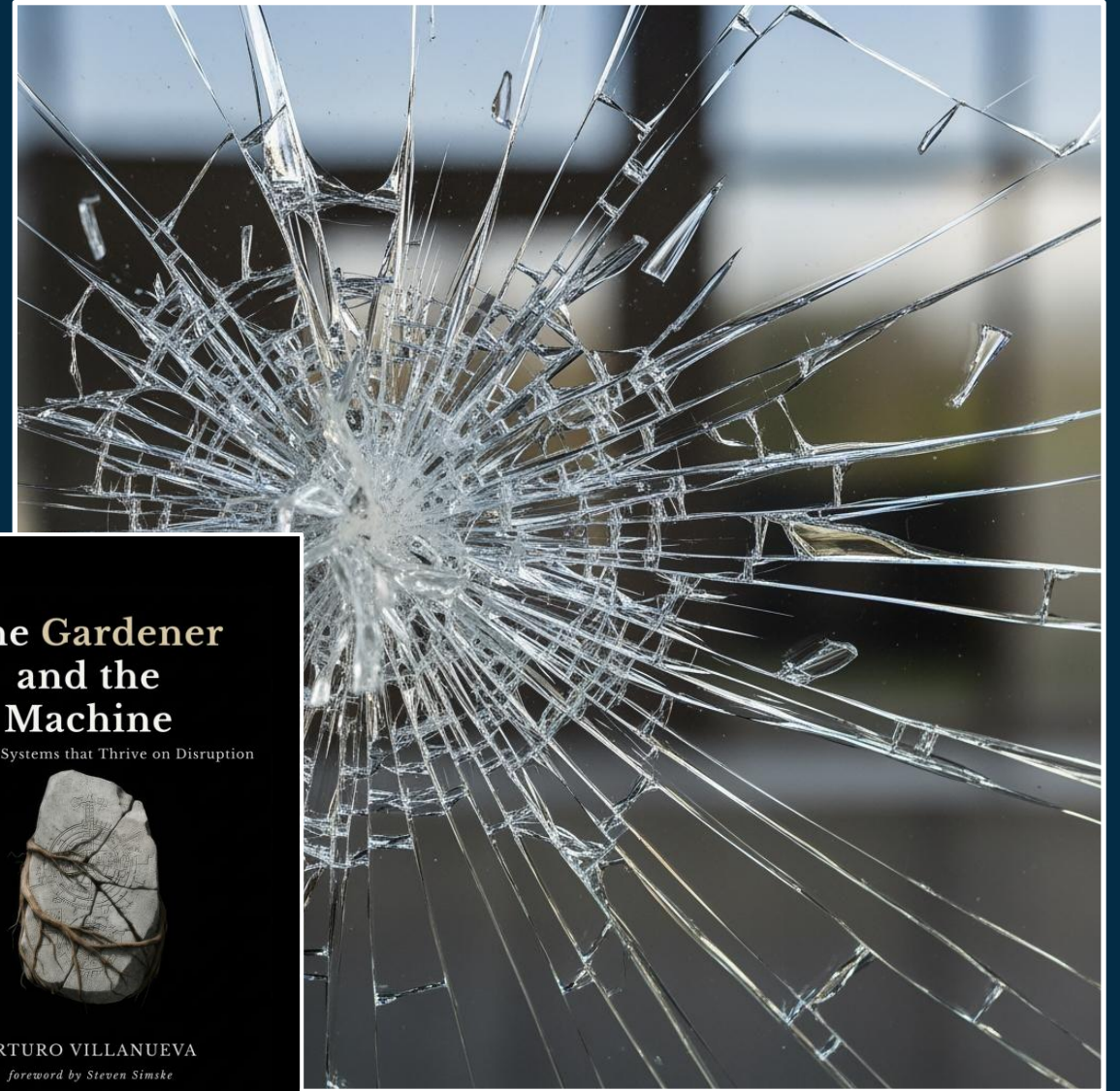
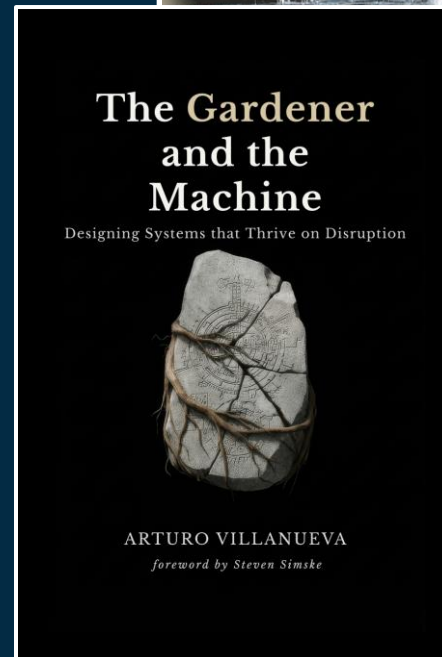


The Fragility of Efficiency

Supply Chains, Traffic Lights, and MBSE

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PHRONOS



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Dr. Art Villanueva is the author of the book ***The Gardener and the Machine: Designing Systems that Thrive on Disruption.*** He is a systems engineer and AI practitioner who tackles complex, real-world challenges as the founder of Phronos, and as a Senior Staff Engineer developing next-generation aerospace technologies at General Atomics.

Dr. Villanueva's career spans defense, clean tech, and enterprise strategy, including leadership roles at Northrop Grumman and Dell Technologies. He is a published researcher, holds multiple U.S. patents, and is a certified INCOSE ESEP.



Agenda



- I. The Illusion of Control
- II. The Technological Domain (Optimizing for Cost)
- III. The Biological Domain (Optimizing for Speed)
- IV. The Social Domain (Optimizing for Compliance)
- V. Conclusion
- VI. Question-Answer-Discussion



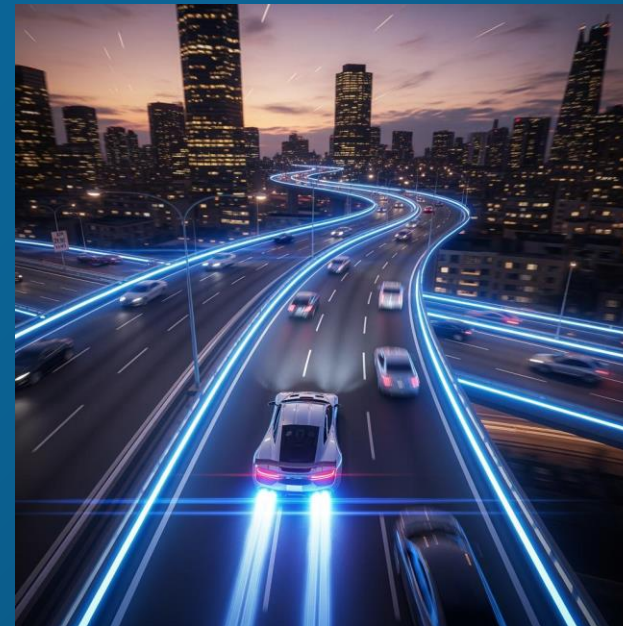
The Illusion of Control

When Optimization Backfires

- We are very good at optimizing code, schedules, cost, etc.
- Result: Breakage → cascading failure



