Self-Healing Supply Chains from the Shipment Up

Semarx Research · White paper

We measure **predictability** everywhere in the supply chain: on every leg, along every shipment's path, and across the whole network. Each shipment has its own digital twin, which adjusts its route as the **predictability** of its path changes.

What is new: a shipment digital twin that measures predictability

Most self-healing designs build a supply chain digital twin: one central model that tracks outcomes and decides for every shipment. We build a shipment digital twin instead. The decision moves to the shipment; the network learns, keeping a shared vocabulary and a shared record from which **predictability** is read at every scale.

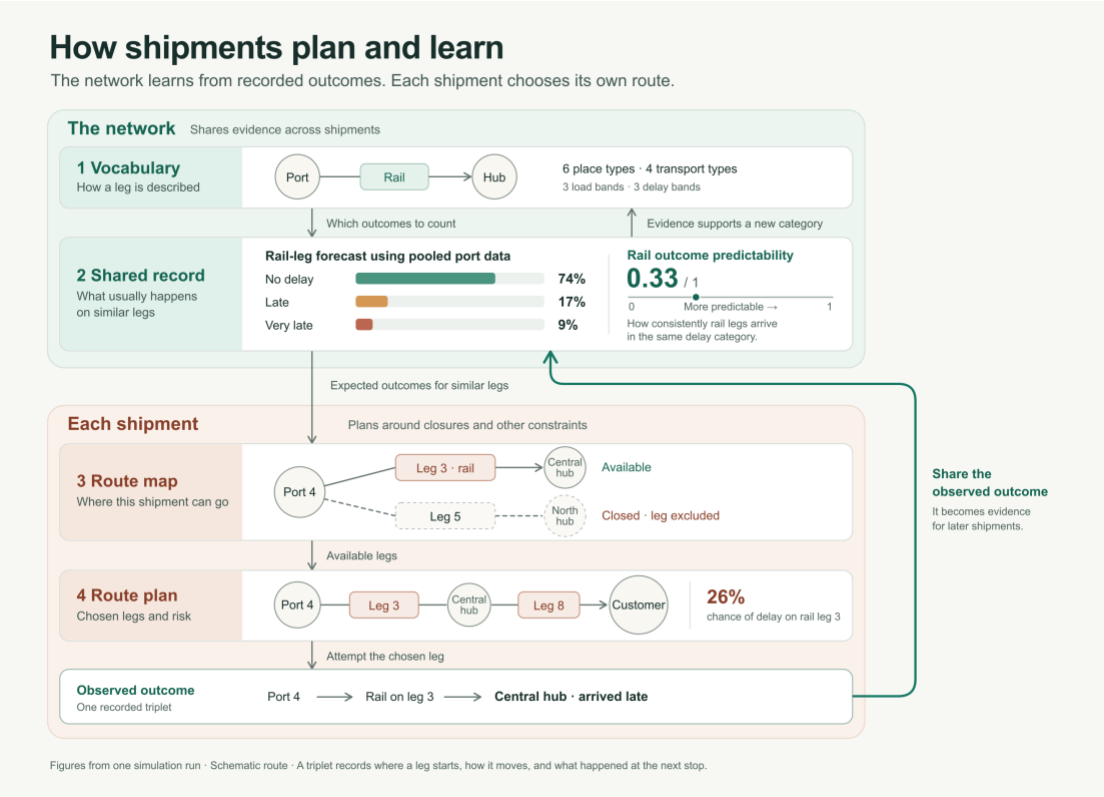


Figure 1. How shipments plan and learn: the four levels, the triplet, and the information that moves between the network and each shipment.

1. **Vocabulary: everything is a triplet.** A small set of types (6 place types, 4 transport types, 3 load bands, 3 delay bands) describes every leg as one triplet: where it started, how it moved, where it ended up, such as port → rail → hub. Because every shipment uses the same types, legs from different places add up.
2. **Shared record: distributions and their predictability.** Counting triplets shows what usually happens on each kind of leg. Pooled over port rail legs: 74% no delay, 17% late, 9% very late, a **predictability** of 0.33 out of 1. When **predictability** drops, the process on that kind of leg has changed.
3. **Route map: the shipment digital twin sees its path.** Each shipment digital twin keeps the legs it can still use and reads the **predictability** of each. Leg 3 by rail from Port 4 to the Central hub is available; leg 5 to the closed North hub is excluded.

4. **Route plan: the shipment adjusts as its path changes.** The shipment digital twin chooses its legs and reads their risk from the shared record: a 26% chance of delay on rail leg 3. When the **predictability** of its path changes, it rebuilds its plan.

