FROM SILOS TO SUSTAINABLE DIGITALIZATION

THE IT/OT HANDBOOK

The Practitioner's Guide to IT and OT Cooperation in Manufacturing

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Foreword

BY RICHARD BEESON

An early academic design project brought me to the sulfur plant of a refinery with a requisite tour of the control room. I had been working on early digital control. Discovering the control room was hissing and whining with pneumatic controls opened my eyes to the fact that operations digitization was still a work in progress. And an opportunity.

The opportunity was real—but so was the constraint. Those plants weren't undigitized because nobody had tried. They were undigitized because the capital costs were enormous and, more importantly, because the cost of getting it wrong was categorically different from anything in enterprise software. You couldn't roll back a bad call. You couldn't push a patch and restart. Lives and equipment were on the line. The people running those plants weren't being cautious because they lacked ambition. They were being cautious because the physics demanded it. I spent the next thirty years at OSIsoft—building enterprise data infrastructure for the process industries, the PI System—working inside that tension between opportunity and consequence.

Here's the thing that most people writing about industrial digital transformation often miss: The goals of Operational Technology have not fundamentally changed. Not in thirty-five years. Not in fifty. The people running plants today want exactly what the people running plants in 1985 wanted—maximum uptime, uncompromised safety, consistent quality, controlled cost, and regulatory compliance. Strip away the vocabulary of every technology wave we've lived through—SCADA, MES, IIoT, Industry 4.0, digital twins, and now AI—and you find the same operational imperatives on the whiteboard that were there when the first PLC replaced a relay panel.

The authors make a point early in this book that truly resonated with me. They reach back to economist Paul David's study of early factory electrification—plants that replaced steam engines with electric motors but kept the same layouts and got almost no productivity gain for thirty years. The gains

only came when manufacturers reorganized the factory around electricity's characteristics. Ariens and van Lammeren argue—compellingly—that we've been making the same error with data and connectivity for a decade: better sensors feeding the same broken information flows, smarter algorithms sitting on top of inaccessible data, impressive pilots that never scale because the organizational substrate to sustain them was never built. I've watched enough of that decade up close to know they're right.

What has genuinely changed is the solution space—and dramatically enough that I believe we are at an inflection point that is real, not rhetorical. It operates at three levels worth naming clearly.

The first is better tools in service of permanent goals—more sensors, cheaper connectivity, cloud-scale compute, machine learning on decades of historical data. Valuable, but not transformative on its own, as the productivity numbers from the last decade confirm.

The second is where this book lives. The solution space has expanded enough that the how of achieving those permanent OT goals can be fundamentally reimagined, not just optimized. When we added the Asset Framework to PI, the goal wasn't to give engineers better data—it was to model the physical world in a way that changed how decisions could be made. Same underlying goal. Reimagined method. That distinction matters enormously, and it is the territory Ariens and van Lammeren have mapped with more rigor and practicality than anyone I've read.

The third level is where credibility either compounds or collapses. Formerly unrealistic goals are now worth stating seriously: continuous optimization at the physics boundary across thousands of simultaneous variables; organizational knowledge that doesn't retire when your best operators do; carbon and sustainability as a real-time optimization dimension alongside yield and throughput; fleet-level learning where a discovery in one plant immediately becomes operational knowledge at fifty others. These are entering the realm of serious engineering ambition—but only for organizations that build the right foundations first. The sequence matters. Chasing level three without solving level one produces expensive science experiments and disillusioned teams.

Most writing in this space operates at level one. A smaller body gestures toward level three without the grounding to make it credible. What David Ariens and Willem van Lammeren have done is occupy the hard middle ground almost no one else is working: the organizational and technical foun-

dations that make transformation durable rather than decorative. They understand—as anyone who has worked in these environments understands—that the IT/OT divide is not a technology problem. It is a human and organizational problem that technology alone cannot fix. And they write with equal honesty to both sides of that divide. The CIA versus SIAC insight alone—the same words meaning opposite priority orders to the two communities that must cooperate—is one of the clearest explanations I've encountered of why IT practitioners and operations teams keep talking past each other.

Ariens and van Lammeren have written the book the industry has needed for a decade because writing it well requires having genuinely lived on both sides of the divide. These authors have. It shows on every page.

The next generation of practitioners—whether from IT or from operations—has more capable technology at their disposal than any before them. What they need is what this book provides: a shared language for the organizational problem, a framework for cooperation that compounds rather than collapses, and the discipline to build foundations before chasing horizons. The goals haven't changed. What's now possible in service of those goals has.

—Richard Beeson,
former CTO of OSIsoft

Foreword

BY JONATHAN SMART

Every organization today is, in some sense, a technology organization.

More precisely, organizations that wish to optimize for outcomes and remain competitive must become competent in the latest means of production—that is, the latest technology. Some organizations lead as innovators. Others succeed as fast followers or late adopters. What matters is the willingness to experiment, learn, and apply technology in ways that fit each organization's unique context.

Doing nothing is not standing still. Maintaining the status quo is effectively moving backward, as competitors evolve, markets change, and both colleagues and customers develop new expectations.

Each major technological revolution, from stone, bronze, and iron to water power, steam, railways, steel, electricity, the telegraph, oil and mass production, and now digital and AI, has brought not only new tools but new ways of working.

Every new means of production triggers innovation in how we do what we do.

The most important improvements are rarely purely technical. They are social, behavioral, and human. Our behaviors determine our outcomes. If we want outcomes to improve, behaviors must change.

Making the most of each successive technology-led revolution is, therefore, both a social and technical endeavor. My own rule of thumb is that improving outcomes is roughly 80% behavior and 20% technology or processes.

A healthy, generative culture can address poor technology or processes, but the reverse is not true. Excellent technology will not compensate for a dysfunctional culture.

In bureaucratic or pathological cultures, where fear dominates, incentives are misaligned, and work is organized into rigid functional silos, people

inevitably optimize locally. Work is thrown "over the wall." Blame replaces learning. Language like "The hole is on your side of the boat. I've done my bit, it's not my problem!" is often heard.

These behaviors make it almost impossible to realize the full value of new technology.

We have organized ourselves into functional role-based silos with work passing, at scale, since 1771.

The world's first factory system was Cromford Mills in Derbyshire, UK. Around a thousand people worked together in one location, divided into roughly fifteen specialized roles aligned to each step of transforming raw cotton into thread.

In the early twentieth century, Frederick Winslow Taylor accelerated this division of labor through Scientific Management. Taylor separated thinking from doing. Planning departments determined the work in detail; workers were expected to execute those instructions precisely and without question.

This approach enabled lower-skilled workers to perform tasks previously done by higher-skilled craftsmen, increasing efficiency and reducing the cost for the employer.

But it also entrenched functional optimization. As Eliyahu Goldratt later observed in his novel *The Goal*: "A system of local optimums is not an optimum system."

Strengthening anything other than the weakest link in a chain does not improve the system as a whole.

Despite the profound changes in our technological landscape, many organizations still operate using these inherited patterns: functional silos, local incentives, order-giving, and order-taking.

Yet this model rarely optimizes value end-to-end. In many cases, it produces the opposite effect, increasing inventory, delays, and complexity as work accumulates behind bottlenecks.

We now operate in the Age of Digital and AI, where work is increasingly unique, unknowable, and emergent.

Operational Technology (OT) and Information Technology (IT) have automated vast numbers of tasks once performed manually. Robots, sensors, hardware, and software run production lines. Aircraft, cars, and combine harvesters can pilot themselves autonomously. Entire services, from banking to insurance to travel, can be delivered digitally without human intervention.

As a result, fewer people spend their time performing repetitive tasks. More people are engaged in discovering new ways to create value, combining technologies and capabilities in novel ways. This kind of work cannot be optimized through narrow functional silos. It requires a focus on the flow of value end-to-end, supported by multidisciplinary teams, shared goals, and a focus on outcomes over output.

Generative and agentic AI amplify this dynamic, including our existing ways of working. If work remains fragmented across functional silos, AI will produce more activity faster. More output, but not necessarily more value.

If, however, organizations focus on value, flow, collaboration, and learning end-to-end, then AI can dramatically accelerate improvement.

We don't want stovepiped Operational Technology and stovepiped Information Technology. We don't want islands of data that cannot be turned into insights to enable reflection and adaptation in order to improve outcomes. We don't want duplication of work and learning. We don't want stovepiped incentives and skill sets, with a focus on "done my bit." We don't want to make it hard for ourselves to do our jobs and to add value end-to-end.

Instead, we need organizations where multidisciplinary teams come together, with shared goals, in order to realize better value sooner, safer, and happier.