Packing your schedule to 100% capacity



Driving the fastest possible route

Tightly Coupled Systems

- Small changes don't stay small
- Efficiency can create fragility



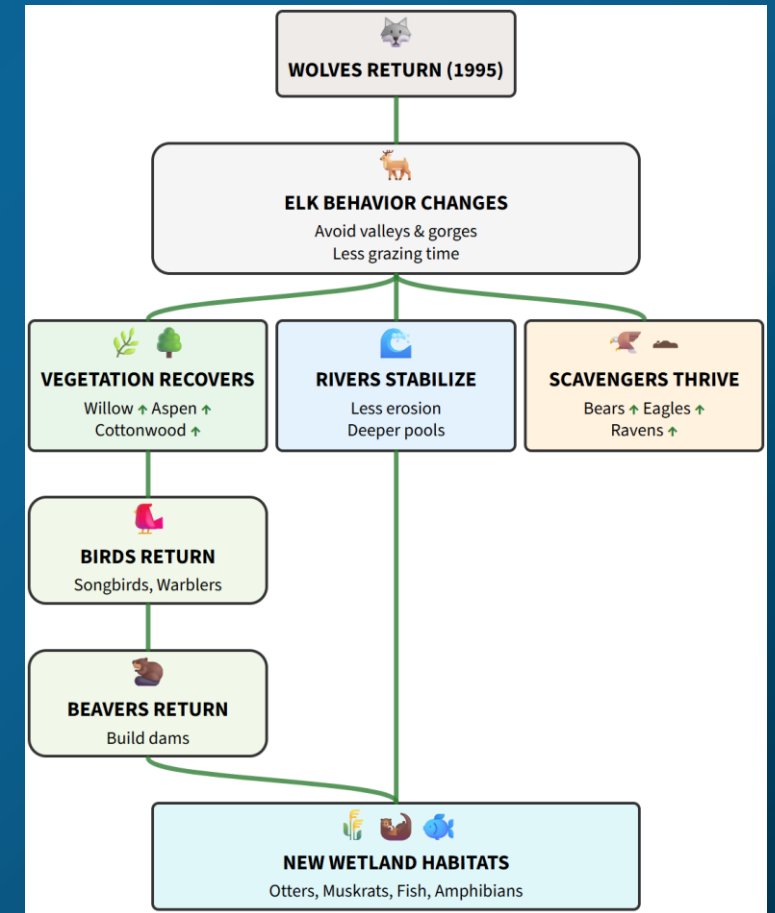
A delayed flight cascades across the entire network



One late supplier halts final assembly of a plane

Complex Adaptive System (CAS)

- A system composed of many interacting agents that are capable of learning and adapting.
- CASs are characterized by **self-organization**, **nonlinearity**, and the **emergence** of patterns that are not dictated by a central controller.
- A more recent example: The introduction of buffalo (keystone species) in the prairies and savannas of Illinois



The Gardener vs. The Mechanic

- We have an “Illusion of Control”: the belief that complex systems can be optimized like complicated machines.

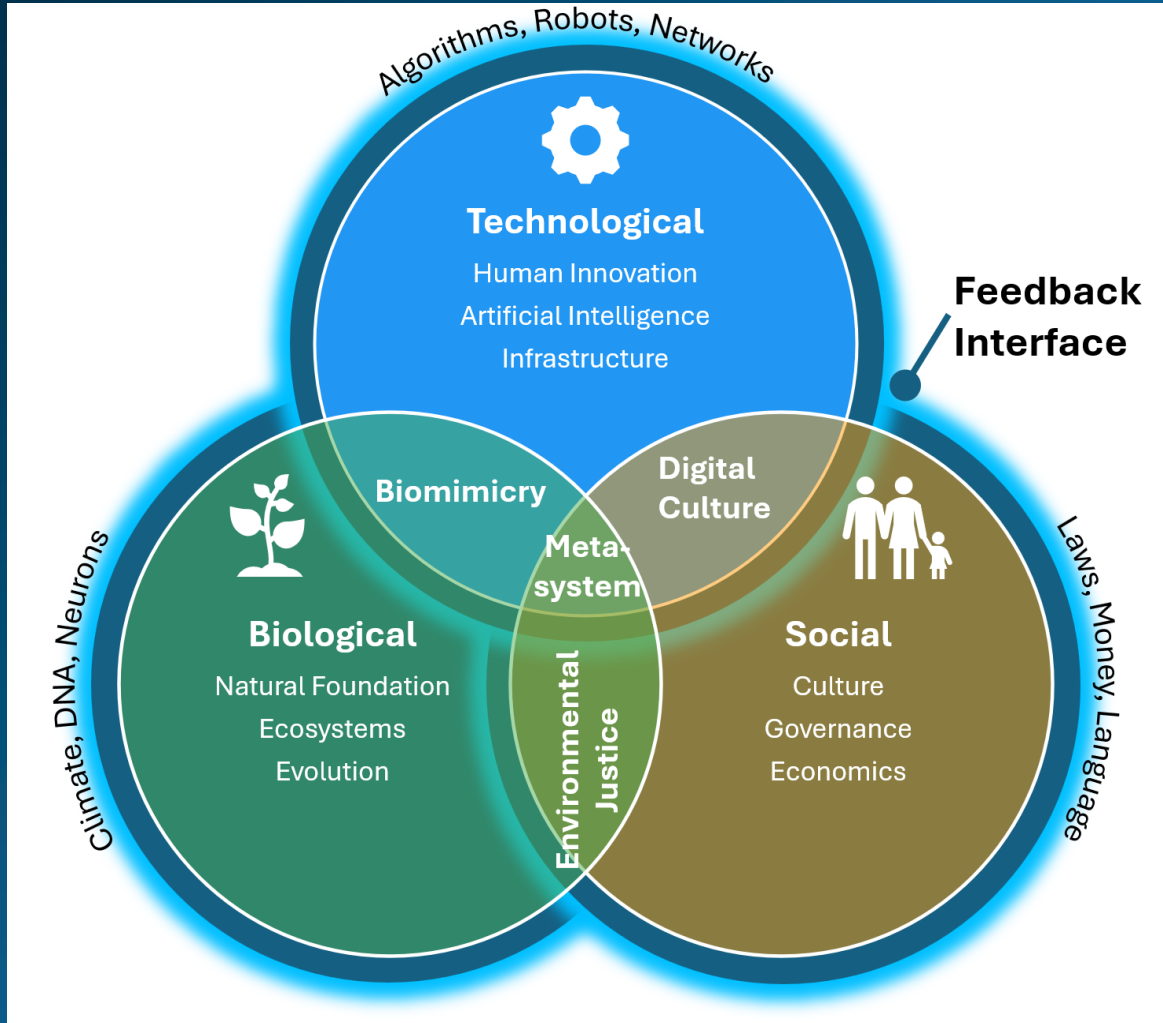
The Gardener:
Understands that complex systems require slack, variance, and adaptation to survive disruption. Seeks resilience and healthy outcomes under uncertainty.



The Mechanic:
Relentlessly drives out inefficiency, redundancy, and variance. Seeks mathematical perfection and steady-state throughput.

We are using the wrong paradigm to manage complexity.

