OPERATING DECISION

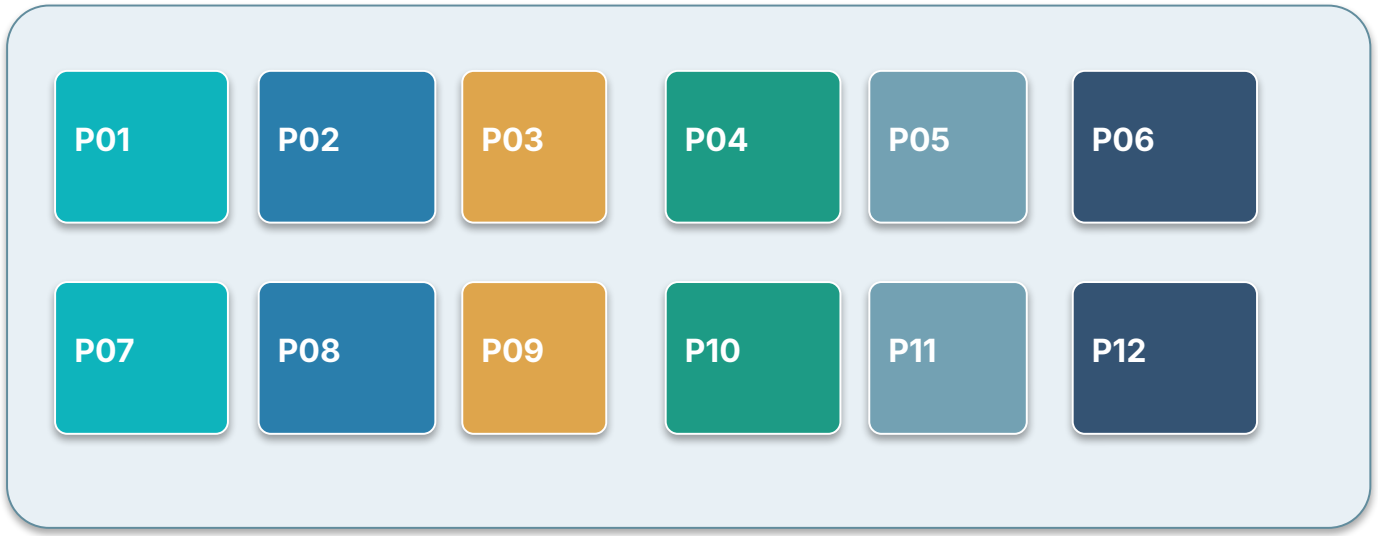
Show uncertainty rather than marketing a single best-case packing result.

MODEL BOUNDARY | Depends on approximately independent replications and appropriate sampling.

SIMULATION VISUALIZATION

From candidate coordinates to a feasible loading plan

Illustrative schematic: a packing visualization is only the surface of a constraint-checked model.



TOP VIEW • All labels and dimensions are schematic

Every proposed placement

- ✓ Inside geometric envelope
- ✓ No overlap / orientation valid
- ✓ Payload and support compliant
- ✓ Unload sequence accessible

ILLUSTRATIVE SCHEMATIC ONLY | No live optimizer, CAD connection or measured packing efficiency is asserted.

SCENARIO COMPARISON

Why a single “maximum CBM” KPI is misleading

Illustrative alternatives only — not measured system outputs.



A plan with a higher nominal fill ratio is not superior if it violates payload, floor loading, securing or unloading rules.

ALGORITHM ENGINEERING

Solver architecture: no single algorithm fits every job

A robust optimizer combines fast feasibility checks, constructive placements and repeatable improvement search.

PRE-PROCESS

Normalize units; remove impossible orientations; detect overweight single items.

CONSTRUCTIVE HEURISTIC

First-fit decreasing, maximal rectangles/empty spaces or layer-building.

CONSTRAINT SOLVER

CP-SAT or MILP for tightly constrained smaller instances and critical subproblems.

LOCAL SEARCH

Swap, relocate, reorient and re-sequence moves with hard-constraint preservation.

SIMULATION EVALUATOR

Replay loading, handling and unloading, rejecting infeasible plans.

EXPLAINABILITY

Report why an alternative was rejected: volume, weight, CG, support, corridor or sequence.

Algorithm options presented as engineering methods; exact implemented solver in the current service has not been verified.

LOWER BOUND

Volume- and payload-based lower bound

$$K_{LB} \geq \max(\text{ceil}(V_{total} / V_{unit}), \text{ceil}(M_{total} / M_{payload}))$$

VARIABLES & UNITS

Assumes identical units and full geometric utilization; first-pass lower bound only.

OPERATING DECISION

Prove that fewer containers are impossible under basic capacity constraints, then apply packing and safety restrictions.

MODEL BOUNDARY | Actual feasible number may exceed this bound due to geometry, compatibility and handling.

KPI SYSTEM

Effective utilization versus nominal fill

$$U_{feasible} = V_{loaded,approved} / V_{usable}$$

VARIABLES & UNITS

Numerator includes only cargo in plans passing all configured mandatory gates.

OPERATING DECISION

Prevent high utilization values from hiding unsafe, inaccessible or infeasible packing.