This is where this book by David Ariens and Willem van Lammeren becomes particularly valuable.

David and Willem are experienced practitioners in industrial organizations. Based on their experience, they can see the trajectory for the future and how the functional silos that OT and IT separately evolved over time can benefit by working together, bringing all the skills to bear, to optimize for outcomes in an industrial context.

The authors are serving an underserved market. There is much that IT can learn from OT, and much that OT can learn from IT, and much that both can learn from the authors of this book!

Ariens and van Lammeren address the organizational and technical realities that shape digital transformation in manufacturing and critical infrastructure. They provide leaders and practitioners with a shared language to navigate a space that is often technically complex and politically challenging.

Ultimately, this book helps us to see that our identities should not be constrained to a functional silo. Instead, we should recognize that we are all part of the same system, a system that produces value for customers and society.

In the Age of Digital and AI, optimizing for outcomes requires us to work together with shared goals and a shared identity aligned to the value we create. This book is a valuable guide for organizations ready to make that journey.

—Jonathan Smart,
author of *Sooner Safer Happier*

Preface

WHEN SYSTEMS DON'T TALK

It is 8 p.m.

The kids are in bed, and I'm ready to finally relax when my phone rings. I take a look at the screen and sigh. It's the "OT shift" team calling. I tell my wife to start watching TV without me and that I'll be back in fifteen minutes.

I'm an engineer working in manufacturing digitalization. "IT for factories" is how I describe it for friends and family. They still don't really know what I do, but the description is good enough for them to stop asking more questions. I sort of rolled into this position because I'm one of the few people in IT who has actually worked in a plant.

I love it. On one hand, I work with bits and bytes, cloud architectures, and data centers. But I also have my feet on the ground, in the physical reality of production. When I need to talk to my stakeholders, I get my safety gear on and walk between the pipes, reactors, and distillation columns. Boats, trains, and trucks get loaded and unloaded, products are analyzed in labs, and the list goes on. My reality isn't virtual.

A few years ago, my company automated everything in logistics. We went from a semi-manual process to a fully automated system using biometric authentication and barcodes. Overall, it's been great, but some of the truck drivers miss the social contact. However, for people working in industrial digitalization, it was a very fun project where we learned a lot.

We connected production sensor data, supply chain data, and weighbridges into one solution. We trained the staff in the plants, on the loading docks, and at the gates and implemented it across twenty-five world-scale chemical facilities.

Our industrial digitalization group also supports everything we make. This incentivizes them to create a robust, redundant solution and to properly train users. You look at your architecture differently when you're the one responsible for fixing it on Christmas Eve.

The real challenge was not so much the technology itself; that was the easy part. Making sure that a random truck driver understood what he had to do without training or instructions was a lot harder.

The OT shift calls. The trucks aren't getting the legal documents they need to enter and exit the site…

This team is the plant's 24/7 support. They're on-site to solve problems with plant electrical and automation systems, but they also know the basics of our IT systems. They solve 90% of the problems for us at night and on weekends and holidays. But when the standard procedures fail, they call us manufacturing IT people. Normally, it's easy: rebooting/restarting a service or just telling the users to stop complaining and use the manual workaround and that we'll fix the problem tomorrow morning.

It's 8:00 p.m., and the printers aren't working. That's not too bad. I know they can handle the last trucks of the day with the manual workaround we have in place. But I also know that if we don't fix this by tomorrow morning, we're screwed. At 6:00 a.m., trucks will be waiting to enter the site. Hundreds of them. If we can't process them fast enough, we'll create a traffic jam blocking the highway. And in the worst-case scenario, we'll have to slow down production since the silos might fill up if not unloaded.

I open my laptop and log in remotely to see what's happening.

Everything seems fine…no errors. Servers are up; networks are working fine. I see the files, and I can print them on my printer at home. I check the weighbridge control system, and everything there seems okay too. Everything is just…fine. Except it obviously isn't. This will be one of those tough ones. I grab my coat and tell my wife not to wait for me.

On the drive to the site, I have some time to think. This wasn't the only challenge we were facing at the time. Our company was also undergoing its own digital transformation. Started by a handful of people, it was now handled by a reasonably sized group that was struggling to merge the IT and OT departments. This merger was causing a lot of political discussions between the two departments, making the process very slow and heavy. But we knew this was key to moving the company's production forward. The future is digital, after all!

Once on-site, I get to work and try to solve the problem again. I physically check the printers, the local network, the control systems, the ERP (enterprise resource planning) system…Every step works just fine on my PC, and I even get to print the documents without a problem from my PC. But the printers still refuse to do it automatically.

It's time for damage control. I call the logistics team to be prepared for tomorrow morning. We might have to go fully manual. My stomach clenches. First of all, I don't like it when I have to call people up for more work. And second, I hate that my system is failing and causing all this disruption. But I'll take a hurt ego over a traffic jam on the local news tomorrow morning.

I need to extend the perimeter of my search. We didn't modify anything, but maybe something outside our scope changed? Maybe it's the ERP after all? I'll check with my colleagues who know more.

This isn't the Fourth Industrial Revolution everyone knows from the PowerPoint slides. On paper, it all looks so easy, so clean. We'll have remote sensors everywhere running flawlessly. Everything will run in the cloud, and people in production will walk around doing "stuff" on smartphones. Executives can look at pretty dashboards with real-time data, (self-made, of course, in mere minutes) so they can drill down to the smallest detail. Engineering works on digital twins using VR goggles, and the executives and shareholders are dreaming of the day when AI will run their plants without the need for human intervention.

But the reality is that our software vendors use today's digitalization buzzwords while forgetting that the installed technology is from a decade or two ago. There is a disconnect in this reality, so most of the promises of digital transformation usually fail or underperform.

And my reality at the moment is that the *#@$! printer still doesn't print.

I call one of our supply chain specialists. He was already aware of the problem and confirmed that they hadn't changed anything on the ERP. At least not in Europe. He only knows of a small change that went live for the Chinese customs documents.

I ask him when exactly the system went live and start checking my suspicion. It's a long shot, but I have nothing else to go on. I check everything and see that one minute before the change, everything was working just fine, and five minutes after the change, the problem started. This isn't a coincidence.

I call him to see if we can roll back the ERP changes through an emergency procedure. It's a good thing I worked in IT before this. I understand well how ERP incidents and changes are handled in our company. You need to know your way around in a multinational like this one to speed things up.

Luckily, there is a deep level of trust and cooperation between our team and the local logistics team. We work closely together day in and day out. They trust that if we're calling at 11:00 p.m. for an ERP rollback, we understand what we're asking for.

The small change for Chinese documents corresponds perfectly with our problems in Europe. Rolling back ERP changes isn't a small request. You can't simply ask the helpdesk. We need to escalate this fix quickly. With the help of site management, production managers, and the logistics team, we raise the priority as high as we can to get this rolled back during the night.

It's 1:00 a.m.

A war room is initiated with all the representatives we think might be connected to this: ERP specialists, infrastructure, vendors… We don't care if somebody needs to be called up; this needs to be fixed now! Looking at all this theater, I really hope my analysis is right. What if I missed something stupid and made an error?

After thirty minutes, the ERP team confirms that the change is rolled back and asks us to verify. We simulate everything in production (because why not) and…I hear the wonderful, sweet sound of a laser printer warming up to print something. Just because we can, we do it three more times, and every time, it just…works.

We thank all our colleagues for their fast response and high-five the guys and girls from logistics who also came on-site to solve this. After finishing our lukewarm coffees, we bring the good news to all who need to know. Tomorrow morning will be a normal day, like yesterday and the day before that. The work we did over the night might have been invisible for most, but it made a huge impact.

The afternoon after we recovered from this debacle, I was thinking about how a small change in the Chinese documents caused such a serious issue: The font of a single template symbol reused for our system was incompatible with our printers. This small change shut our printers down.

I'm fascinated by how an insignificant change on the other end of the world had such an effect in our plant. But I'm equally worried. These kinds of heroics aren't sustainable. How are we supposed to bring IT and OT together? How is it possible to manage the complexity of both worlds at the same time? Is industrial digitalization creating more problems than solutions? Surely there must be a better way to do this.

(Oh, and I hate printers. From the bottom of my heart, I hate printers.)

—Willem

Introduction

THE BUSINESS IMPACT OF DISCONNECTION

It was 8 p.m. when Willem got the call—early by the standards of digital transformation emergencies. A printer had jammed at a chemical plant. Normally, that would be a five-minute fix. But this printer wasn't just producing shipping labels. It was the final output of a complex handshake between the plant's Operational Technology and the company's global logistics system. And this was just one call. There were others—many others. The rogue modem an engineer had plugged in four years earlier to troubleshoot a weekend go-live was now actively exploited by hackers. Or the quality system was not producing product certificates, meaning a gigantic ship couldn't unload.