The Metasystem Framework



- Over-optimization causes catastrophic failures across all domains of reality.
- In our pursuit of the perfectly optimized system, we inadvertently strip away the very **slack** required for resilience.
- We will look at failure of efficiency in **Complex Adaptive Systems Engineering**



The Technological Domain (Optimizing for Cost)

“Just-in-Time” Logistics

- Supply chain strategy where materials and products are delivered exactly when they are needed.
- Instead of storing large inventories, companies:
 - Keep minimal stock
 - Receive parts shortly before production
 - Ship products immediately after completion
- Why Companies Use It
 - Lower warehousing costs
 - Less tied-up capital
 - Reduced waste
 - Higher short-term efficiency
- Became popular through Toyota’s production system



JIT Logistics is a Masterpiece of Fragile Efficiency

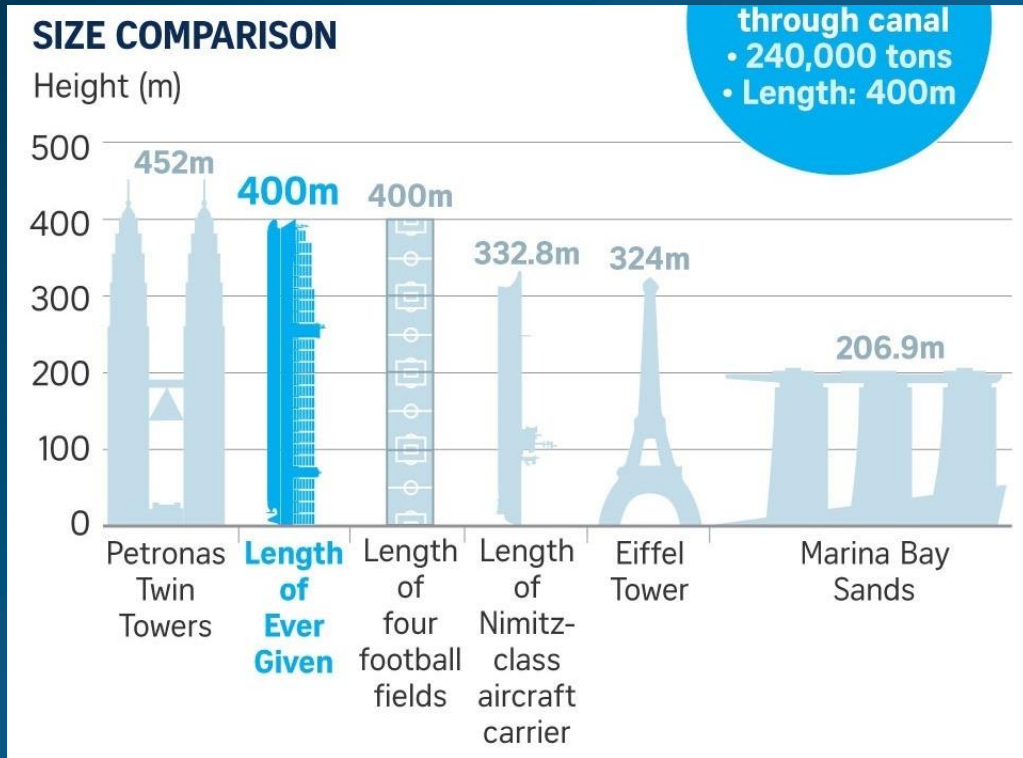
- The Mechanic's goal: eliminate the “waste” of warehousing. Parts arrive exactly when needed.
- Until...in March 2021, the *Ever Given* container ship got stuck in the Suez Canal for six days.
 - Global supply chain was perfectly optimized with **zero slack**, no buffer inventory, and perfectly timed node transfers
 - Single, localized failure didn't just delay ships; it **halted auto manufacturing in Europe** and **caused medical supply shortages globally**.



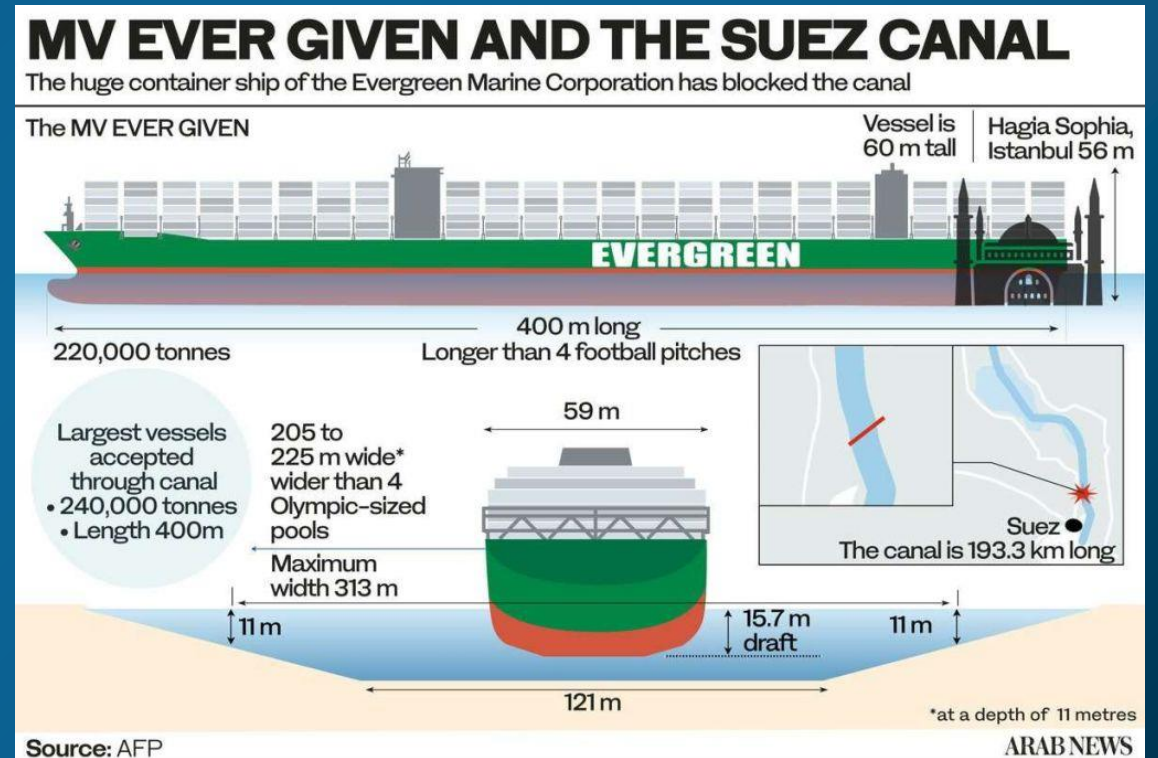


Ever Given Size Comparison

- Container Capacity: 20K TEU



straitstimes.com



TEU = twenty-foot equivalent

Tugs

Ship 400m long and
angled across canal



Digger used to
excavate bow

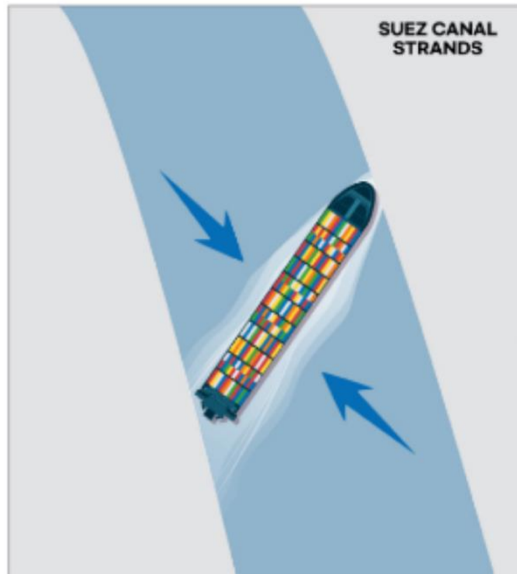
Tugs attempt to pull and
push the ship free