Each completed leg becomes one triplet of evidence for every later shipment. When one type covers places that behave differently, the network proposes a new type and a planner approves it.

What we measure: predictability, not only outcomes

	What others measure	What we measure
The question	Did the shipment arrive on time?	How sure is the next step, given where the shipment is and how it moves?
The signal	on-time rate, cost, error in estimated arrival time	**predictability** of every leg, every path and the whole supply chain
When it moves	after outcomes have moved	as the process itself changes
Who acts on it	a central twin, for all shipments	each shipment digital twin, on its own path

Predictability is measured at three scales from the same triplets:

Scale	What predictability tells	Who uses it
Leg (one triplet)	how consistently this kind of leg ends in the same outcome	the network, to locate change
Path (one shipment's route)	how sure the shipment can be of its route, leg by leg	the shipment digital twin, to keep or rebuild its route
Supply chain (all triplets)	where the network is becoming more or less predictable	planners, as a reading of the whole supply chain

Results at a glance

In a simulated supply chain of 300 places:

- **Predictability showed where the process changed, and the cause was named.** Rail out of a busy port degraded without notice. Its **predictability** fell by more than half within seven weeks while other ports held steady. The network proposed a new type 7 to 9 weeks after the change began and identified rail access as the cause in 6 of 6 runs, with no false alarms in runs where nothing changed.
- **The lesson reached a place with almost no evidence of its own.** A quiet port with the same rail access inherited it: its rail leg's expected delay rose from 26% to 37%, and its forecasts improved in 4 of 4 runs.
- **Shipments rebuilt their paths around a closed hub.** Through the shared record, 8 of 24 and 6 of 18 shipments dropped a closed lane before reaching it; without sharing, none did (0 of 21).

The challenge

- **Outcome measures see that something changed, not where or why.** On-time rates can be held steady by buffers and expediting while the process underneath becomes less predictable.
- **A supply chain digital twin has to mirror everything.** One network-wide model must stay in step with reality, and it drifts as lanes, carriers and volumes change.
- **Learning stays local.** What one shipment meets at a disrupted port rarely reaches the next shipment heading for a similar place.

The simulation

Scope. A supply chain of 300 places (suppliers, factories, ports, hubs, distribution centres, customers) in three regions, joined by about 1,200 truck, rail, sea and air lanes. 60 new shipments start each day, about 800 are on the move at any time, in three classes: express (30%), cheapest (50%) and food (20%). Delays, congestion and hub capacity follow hidden rules that no shipment and no part of the network can see. Legs are counted daily; each week the network checks whether legs of one type still behave alike.

Runs. Thresholds were set on separate runs where nothing changed. Results come from fresh runs: six with the port change, two with no change, three hub closures (two with sharing, one without), and a step-by-step replay.

Scenario	What happens	What it shows
Learn	rail at a busy and a quiet port, both with off-dock terminals, degrades unannounced	**predictability** shows the change; the lesson reaches the quiet port
Heal	the North hub closes; three displaced shipments request one free Central hub slot	shipment digital twins rebuild their own paths
Sham	nothing changes	control: nothing may fire

Results

Learning: predictability at the leg and the network (levels 1 and 2).

Result	Evidence
Change visible in **predictability**	the busy port's rail lost more than half its **predictability** within seven weeks; rail at other ports held steady
Cause named	new type proposed 7 to 9 weeks after the change began; rail access selected, not region or port size, in 6 of 6 runs; none in no-change runs
Lesson transfers	the quiet port's forecast improved in 4 of 4 runs where it also degraded; its rail leg's expected delay rose 7 to 11 points before any evidence from the quiet port

Healing: each shipment's path (levels 3 and 4).

- **Each shipment digital twin repairs its own path, and sharing spreads healing.** Every shipment that met a closed lane dropped it; with the shared record, 8 of 24 and 6 of 18 did so before reaching it (0 of 21 without).
- **Hub closure, step by step.** The North hub closes on day 10. Its three shipments each replan toward the Central hub. The network allocates the one free slot to the food shipment by priority, the two confirmed reservations stand, and the other two shipments switch to the South hub. All five keep a feasible plan.

What is next

1. **Predictability of paths and of the whole supply chain,** reported run by run, and healing at scale across many hub closures.
2. **Partner pilots:** measuring the **predictability** of a partner's own shipment records. Semarx provides the method and the engineering capability to build it into a partner's own systems.