You probably have your own version of these stories. Different industries, different technologies, same root cause: the gap between the people who run Operations and the people who run Information Technology. When these two worlds don't speak the same language, don't share the same goals, and don't operate from the same playbook, digital transformation stalls—no matter how much money you throw at it.

This book is about closing the gap between both. Not through convergence projects, org-chart shuffles, or steering committees, but by rethinking how industrial organizations design, deploy, and scale their industrial digital systems.

To understand the digital and AI shift we are living in today, it's worthwhile to learn from a similar big-impact moment from history: the introduction of the electrical motor.

In the 1880s, electricity became commercially available. Thomas Edison's Pearl Street Station began powering parts of New York City in the 1880s.[1] By the early 1900s, electric motors were reliable, scalable, and demonstrably superior to steam engines in nearly every technical dimension. Yet by 1900,

less than 5% of mechanical drive power in US factories was electric.[2] It would take another two decades before adoption accelerated. And it wasn't until the 1920s—forty years after electricity became available—that productivity gains truly materialized.

What took so long?

Economist Paul David studied this puzzle in his landmark 1990 paper, "The Dynamo and the Computer."[3] His answer: Early adopters tried to apply the new technology to old processes. Factories replaced their central steam engines with electric motors but kept the same layout—massive drive shafts running the length of the building, with belts distributing power to individual machines. Switching from steam to electricity didn't improve productivity because the constraint wasn't the power source. It was the design of the factory itself.

Only when manufacturers redesigned their plants—moving to unit drive systems where each machine had its own motor, reconfiguring workflows to eliminate the central shaft, and rethinking maintenance and safety protocols—did the productivity gains appear. And they were massive. Factories became cleaner, safer, more flexible, and vastly more efficient. But it required a fundamental reimagining of how work was organized, not just a swap of power sources.

Unfortunately, we're making the same mistake today.

Companies bolt AI onto legacy systems and outdated ways of thinking. They run dashboards as side projects. They deploy wireless sensors but leave the data architecture unchanged. Then they wonder why pilots don't scale and why digital transformation feels like an expensive science experiment.

Just like the electrical motor, today's technology works. What's missing is the willingness to reorganize around it with shared goals, shared language, and shared accountability.

Why Now?

If digital transformation were optional, most manufacturers would be content to wait. The problem is that waiting is no longer viable. Four simultaneous pressures are converging to make digitalization not just a competitive advantage but a survival imperative.

First, the workforce crisis. The generation that built modern manufacturing—the engineers and technicians who know every quirk of every machine,

who can diagnose a problem by sound alone—is retiring. And they're not being replaced. A recent study found that manufacturing workers now stay in a role for an average of just three years.[4] Worse, half of all new hires leave within the first ninety days. Meanwhile, blue-collar manufacturing jobs struggle to attract talent in a world where remote work and tech careers dominate. The institutional knowledge walking out the door won't be replaced by patience or apprenticeships. We need technology to radically compress the learning curve.

Second, geopolitical volatility. Supply chains that were optimized for cost efficiency over decades are now being rewritten for resilience and proximity. Tariffs shift. Regulations diverge. Energy prices spike. Companies that can't adapt their Operations quickly—reconfigure production lines, onboard new suppliers, adjust product mix—find themselves outmaneuvered by more agile competitors. Flexibility is no longer a luxury. It's table stakes.

Third, stagnating productivity. Between 2004 and 2024, labor productivity in US and European manufacturing declined by roughly 5%.[5] The digital dividend promised by Industry 4.0, smart factories, and the Industrial Internet of Things (IIoT) has largely failed to materialize. Not because the technology doesn't work but because most companies have bolted it onto legacy processes and architectures without rethinking how work gets done. We've spent a decade deploying sensors and dashboards while productivity flatlined.

Fourth, the acceleration of AI. Machine learning is no longer experimental. Generative AI and agentic systems are on the rise. They're entering the shop floor—augmenting operators, automating routine engineering tasks, enabling predictive maintenance at scale. But AI only delivers value when it has access to clean and contextualized data in combination with strong process know-how. And in most plants, that data is locked in silos, formatted inconsistently, and inaccessible to the people who need it (and often, the data lives only in the brains of those working on the shop floor every single day).

These four pressures don't arrive in sequence. They compound. And they demand a response that goes deeper than another round of digital pilots.

Why At All?

Digital transformation can deliver value in three domains that every CEO cares about: asset reliability, process performance, and sustainable operations. Each represents a different line on the P&L or balance sheet. And each

requires the integration of Operational Technology (OT) and Information Technology (IT) to achieve—not as separate initiatives, but as a unified capability.

1. Asset Reliability

Asset reliability is about keeping critical production equipment running predictably and safely. It directly impacts CapEx efficiency—longer asset life cycles mean deferred replacement costs. It determines maintenance budgets—predictive maintenance is cheaper than emergency repairs. And it protects revenue stability—unplanned downtime is expensive, especially in industries running at high utilization rates.

Digitalization can enable a fundamental shift from a reactive to a predictive reliability approach. Instead of fixing equipment after it fails or replacing parts on fixed schedules regardless of condition, organizations can monitor asset health in real time and intervene only when data indicates an actual need. Real-time monitoring can reveal early warning signs that manual inspection misses: subtle changes in vibration patterns, temperature drift, or power consumption that signal impending failure days or weeks before it occurs.

2. Process Performance

Process performance encompasses everything that affects cost of goods sold and product quality: energy consumption, raw material utilization, labor productivity, throughput, and yield. In commodity industries with thin margins, small improvements compound to millions in annual impact. In high-mix discrete manufacturing, the ability to adjust production quickly without sacrificing quality determines market responsiveness and competitiveness.

Digitalization can enable responsive and optimized Operations. When IT planning systems and OT control systems share real-time data, organizations can respond to disruptions without manual coordination delays.

Beyond reactive adjustments, integrated systems enable continuous optimization. Advanced analytics can identify improvement opportunities that humans can't see, subtle correlations between variables, multifactor interactions, or process inefficiencies that only emerge when analyzing months of data across operational and business contexts. These insights drive energy

reductions, yield improvements, and quality consistency—all while keeping Operations within safe boundaries.

And here's where workforce empowerment connects to performance: Attracting and retaining talent is harder than ever, and the veterans who were there from the start are now retiring. Digital tools don't replace workers—they should give them superpowers. Operators can diagnose complex issues faster when systems surface relevant historical context and suggest likely root causes. Engineers can focus on problem-solving rather than data gathering when analytics platforms do the heavy lifting. New hires compress their learning curves when they can access expertise on demand or try to solve a problem in a virtual simulated environment instead of in the real plant.

The goal isn't necessarily to deliver the same output with fewer people. It's to deliver more value with the same head count by augmenting human expertise, reducing friction, and helping every worker make better decisions faster.

3. Sustainable Operations

Sustainable operations covers three interconnected concerns: environmental impact (emissions, water use, waste), safety (worker health, process hazards, incident prevention), and regulatory compliance (traceability, audit trails, cybersecurity, product documentation).

These are often treated as nonfinancial objectives, and their importance waxes and wanes with the current zeitgeist. But fundamentally, they determine whether you have a license to operate—and increasingly, whether you have market access. Customers demand transparency on carbon footprints. Regulators require digital traceability and product passports. Investors evaluate ESG (environmental, social, and governance) performance. A failure in any of these areas can shut down production, trigger fines, or cost contracts.

Digitalization can transform how organizations manage these obligations. Automated traceability turns compliance from a manual reconciliation exercise into a continuous by-product. When all systems share a common data architecture, generating audit trails or regulatory reports becomes straightforward rather than multiweek projects.

Real-time safety monitoring enables proactive intervention. Instead of investigating incidents after they occur, integrated systems can identify near-miss patterns and operating conditions that correlate with elevated risk. This allows organizations to adjust processes before incidents happen, protecting

workers and avoiding the operational and reputational damage that follows serious accidents.

Environmental optimization works the same way. When energy consumption, material flows, and emissions data flow into analytical systems alongside production schedules and regulatory constraints, organizations can balance operational goals with environmental limits dynamically.

The companies that build these capabilities into their organizational and technical architecture from the start treat them as competitive advantages. Those that bolt them on afterward treat them as cost centers.

The Missing Ingredient

These three domains—asset reliability, process performance, sustainable operations—aren't independent workstreams. Asset failures affect process performance. Process improvements often reduce environmental impact. Safety and security incidents disrupt reliability and the license to operate.