Note: Some objects not to scale

Source: BSM, media reports



Distance 9,286 nautical miles / Departure date March 13, 2021 / ETA March, 2021



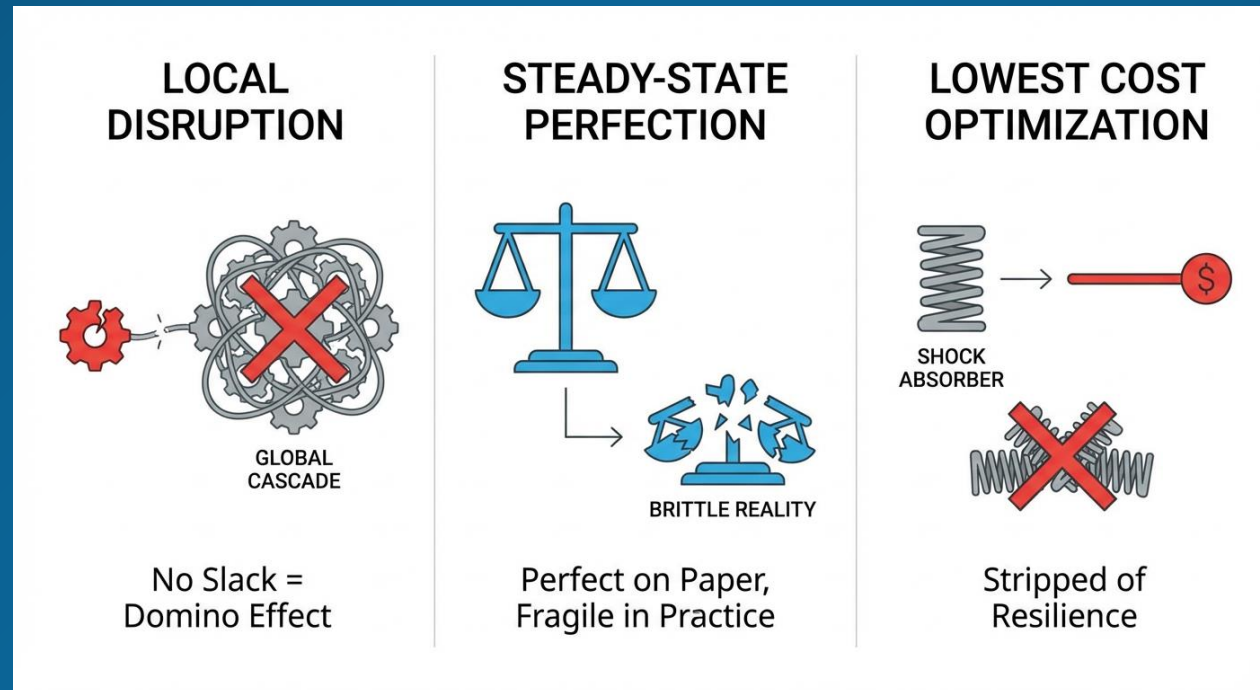
Grounded Ship Particulars

Vessel Name : MV Ever Given
Ship Owner : Shoen Kisen Kaisha
Ship builder : Imabari Shipbuilding
Flag : Panama
Length : 399.94m
Beam : 58.8m
Gross Tonnage : 219,076 GT
Speed : 22.8 knots



The Cost of Zero Slack

- The system was mathematically perfect for steady-state throughput, but catastrophically **brittle**
- Efficiency without slack turns local disruptions into global cascades
- When you optimize for the absolute lowest cost, you strip out the **shock absorbers**



The Gardener's Fix (Toyota's Chip Stockpile)

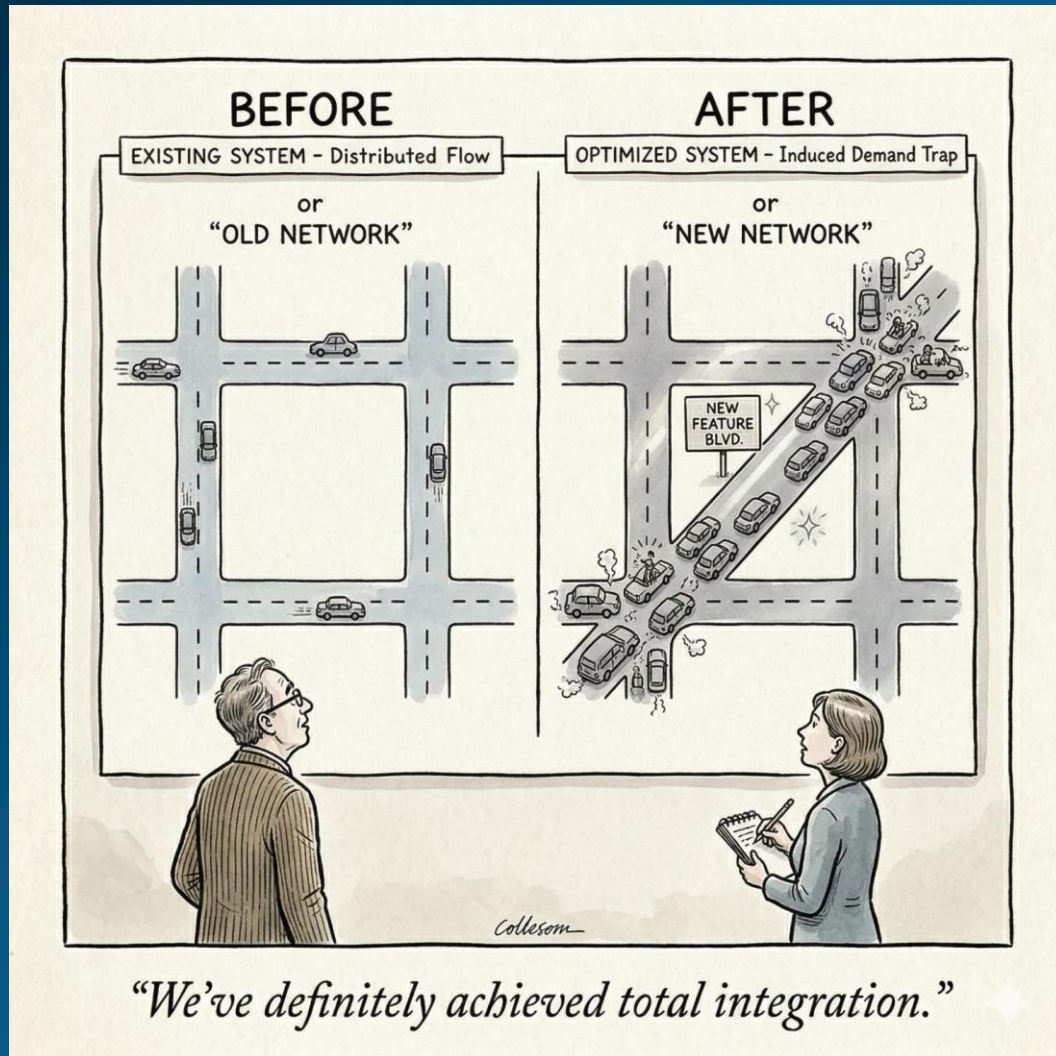
- Resilience requires deliberate, strategic inefficiency.
- 2011 Fukushima earthquake:
 - destroyed their supply lines
 - Toyota realized the fragility of their own creation
- They then applied a Gardener's mindset:
 - They identified critical, hard-to-replace nodes (like semiconductors) and deliberately introduced "inefficiency" by stockpiling months' worth of them.
- 2020 pandemic:
 - caused a global chip shortage that crippled Ford and GM
 - Toyota kept building cars. They paid a "resilience tax" (warehousing chips) that saved the system.