MODEL BOUNDARY | Operational definition and tolerance must be agreed before performance claims.

04

Worked engineering case

An illustrative numerical example that operators can audit line by line.

WORKED CASE

Illustrative cargo manifest — not customer data

All example values below are invented solely to explain methods.

CARGO A

40 cartons; 1.0 × 0.8 × 0.6 m; 180 kg each; upright only.

CARGO B

20 crates; 1.2 × 1.0 × 0.8 m; 400 kg each; no stacking above.

CARGO C

16 cartons; 1.0 × 1.0 × 1.0 m; 250 kg each; stack strength to validate.

Gross masses, dimensions and packaging rules must be supplied and signed off before a real optimization run.

WORKED CASE

Total volume and payload

$$V = 40(0.48) + 20(0.96) + 16(1.00) = 54.4\ m^3$$

VARIABLES & UNITS

Unit volumes: A = 0.48 m³, B = 0.96 m³, C = 1.00 m³.

OPERATING DECISION

A plan may have adequate nominal volume yet still fail due to shape, no-stack restrictions and door opening.

MODEL BOUNDARY | All values illustrative only.

WORKED CASE

Total cargo mass

$$M = 40(180) + 20(400) + 16(250) = 19{,}200 \text{ kg}$$

VARIABLES & UNITS

40 A, 20 B, 16 C cargo units; gross mass in kg.

OPERATING DECISION

Compare with the actual selected unit payload and transport limits; do not assume a named 40-ft container has a universal payload.

MODEL BOUNDARY | Payload screening is only the first safety gate.

WORKED CASE

Volume result under an assumed unit

54.4 m³ / 58.0 m³ = 93.8% nominal volume

VARIABLES & UNITS

Assumed effective interior volume = 58.0 m³ for teaching only.

OPERATING DECISION

A near-full nominal plan is not accepted until each box fits, support and stacking constraints hold, CG is approved and exit sequence works.

MODEL BOUNDARY | The chosen 58 m³ value is illustrative, not a manufacturer specification.

WORKED CASE

Audit the candidate plan

Use six review gates, always in a consistent order.

01	02	03	04	05	06
GEOMETRY	**MASS**	**BALANCE**	**SUPPORT**	**ORDER**	**EVIDENCE**
Inside envelope; no overlap; door entry.	Payload and gross-mass limits.	CG and load distribution.	Floor and lower-tier cargo loads.	Load and discharge accessibility.	Traceable replay and acceptance.

A candidate failing one mandatory constraint is REJECTED regardless of nominal CBM utilization.

ALTERNATIVE DECISION

What a decision report should show

Do not substitute a simple fill percentage for a decision-grade loading plan.

ACCEPTED

Unit IDs, cargo allocated, layout and orientation, utilization and total mass.

REJECTED

Item ID, violated rule, threshold, impact and proposed corrective action.

OPERATIONS

Loading sequence, handling paths, accessible exits, resource demand and planned labor hours.

AUDIT

Manifest hash, solver version, scenario ID, parameter set, seed, approval and export timestamp.

Illustrative management reporting contract; field availability must be confirmed against the current application.

05

Operator procedures & governance

A textbook-style operating discipline for repeatable results.

STANDARD OPERATING PROCEDURE

Daily loading-plan process

Role-based checkpoints separate optimization from release authorization.

01	02	03	04	05	06
RECEIVE	**RECONCILE**	**CONFIGURE**	**SIMULATE**	**REVIEW**	**RELEASE**
Manifest and equipment list; freeze source version.	Check cargo counts, duplicates and exceptions.	Select CTU/ULD and safety rule profiles.	Run candidates and record rejected placements.	Confirm balance, support and securing.	Export approved plan and retain evidence.

Approval authority rests with qualified operators; the simulator does not replace legal or safety responsibility.

ACCEPTANCE

Model verification and acceptance matrix

Test each rule with a deliberately failing example and an expected rejection message.

TEST	EXPECTED RULE	PASS EVIDENCE
Oversized item	No illegal dimension or door pass	Rejected with geometry reason
Overweight manifest	Gross/payload limit enforced	Rejected with mass reason
CG displacement	Permitted balance envelope	Rejected or warning per rule
Unsupported stack	Support & crush constraint	Rejected with support reason
Blocked discharge	Destination precedence maintained	Sequence conflict explained
Repeatability	Same snapshot+seed+version	Same output and event hash

Acceptance thresholds are equipment/site-specific. The model must expose rule sources and versions.

KPI DASHBOARD

What management should monitor daily

Separate efficiency from safety and execution reliability.

KPI	DEFINITION	MANAGEMENT USE
CBM utilization	Approved loaded volume / usable volume	Space efficiency
Payload utilization	Approved gross cargo / payload	Mass capacity
Rejected items	Count by constraint cause	Data and planning quality
Build makespan	Last finish – first start	Labor/resource productivity
Rework ratio	Repacked or moved / loaded units	Plan executability
Simulation validity	Tests passed / tests required	Trust in model output

Never publish customer benefit percentages without a measured baseline and comparable tested alternative.