Digital transformation succeeds when it addresses all three simultaneously, and that only happens when IT and Operations work from shared goals and integrated systems.

So, if the value is clear, why do so many companies struggle to capture it? The answer lies in the gap between the two organizations that must collaborate to make it happen.

IT is built for change. It optimizes for agility, iterative improvement, and rapid deployment. IT teams version software, run A/B tests, provision infrastructure as code, and patch systems on a monthly cadence. Downtime is measured in uptime percentages—99.9% is acceptable, even celebrated. The mindset is move fast, test, learn, iterate.

Operations is built for stability. It optimizes for safety, reliability, and uptime measured in dollars lost per minute. In an ethylene cracker, shutting down for an unplanned maintenance takes weeks and costs millions. In a water utility, "acceptable downtime" doesn't exist—you can't stop delivering water, even for a minute. Engineers think in twenty-year asset life cycles. They change software only when absolutely necessary. The mindset is don't break what works.

These aren't personality differences. They're rational responses to different constraints. IT can roll back a failed deployment. Operations can't roll back a plant trip that sends flammable gas into a flaring system.

Other industries have cracked versions of this problem. Banking moved from manual stock trading to high-frequency algorithms by building shared platforms where traders and technologists collaborate in real time. Media shifted from broadcast schedules to streaming architectures by aligning content creators with infrastructure engineers around new operating models.

Manufacturing can do the same.

Real impact comes when transformation is owned by the core of the business, not orbiting around it. Once we stop treating digital as a project and start treating it as the way we work, we'll begin to see the same kind of compounding progress that other industries have enjoyed.

That's the missing ingredient. And as you'll discover when reading this book, it's entirely within our reach.

Who This Book Serves

This book is written for three groups working at the intersection of IT and OT in industrial settings:

- IT and OT practitioners who implement digital change on the shop floor—automation engineers, data scientists, plant IT managers, and control-system specialists.
- Operational and technology leaders who must fund, sponsor, and scale those initiatives—plant managers, CIOs, CTOs, and heads of manufacturing excellence.
- Consultants, vendors, and system integrators who advise industrial clients on digital-transformation strategy and execution.

Whether you're from IT, OT, or Operations, this book is designed to equip you with the tools, frameworks, and mindset needed to navigate the complexities of digitalization. But transformations don't happen in isolation. Consultants, technology vendors, and system integrators play an equally critical role in shaping the outcome. If you're advising clients or delivering technology into industrial environments, this book will help you better understand the context in which your solutions need to operate. You'll learn what really matters on the shop floor, how decisions are made (and delayed), and why certain initiatives succeed while others quietly fade out. By working through each step and building on a solid foundation, everyone involved can

contribute more effectively. You'll be prepared to tackle challenges, overcome silos, and help lead the charge.

In our work, we focus on sectors in which raw materials are transformed, assembled, or distributed to create tangible products or essential services. These fall into three broad categories: process industry, (discrete) manufacturing industry, and critical infrastructure.

The process industry transforms raw materials—often liquids, gases, or bulk solids—into finished or semi-finished products through chemical or physical reactions. Think of crude oil becoming gasoline, raw ingredients mixed and heated into pharmaceutical tablets, or natural gas refined into industrial chemicals. These transformations typically happen in one of two ways: continuous production, where materials flow through the system 24/7 (like a refinery that never stops), or batch production, where discrete quantities are processed in sequential steps (like making specialty chemicals). Examples include oil and gas, chemicals, pharmaceuticals, and food ingredients. What sets this sector apart is that you're managing flowing materials through complex processes—not assembling discrete parts.

By contrast, the (discrete) manufacturing industry creates products. Design, manufacturing, assembly, and inspection go hand in hand to create products that meet specific technical specifications and quality standards. In many cases, products from the process industry are used and transformed into a finished product. The manufacturing industry is broad and includes several industries, such as food and beverage (typically packaged foods and drinks), automotive, electronics, aerospace, and many more.

The critical infrastructure (or utilities) sector is characterized by assets, systems, and networks (physical and virtual) so vital that should these not work, society would destabilize. Water treatment facilities, energy production and distribution, and highway control are some examples. All of these companies (public or private) provide essential services that underpin daily life.

These industries (process, manufacturing, and critical infrastructure) touch every aspect of our daily lives, from the mundane to the extraordinary. The combined efforts that go into these industries ensure that the products we depend on, from the simplest household items to the most sophisticated medical testing machines, are available, affordable, safe, and of high quality.

In this book, our focus lies solely on the digitalization of the physical processes within these industries—we refer to that as "Operations." We fully understand that there is much more to running an industrial business, such

as finance, sales, marketing, engineering, supply chain, quality, R&D, and SHE (safety, health, and environment), just to name a few.

Some industries will produce "smart" products, or products that consist of hard- and software themselves (e.g., a car, your electric toothbrush, a rocket, a dishwasher). Often, people refer to these smart products as an Internet of Things (IoT) device or a cyberphysical product. In this book, we do not discuss how you should develop such devices; instead, we'll go to the production lines where the car or dishwasher is being physically built.

For the sake of simplicity (and because we don't want to introduce yet another three-letter acronym), we'll just refer to "Manufacturing," but know that we mean all the industries we listed above.

The Three-Step Framework

In this book, we offer a three-step framework to bridge the IT/OT divide and achieve sustainable digital transformation—not just successful pilots but genuine change at scale: (1) understand, (2) cooperate, (3) scale and sustain.

Step 1: Understand

The foundation of any transformation is trust, and that is also true when building a bridge between IT and OT. Building trust starts with IT understanding Operations and Operational Technology, and similarly, Operations and Operational Technology understanding IT. Not just who they are as human beings and the context they all work in but also what they need to excel in their line of work.

This understanding will almost automatically lead to concrete requests, which can originate from all directions: "Can you help me increase the throughput of my lines?" "Can you support me in adhering to these new cybersecurity guidelines?" And many more.

Step 2: Cooperate

Connecting and understanding are the first step, but in order to make any progress, we need to cooperate. Cooperation comes in many ways and forms, from a very small ad hoc team tasked with implementing a mini pilot to a

large enterprise-wide platform team keeping the company's core data platform running 24/7.

In this step, we will make cooperation formats tangible. We'll guide you through the different organizational maturity stages and describe how to get started and how your organization will evolve over time as your maturity grows and complexity increases. Once we find a way to work together, we can step into the technical and solution domain.

Step 3: Scale and Sustain

With the groundwork in place, it's time to execute. This is where technology comes into play. The third step focuses on starting small: solving immediate problems with practical solutions followed by scaling those successes to drive widespread transformation. It's about balancing short-term wins with long-term vision. In this step, we will give you the frameworks needed to select, implement, and scale data initiatives in an industrial environment.

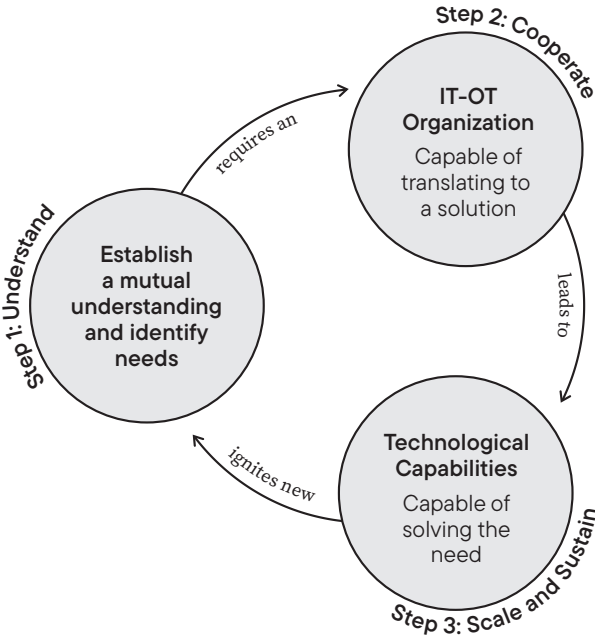


Figure 0.1: The Three Steps of Industrial Digital Transformation

As shown in Figure 0.1, each step builds on the last, like progressing through levels in a video game. You can't skip straight to the boss fight without first mastering the basics. And while we all know it, many will still try to rush into buying technology nobody is waiting for.

However, the journey doesn't end with a single successful pass through the three steps. This is not a linear time constraint problem with a clearly defined start and end. Quite the contrary: Digital transformation should always be an ongoing, iterative process. When done right, each solution ignites new ideas and restarts the cycle, continuously driving improvement.

What's Ahead

This book follows the three-step framework we introduced: understanding, cooperation, and scaling. Each part builds on the previous one, but you don't need to read sequentially. Each part stands alone, with cross-references where concepts build on one another. Use this guide to navigate based on your role and immediate needs.