The Biological Domain (Optimizing for Speed)

The Braess Paradox (Both pre- and post-GPS!)



In 1969, German mathematician Dietrich Braess proved that adding a new road to a network can make everyone's commute slower.

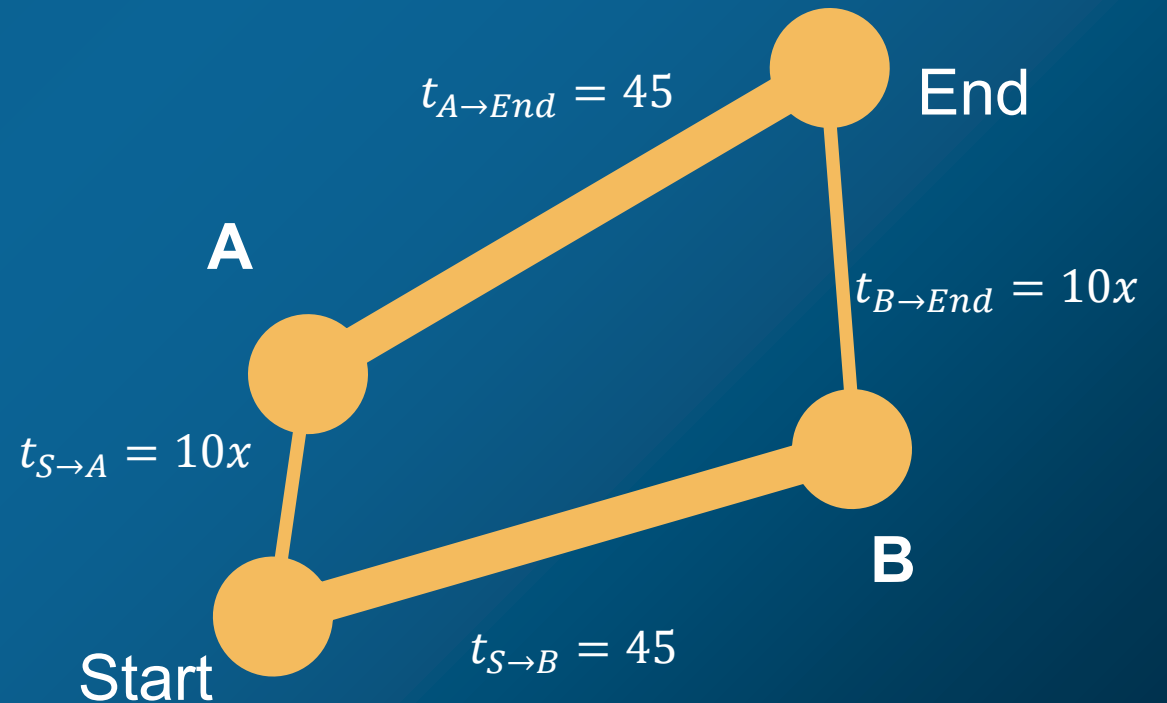


The Setup: A Simple Network

- Imagine a starting point **Start** and a destination **End**.
- There are two routes:
 - Path 1: Start \rightarrow A \rightarrow End
 - Path 2: Start \rightarrow B \rightarrow End
- Highway = always 45 minutes

*x = # of drivers in thousands
= 4 for this example*

$$t_{A \rightarrow \text{End}} = 45$$



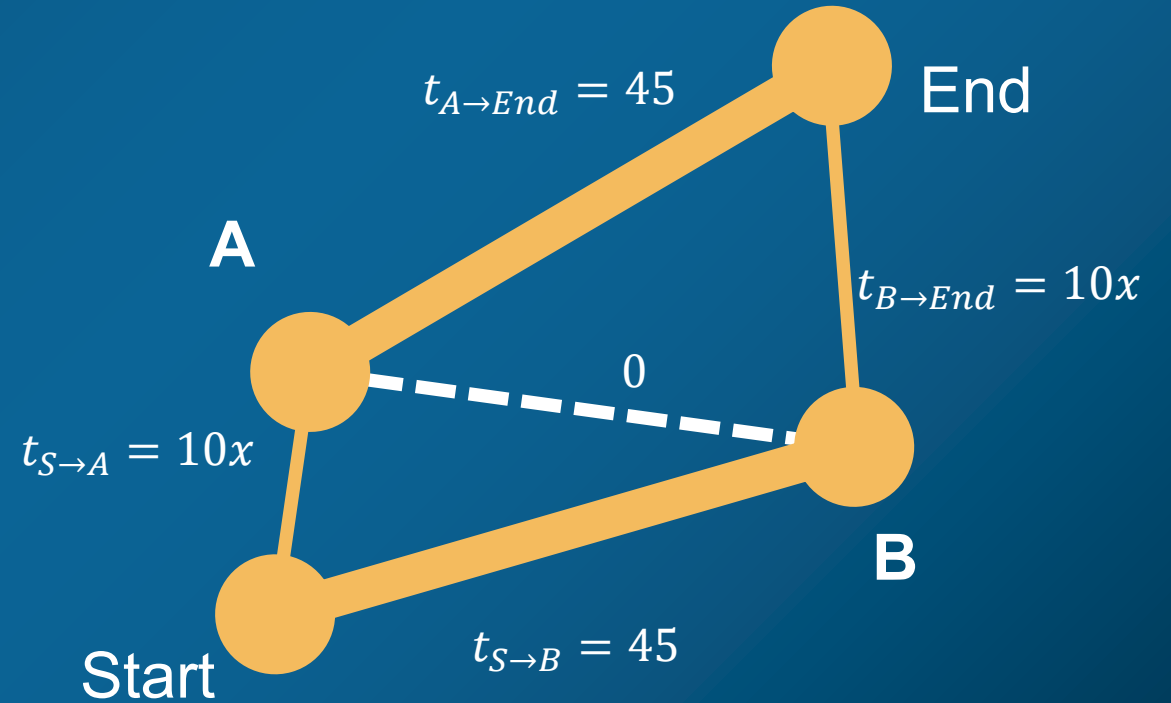
Step 1: Initial State (Equilibrium)

- With no shortcut, drivers split 50/50.
 - 2,000 take Path A
 - 2,000 take Path B