EXCEPTION GOVERNANCE

Five reasons to stop an automatic plan

Software should fail safely and visibly.

DATA GAP

Missing unit, gross weight, dimensions, package restrictions or equipment profile.

PHYSICAL FAILURE

No legal 3D placement or door path; collision or overhang.

SAFETY FAILURE

Payload, floor pressure, support, mass distribution or securing not demonstrated.

OPERATIONS FAILURE

Required pickup/discharge sequence or handling equipment cannot execute.

EVIDENCE FAILURE

Mismatch between manifest, optimizer result, visualization and exported plan.

Statuses should distinguish NOT_AVAILABLE, ESTIMATED, FAILED and APPROVED — never convert unknown data into a silent PASS.

PILOT DELIVERY

A practical 6-step customer pilot

Start small enough to validate technically, but broad enough to prove operational value.

01	02	03	04	05	06
SCOPE	**DATA**	**BASELINE**	**CALIBRATE**	**COMPARE**	**REPORT**
Define sea CTU or air ULD use case, acceptance thresholds.	Gather two typical and one difficult manifest.	Measure manual plan and actual handling.	Check equipment, solver constraints and time model.	Same loads; compare feasible alternatives.	Operational evidence, economics and scale-up gate.

Pilot outcomes are recommendations for future validation, not already-achieved product performance.

COMMERCIAL VALUE

Per-shipment avoided total cost

$$\Delta C = C_{baseline} - C_{proposed} - C_{implementation}$$

VARIABLES & UNITS

Costs may include equipment count, freight, labor, rework, damages, detention and software integration.

OPERATING DECISION

Translate simulation outputs into a case for adoption, with sensitivity analyses for volumes and tariffs.

MODEL BOUNDARY | No ROI claim without customer data and observed counterfactuals.

ROI METHODS

Net present value of a validated rollout

$$NPV = -I_o + \Sigma_{t=1}^{T} \left[(Benefits_t - Costs_t)/(1+r)^t \right]$$

VARIABLES & UNITS

I_o = implementation investment; r = discount rate; T = benefit horizon.

OPERATING DECISION

Compare adoption options under consistent financial assumptions; report risk and uncertainty.

MODEL BOUNDARY | Illustrative financial method, not a promised return.

20-MINUTE DEMONSTRATION

A live demo that wins technical trust

Ask the prospective customer to provide one difficult cargo mix and test whether the plan is both dense and feasible.

00–03 MIN | PROBLEM

Show the manifest, constraints, units and original manual plan.

03–07 MIN | SOLVE

Explain candidate generation and hard constraints; run multiple alternatives.

07–12 MIN | SIMULATE

Replay handling, packing, accessibility and unload events; show rejection reasons.

12–16 MIN | QUANTIFY

Compare approved volume, payload, makespan, rework and cost.

16–20 MIN | COMMIT

Propose a scoped pilot with jointly agreed acceptance criteria.

Do not claim a live solver or measured advantage unless the installed service passes a witnessed end-to-end test.

06

The adoption proposition

From a visually attractive calculator to auditable loading intelligence.

WHY ADOPT

A decision-grade platform earns trust in three ways

The customer does not buy a colored packing diagram; they buy repeatability, fewer errors and defendable decisions.

EXPLAIN THE PLAN

Transparent variables, equations, safety gates and why a load was approved or rejected.

SIMULATE EXECUTION

Time-sequenced placement, labor, handling restrictions and unloading feasibility.

PROVE THE ECONOMICS

Baseline-to-alternative comparison, uncertainty, operational sign-off and traceable exports.

Commercial promise: validate one real manifest before asking the customer to scale.

DEPLOYMENT MATURITY

What is demonstrated, designed or still to be confirmed

A clear maturity statement helps customers trust technical communications.

ELEMENT	STATUS IN THIS MANUAL	REQUIRED EVIDENCE
Service card	Observed in supplied screenshot	Link and screen capture
Formulas and constraints	Engineering reference model	Design review and rule mapping
Optimization engine	Implementation unverified	Code/API walk-through
3D/event simulation	Implementation unverified	Replay log and video sync
Measured customer value	Not supplied	Pilot benchmark and cost model

Scope and maturity statements are intentionally explicit to avoid overstating deployed capabilities.

SOURCES & STANDARDS

Reference framework for professional engineering

Confirm applicability, revision and customer-specific requirements before operational adoption.

IMO / ILO / UNECE CTU CODE

Non-mandatory code of practice for packing and securing cargo transport units in intermodal chains. imo.org / unece.org

IATA ULD REGULATIONS

ULD technical, operational, contour, weight and aircraft compatibility framework. iata.org

CUSTOMER DOCUMENTS

Container/ULD manufacturer data, shipper packaging limits, carrier approvals and route constraints.

MODEL EVIDENCE

Input manifest, geometry model, rule config, scenario ID, event logs, simulation outputs and sign-off.

This manual provides analytical methods; it does not substitute for approved instructions or certified load restraint design.

THE NEXT STEP IS A WITNESSED PILOT

PROVE THAT THE LOAD FITS — AND WORKS.

Select one real load, validate the rules, simulate the sequence, compare alternatives, and approve the result with evidence.