Part I: Understanding the Challenge

Who this part is for: Everyone. Whether you're a practitioner, leader, software vendor, integrator, or consultant, we advise you to always start with Part I.

- **Chapter 1: The Players and Their Realities** introduces the three groups whose collaboration determines success or failure: Operations (the people running physical processes), OT (the technology controlling those processes), and IT (the systems, data, and infrastructure enabling the business). You'll understand what each group cares about and why those differences matter.
- **Chapter 2: How We Got Here** traces the historical journey that created today's divide. You'll explore the "Era of Happy Silos," the period when IT scaled globally while OT converged vertically, and the current "Data Convergence Imperative" forcing these worlds together. This chapter explains why previous attempts at IT/OT convergence often failed and why data changes everything.

- **Chapter 3: Why Organizations Get Stuck** examines the organizational realities that turn technical challenges into political quagmires. You'll recognize the CIO/COO disconnect, understand why "Operations always comes first," and learn to spot the warning signs of divergence.

Part II: Cooperation Patterns

Who this part is for: Most valuable for leaders and strategic consultants, though practitioners will benefit from understanding the organizational context of their technical work.

- **Chapter 4: Engineering Cooperation** draws a parallel that matters. Fifteen years ago, IT faced a similar cooperation crisis between Development and Operations. The DevOps movement offered a way out. This chapter shows you that deep cooperation is possible because IT has already done it once—we only need to adapt the concepts to the industrial world.
- **Chapter 5: Seven Patterns of IT/OT Cooperation** is the heart of Part II. You'll learn to recognize seven distinct patterns—from complete silos to full convergence—and understand when each pattern works and when it fails. This is the longest chapter because these patterns become your primary diagnostic tool. You'll use this vocabulary for years.
- **Chapter 6: From Patterns to Progress** gives you the tools to turn the patterns into reality in your organization by looking at the complexity of the problems you are facing, finding the right cooperation model, and navigating the transitions.

Part III: Building the Technical Foundation

Who this part is for: Most valuable for practitioners (especially those with architectural roles), technical consultants, integrators, and vendors. Leaders should definitely read Chapter 7 to understand the data constraints; the remaining chapters provide implementation depth.

- **Chapter 7: Breaking the Data Bottleneck** tackles the stubborn constraint at the heart of industrial digitalization. You'll discover why operational data differs fundamentally from IT's usual data challenges and why so many digitalization efforts—with or without AI—stumble here.
- **Chapter 8: The Industrial Data Platform Solution** answers the "how" question: What capabilities must a data platform provide to make operational data available to users, applications, and AI models? You'll understand why a platform approach beats fragmented point solutions and what to evaluate when building or buying.
- **Chapter 9: From Reading to Results** provides you with a practical roadmap and examples.

We want to share these insights with you: the mix of technological and organizational ingredients, the lessons from organizations that got it right, and the inspiration you'll need to create your own successful digitalization story.

Let's begin.

PART I

Understanding the Challenge

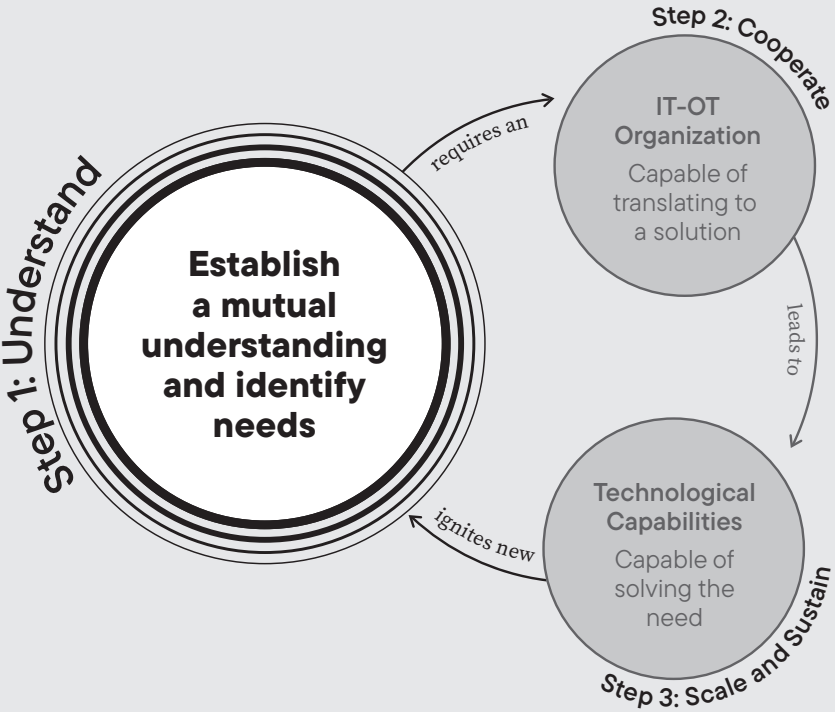


Table 1.1: CIA vs. SIAC

CIA (IT)	SIAC (Operations)
Confidentiality: Protecting information from unauthorized access and disclosure. *Example: A leaked database or document is a breach of confidentiality.*	**Safety:** Protecting lives, preventing any harm to people and environment. *Example: An explosion, toxic gas release, or someone trapped in machinery.*
Integrity: Guarding against improper information modification or destruction. *Example: Unauthorized changes to transaction data compromise integrity.*	**Integrity:** Protecting the physical integrity of Operations. *Example: Preventing equipment failures before they become safety issues; protecting control systems from hackers.*
Availability: Ensuring timely and reliable access to and use of information. *Example: A system going offline due to a power outage without backup compromises availability.*	**Availability:** Production should have maximum uptime. *Example: Every minute of unplanned downtime costs money and disrupts delivery commitments.*
	Confidentiality: Often, manufacturing processes themselves are intellectual property and must be protected. *Example: The secret generations-old recipe to produce a delicious cookie.*

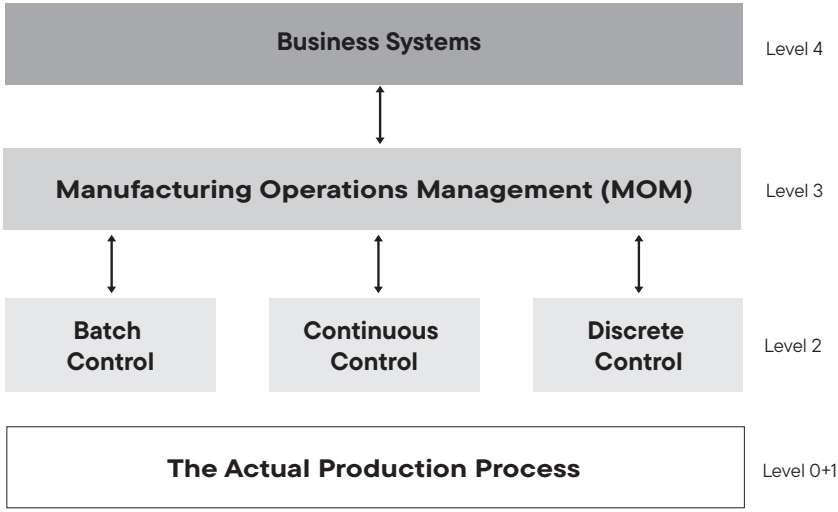


Figure 2.1: The Purdue Reference Model
Also referred to ISA-95 functional hierarchy model.

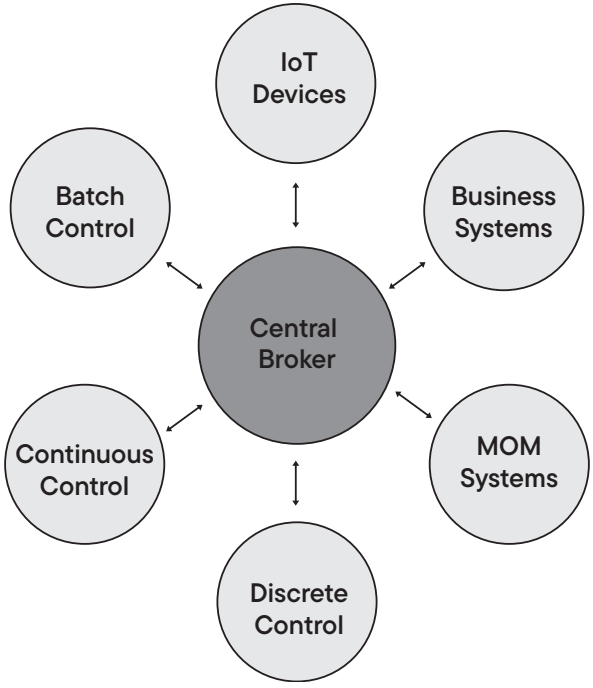


Figure 2.2: Simple Broker Architecture
With a single central broker and multiple nodes.