Path	Segment 1 (Time)	Segment 2 (Time)	Total Trip Time
Start → A → End	Narrow A: $10 \times 2 = 20$	Highway: 45	65
Start → B → End	Highway: 45	Narrow B: $10 \times 2 = 20$	65

Step 2: The Paradox State (The Trap)

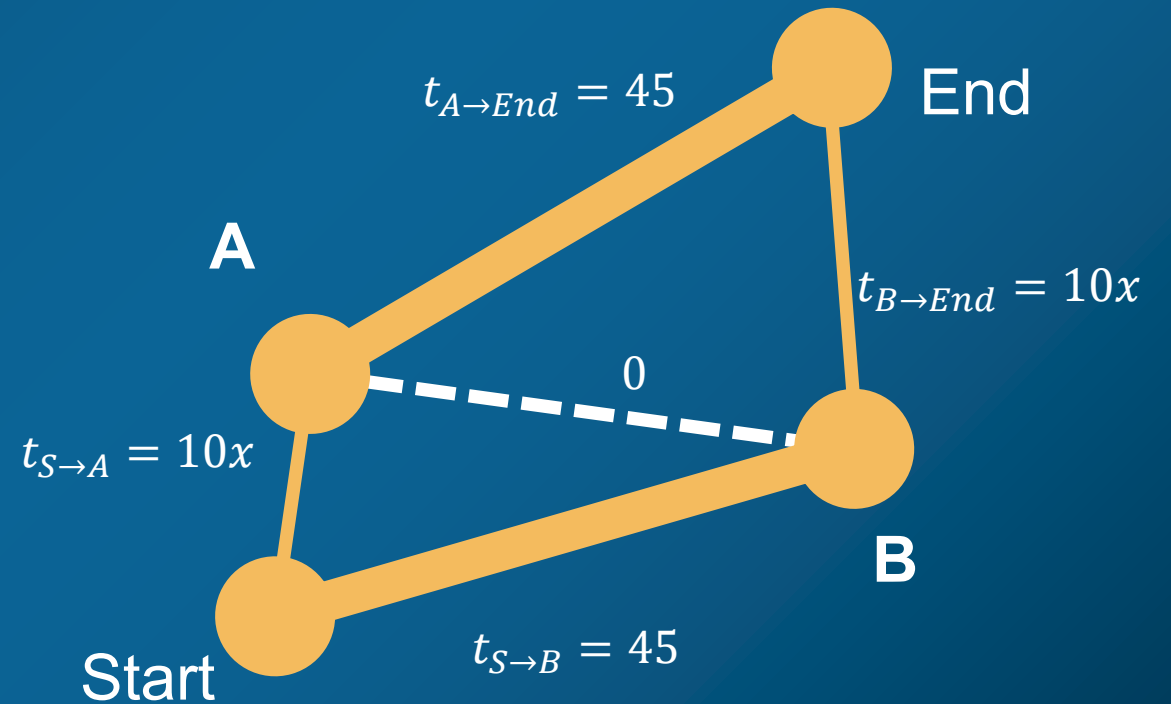
- Now we add a 0-minute shortcut from A to B.
- Everyone switches to the zig-zag route:
 - **Start → A → B → End** because it looks faster
 - Now all 4,000 drivers ($x = 4$) are on the narrow segments.



Path	Segment 1 (Time)	Shortcut (Time)	Segment 2 (Time)	Total Trip Time
Start → A → B → End	Narrow A: $10 \times 4 = 40$	0	Narrow B: $10 \times 4 = 40$	80

Step 3: Why can't they just go back?

- You might think: *"I'll just go back to the old Highway route!"*
- Everyone switches to the zig-zag route:
 - **Start** → **A** → **B** → **End** because it looks faster
 - Now all 4,000 drivers ($x = 4$) are on the narrow segments.



Path	Segment 1 (Time)	Segment 2 (Time)	Total Trip Time
Try Highway A	Narrow A: $10 \times 4 = 40$	Highway: 45	85
Try Highway B	Highway: 45	Narrow B: $10 \times 4 = 40$	85

The Collective Failure

- Why drivers choose the Narrow Road
 - The narrow road represents a shortcut or a local street
- The Temptation:
 - When a driver looks at their GPS, they see that the narrow road currently takes 20 or 40 minutes, while the highway takes 45.
- The Logical Choice:
 - Any rational driver will choose the 40-minute path over the 45-minute path.
- The Collective Failure:
 - Because the narrow road's time is 10x, it only stays fast as long as people don't use it. But since everyone makes the same logical choice to save 5 minutes, they flood the narrow road until the time climbs up to 40 minutes.

The Mechanic's Approach: Linear Optimization

- Views the traffic network as a predictable, controllable entity where “more equals better.”
 - **Diagnosis:** Identifies a “bottleneck” and sees it as a problem of insufficient parts.
 - **Intervention:** Add a new road to increase throughput
 - **Failure:** Assuming that adding a rule or a layer (the new road) will force compliance (faster travel).
 - **Problem:** Ignores the Feedback Interface where individual driver incentives interact with the new infrastructure.
 - **Result:** The system “misbehaves” because the intervention acted on a **component** rather than the **relationships between drivers**, leading to hidden fragility and an increase in total travel time.