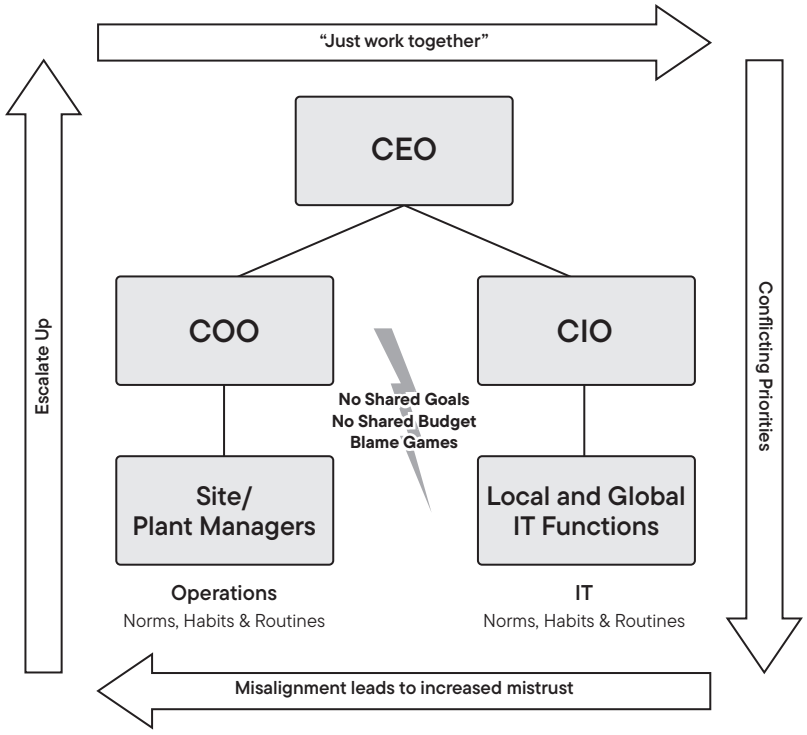


Figure 3.1: Traditional Silo Org Chart

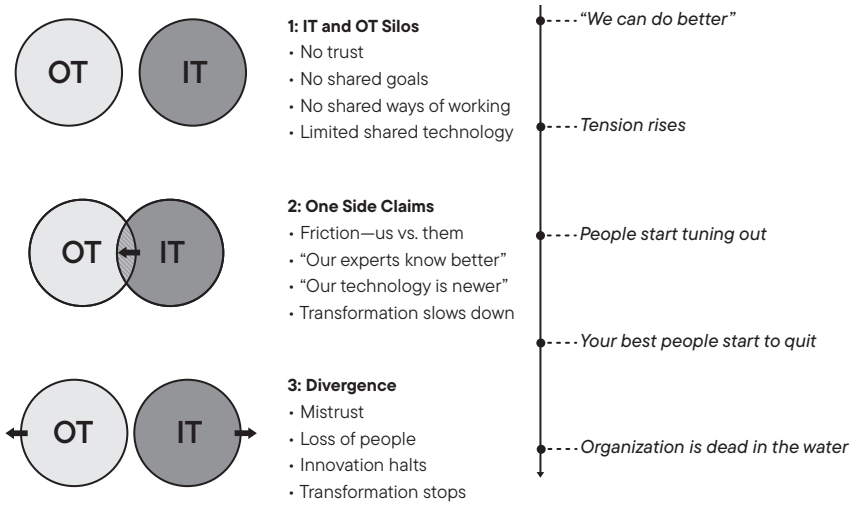
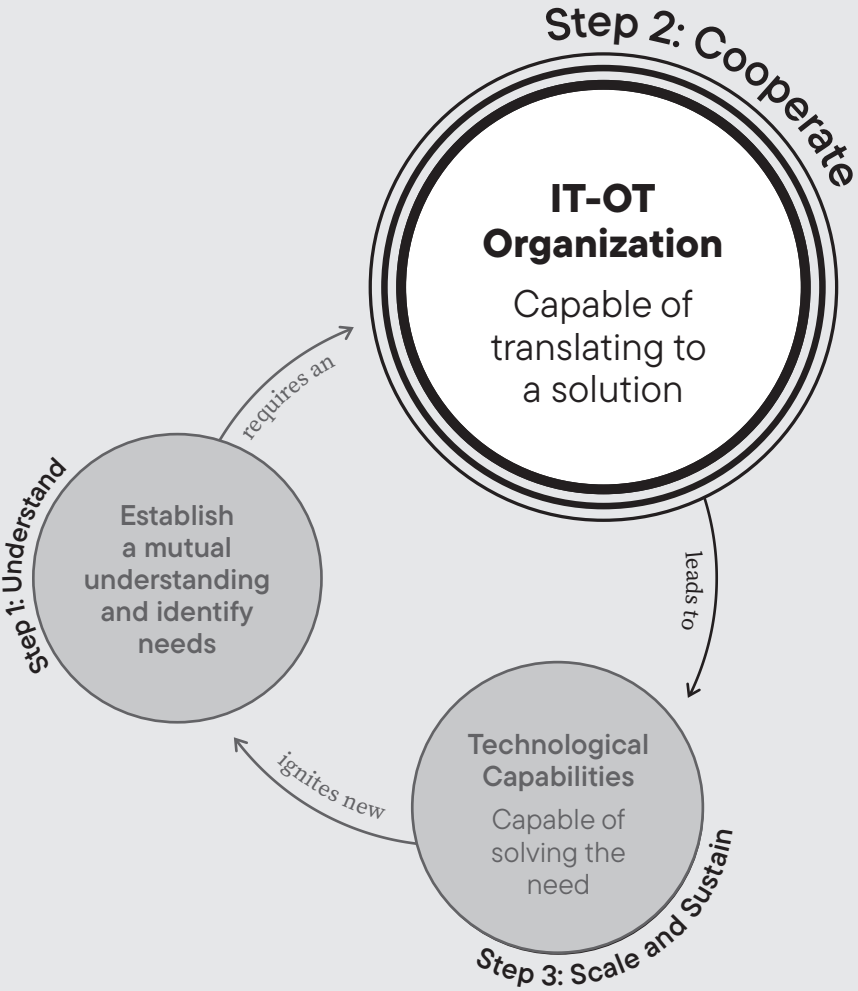
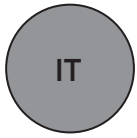


Figure 3.2: IT/OT Divergence in Three Steps

PART II

COOPERATION PATTERNS





Represents all or part of the IT organization, typically reporting to the CIO or similar function.



Represents the operational side of your organization. This could be Operations, OT, or both depending on your context. In your organization, this might report to a COO, VP of Operations, or similar function.



Indicates a virtual team or matrix organization, which means it represents a collaborative structure rather than a separate hierarchical entity.

Figure 5.1: The Visual Structure of IT/OT Patterns

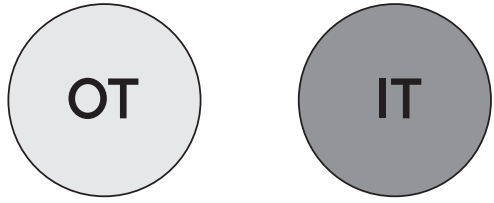


Figure 5.2: Pattern 1: IT and OT in Silos

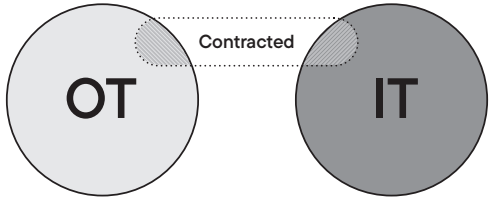


Figure 5.3: Pattern 2: Outsourced Innovation

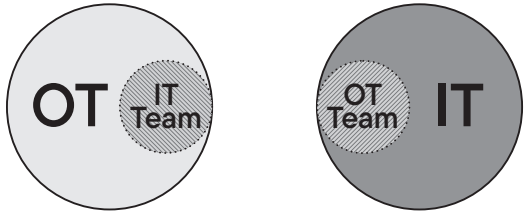


Figure 5.4: Pattern 3: Shadow IT in OT or Shadow OT in IT

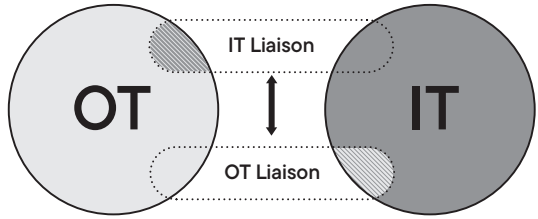


Figure 5.5: Pattern 4: Facilitation

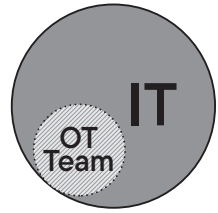


Figure 5.6: Pattern 5: Full IT/OT Convergence
We depict OT as a subset of IT, but clearly not as a separate team (hence the dotted lines).