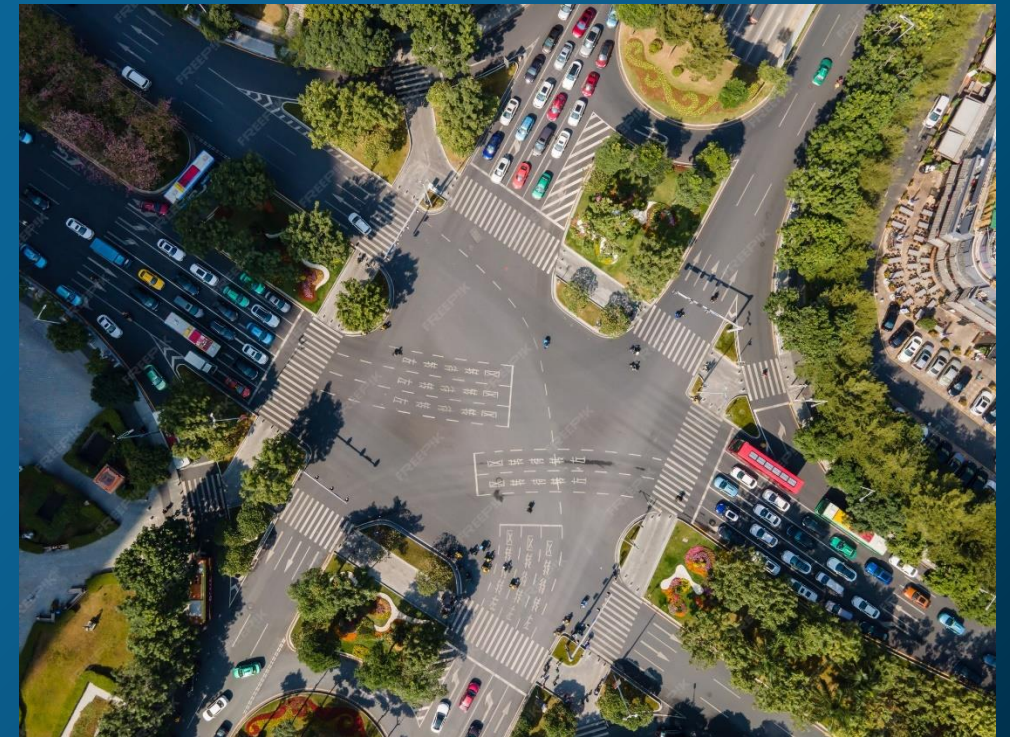


The Gardener's Approach: Cultivating Conditions

- The Gardener recognizes that traffic flow is an **emergent property** driven by the interactions of thousands of independent agents (drivers).
 1. **The Discipline of Subtraction:** Removing the road! Restore the system's ability to self-organize into a more efficient state
 2. **Adjusting the Feedback Interface:** Change the incentives:
 - **Strategic Friction:** Toll road or a lower speed limit to slow down the feedback loop and discourage everyone from choosing the same path simultaneously.
 - **Informational Diversity:** Provide better data to drivers to “loosen the coupling” of decision-making, preventing them from all reacting to the same "shortcut" signal at once.
 3. **Designing for Graceful Degradation:** Prefer a decentralized swarm of routes that are perhaps less efficient individually but more resilient as a whole.
 - The goal is stewardship, not control: accepting that we cannot master the traffic, only “prune” the network carefully to allow desirable behavior (flow) to arise organically.

The Drachten Experiment

- Pre-2000, the accident rate at intersections was around 8.3 per year.
- In the early 2000s, traffic engineer Hans Monderman did the “unthinkable” in the town of Drachten, Netherlands.



Note: This is not Drachten. I just wanted to show an intersection

Moderman's Solution



Note: I don't think this is Drachten. I just wanted to show a roundabout

- At the town's busiest, most dangerous intersection (handling 20,000 cars a day plus bicycles and pedestrians)
- As part of his “shared-space” approach:, he **removed** all traffic lights, signs, and lane markings! WTF
- The Mechanics predicted mass casualties. Instead, accidents dropped to almost zero, and traffic throughput *improved*.

Drachten: Why it worked

- By removing the rigid rules, Monderman forced drivers to become biological agents again.
- They had to slow down, make eye contact, and negotiate space with pedestrians.
- He replaced a fragile, centralized control system with a resilient, distributed network of human judgment.

Intersections: 1.773% fatalities per four-way intersection

Roundabouts: 0.050% fatalities per roundabout

Hamilton-Baillie, B. (2008). "Shared space: reconciling people, places and traffic." *Built Environment*, 34(2), 161–181.

<https://doi.org/10.2148/benv.34.2.161>

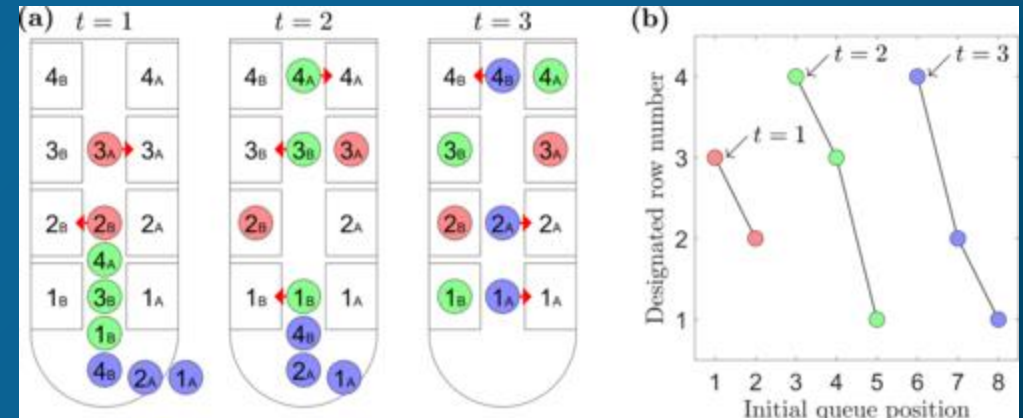
Mechanic's Fantasy at the Airport



- The Mistake: Treating Boarding Like a Machine
- Back-to-front seems logical.
 - Fill the back rows first. Avoid blocking.
 - But boarding isn't a linear machine. It's a complex adaptive system:
 - Humans with different speeds
 - Limited overhead bins
 - Social behavior & stress
 - Tight aisle constraints
- The real bottleneck is luggage interference
- Back-to-front clusters people in the same space → tight coupling → cascading delays.

What Works: Steffen Method

- The fastest methods (e.g., Steffen method) do the opposite:
 - Window seats first
 - Every other row
 - Alternating sides
 - Then middle, then aisle
- Why it works:
 - Maximizes **parallel bag stowing**
 - Loosens coupling between passengers
 - Spreads congestion across the cabin
 - Delays stay local instead of cascading
 - Efficiency emerges from **spacing**, not sequencing.



If Steffen Is Faster, Why Don't Airlines Use It?

Because airlines aren't optimizing boarding speed.

They're optimizing:

- Revenue (priority boarding)
- Simplicity & compliance
- Customer perception
- Total turnaround time

Steffen is physically efficient but socially complex and commercially misaligned.

The aisle isn't the whole system.

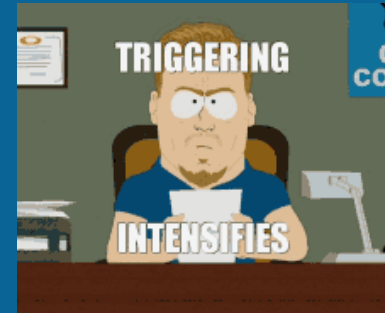


But...Back-to-Front and Steffen are Both “Mechanic” Solutions

- Optimization
 - Back-to-front → optimizes the wrong variable (row order)
 - Steffen → optimizes the right variable (parallel bag stowing)
- Both rely on choreography and compliance.
- A true Gardener approach wouldn't sequence people better: Redesign the conditions:
 - Reduce bin scarcity
 - Shift carry-on incentives
 - Increase storage capacity
- Mechanics optimize movement. Gardeners redesign the ecology.



Warning: This could be triggering



The Social Domain (Optimizing for Compliance)

MBSE and the Category Error in Systems Engineering

- **Claim:** We have conflated systems engineering with compliance paperwork.
- **The Drift:**
 - Reviews focus on artifact completeness.
 - Success is measured by diagram count and traceability coverage.
 - Models become evidence of process adherence, not engineering insight.
- **Result:**
 - The model becomes the product.
 - The system becomes secondary.
- **Transition:**
 - This is social systems problem.

Transition to the Social Domain

- Using the Metasystem lens:
 - **Tech Domain:** SysML tools, repositories, digital threads.
 - **Social Domain:** Incentives, promotions, audit culture, gate reviews.
 - **Feedback Interface:** Compliance metrics define “good engineering.”
- **Observation:**
 - **We are not optimizing for better decisions.**
 - **We are optimizing for audit survival.**
- **Reframe:**
 - Systems Engineering is a Gardener’s discipline — judgment under uncertainty.
 - MBSE, as practiced today, behaves like a Mechanic’s compliance engine.

The Illusion of Compliance

- Models grow:
 - Intricate
 - Fully traced
 - Internally coherent
- Primary function is to pass an audit.
- Real tradeoffs happen elsewhere. The model is updated afterward to keep the story straight

- The hard test:
 - **If the model vanished tomorrow, would the program stop?**
 - Most of the time, the honest answer is no.
 - Which means the model is not load-bearing. It is decorative.



A compliant system can still be fragile.

Compliance Trap: Optimizing the Wrong Metric

- Tech Domain (Tooling):
 - SysML enforces rigid grammar and structure.
 - Excellent for consistency.
 - Poor for ambiguity, exploration, and hypothesis testing.
- Social Domain (Incentives):
 - Organizations reward measurable completeness.
 - Gate reviews reward element counts and trace coverage.
 - Engineers are promoted for navigating the toolchain.

The AI Warning



- SysML v2 + Agentic AI will automate the checklist.
- Artifact generation will become instantaneous.
- The cost of valueless documentation will approach zero.
- This increases fragility by accelerating the wrong feedback loop.
- We will get faster compliance — not better engineering.

The Fix: Reposition MBSE as a Tool for Insight

- Redefine the Goal
 - Not: *“Is the model complete?”*
 - But: *“What risk did this model uncover?”*
- The Model is a Map
 - It connects authoritative analyses.
 - It reveals coupling and fragility.
 - **Its value is measured in decisions improved — not elements created.**
- Clarify Roles
 - Systems Engineer = Gardener (judgment, risk, authority)
 - Modeler = Groundskeeper (structure, consistency, hygiene)
- Call to Action:
 - Abandon the safety of the compliance checklist.
 - Return to the uncertain, messy, and essential work of cultivation.

The model serves engineering judgment, not the audit.



Conclusion

Reclaiming the Garden

- We must trade the illusion of control for the practice of judgment.
- Synthesize the three domains and the Feedback Interface
- Whether it is shipping containers, city traffic, or SysML diagrams, the lesson is the same:
 - Optimization often leads to Fragility



Design for Resilience, Not Just Efficiency

- If you must optimize, optimize at the system level, and understand what you're optimizing
- Add slack deliberately
- Decouple where possible
- Measure recovery, not just performance

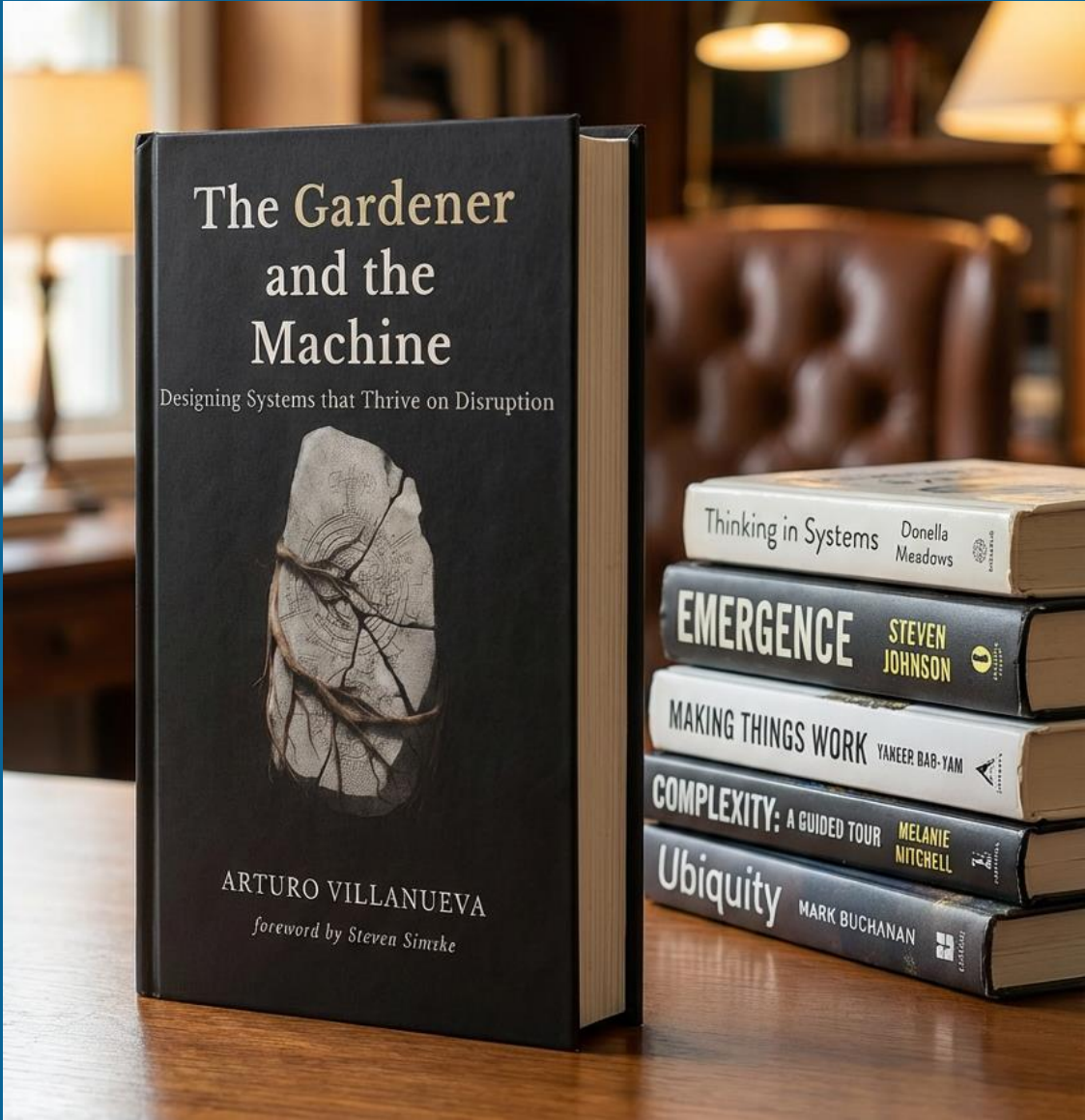
Efficiency is a goal. Resilience is a requirement.



Question-Answer-Discussion



phronos.com/tgm-about-the-book



The Fragility of Efficiency

Supply Chains, Traffic Lights, and MBSE

Keywords:

Complex Adaptive Systems, Antifragility, Resilience, Complexity, Emergence

Systems engineering often falls victim to the Mechanic's fantasy: the belief that complex systems can be optimized like complicated machines. By relentlessly driving out inefficiency and variance, we inadvertently strip away the slack required for resilience. This creates systems that are highly efficient at steady-state but catastrophically fragile during disruptions. To build truly resilient systems, we must shift our paradigm from the Mechanic to the Gardener.

Drawing on themes from the book *The Gardener and the Machine*, this presentation explores the fragility of efficiency by examining catastrophic failures of over-optimization across three domains:

- **The Technological Domain (Supply Chains):** How “Just-in-Time” logistics eliminated vital slack, turning local disruptions into cascading global failures.
- **The Biological Domain (Traffic Lights):** How hyper-efficient traffic algorithms fail in the real world by treating unpredictable humans as predictable machines.
- **The Social Domain (The Illusion of Compliance):** How MBSE has devolved into performative rigor, prioritizing auditable checklists over actual engineering insight to create models that are perfect on paper but hollow in reality.

By exploring the universal physics of system failure, attendees will leave with actionable strategies to escape the compliance trap and return to the essential work of cultivating system resilience.

Disclaimer

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