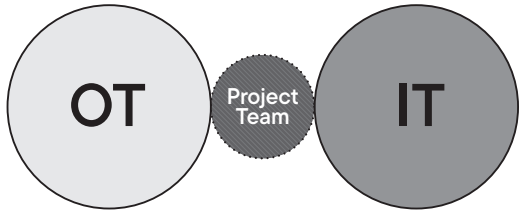


Figure 5.7: Pattern 6: A Project Team Staffed by IT, OT, and/or Operations

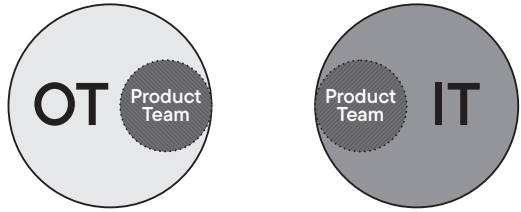


Figure 5.8: Pattern 7: Product Teams Can Sit in OT and/or IT

Table 5.1: Project Team vs. Product Team

Project Team	Product Team
Temporary: 6-18 months	Permanent team
Fixed scope and budget	Evolving roadmap
Success = on scope, time, and budget	Success = aligned business outcomes
Has an end date	Continuous ownership
Funded as initiative	Funded as capability
Optimized for delivery	Optimized for learning and adapting

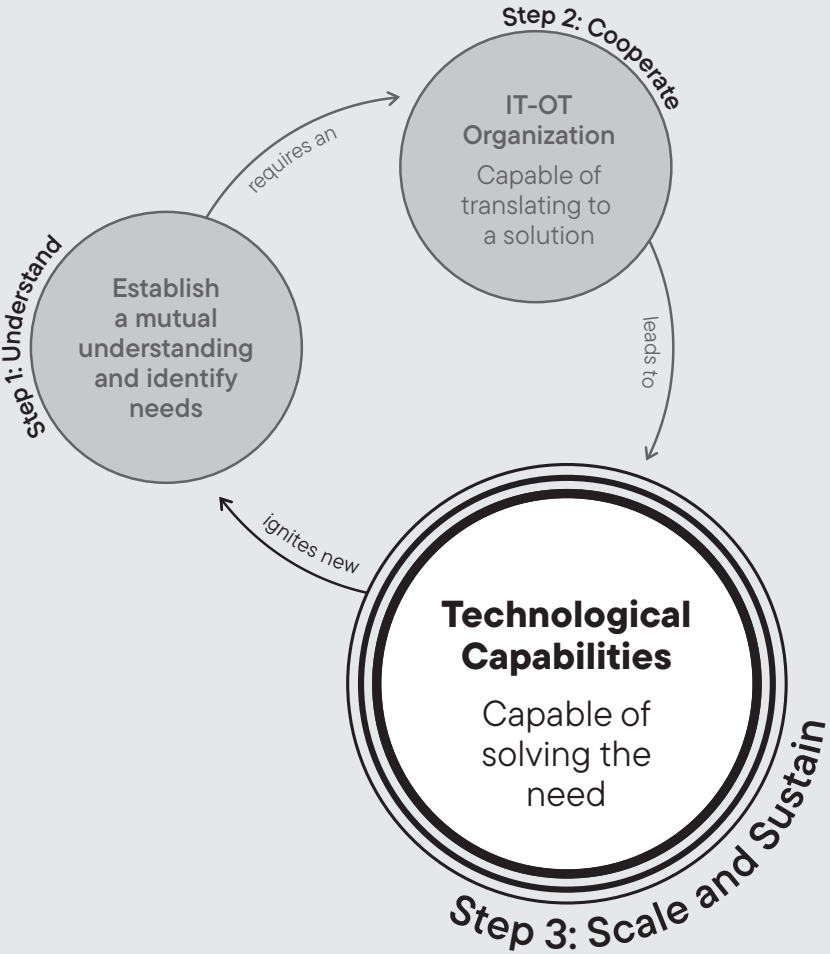
Table 6.1: The Patterns Mapped to Coordination Complexity

Pattern 5 is not included because it does not fall under coordination complexity.

Low Complexity	Medium Complexity	High Complexity
Pattern 1: IT and OT in Silos	Pattern 3: Shadow Teams	Pattern 6: Cross-Functional Project Teams
Pattern 2: Outsourced Innovation	Pattern 4: Facilitation	Pattern 7: Product Teams

PART III

BUILDING THE TECHNICAL FOUNDATION



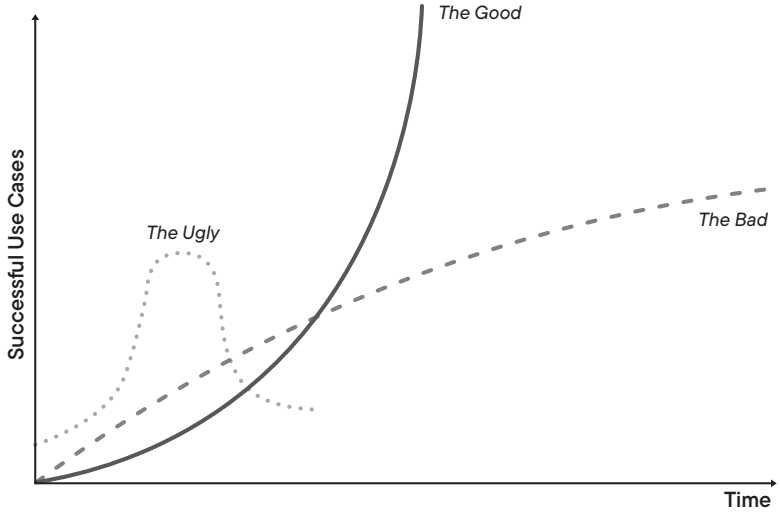


Figure 7.1: Three Scaling Scenarios
The Good (upward trending curve), The Bad (dashed stalling curve), and The Ugly (dotted line).

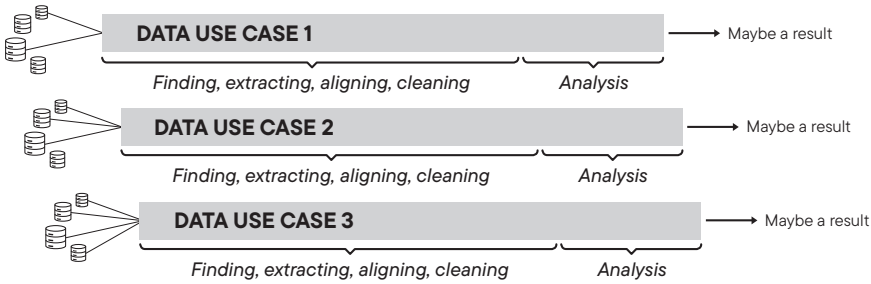


Figure 7.2: Visual of How Three Data Projects Are Executed
It starts with finding, extracting, aligning, and cleaning data from several sources. Only then can the analysis work begin, which might or might not return a result.

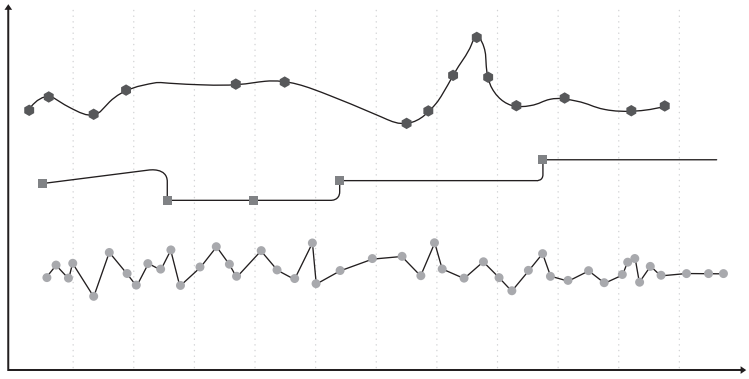


Figure 7.3: Example of Three Sets of Time-Series Data

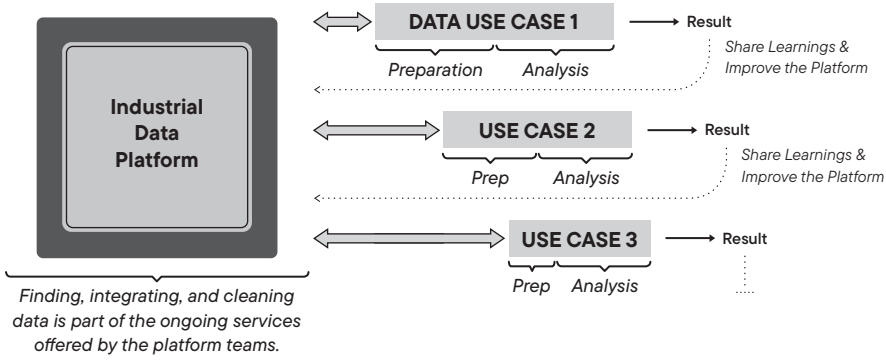


Figure 8.1: The Industrial Data Platform

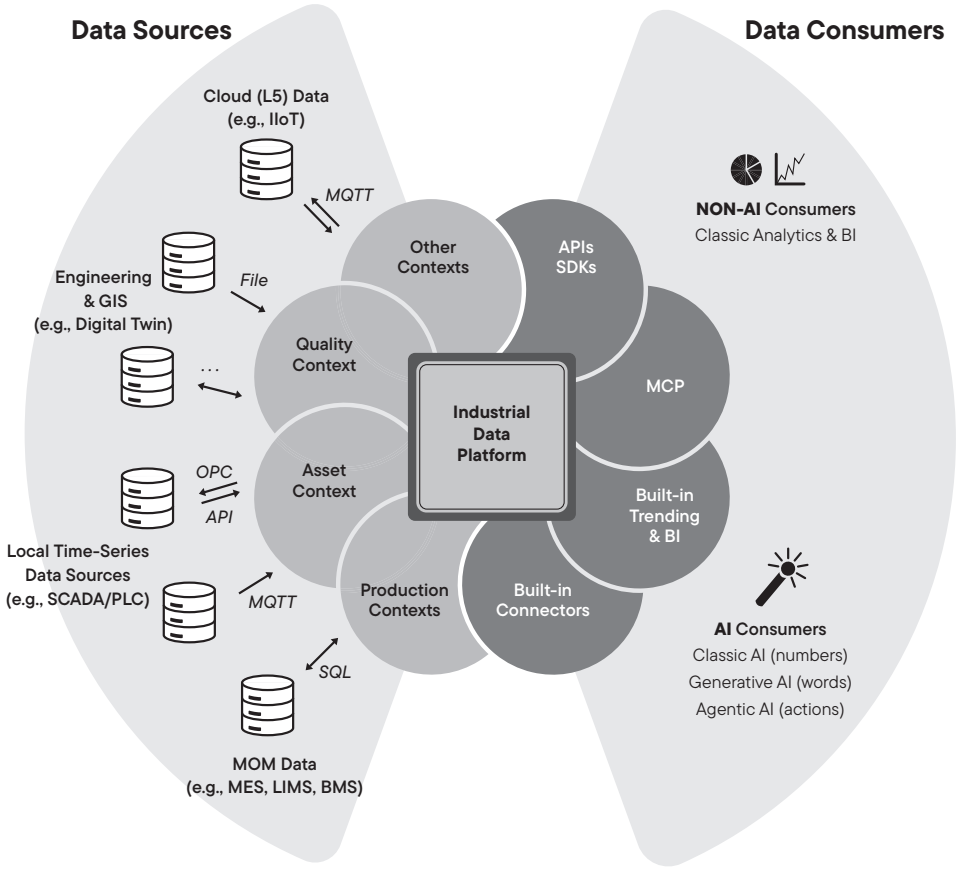


Figure 8.2: Generic Representation of an Industrial Data Platform

Data sources on the left connect through a contextual layer to the platform itself in the middle. The data in the platform is exposed in an open and scalable way to data consumers on the right.

```
Enterprise: Sweet Harmony Treats
 └─ Site: Belgium - Antwerp
    └─ Area: Baked-Goods Production Hall
     └─ Work Center: Waffle Line 01
       ├─ Work Unit: Ingredient-Handling
       ├─ Work Unit: Batter-Mixing
       ├─ Work Unit: Proofing
       ├─ Work Unit: Depositor
       ├─ Work Unit: Baking-Tunnel-Oven
       │  ├─ Heating Zone 01
       │  │  ├─ Temperature: Top, Bottom (°C/F)
       │  │  ├─ Gas burner: Valve Position (%)
       │  │  ├─ Gas burner: Mass Flow (Nm³/h),
       │  │  └─ Circulation Fan Speed (%)
       │  ├─ Heating Zone 02
       │  │  └─ …
       │  ├─ Belt-Drive-Module
       │  │  └─ …
       │  └─ Oven Utility Metering
       │    ├─ Electricity: Total Oven (kW)
       │    ├─ Electricity: Incoming Mains (A)
       │    └─ Gas: Total Oven (Nm³/h)
       ├─ …
```

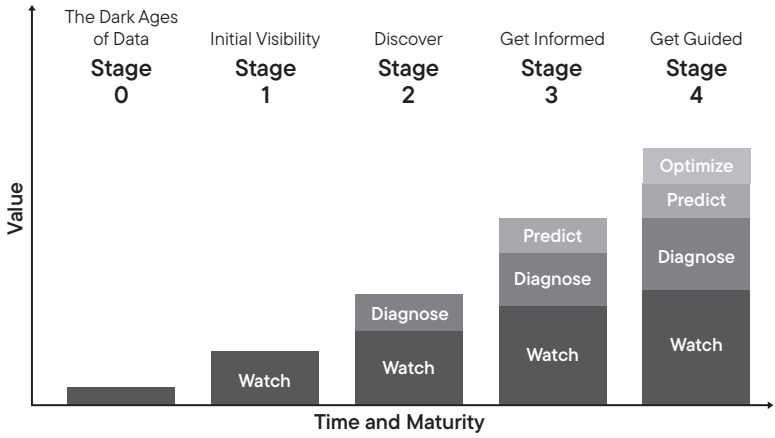


Figure 9.1: Data Journey

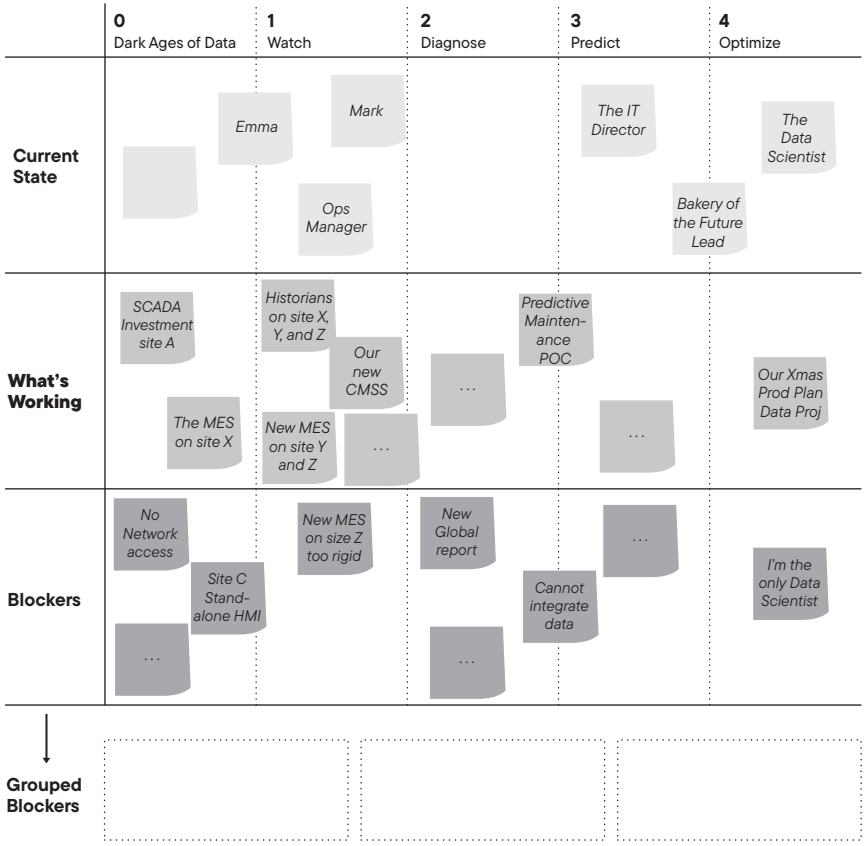


Figure 9.2: Current State, What's Working, and the Blockers

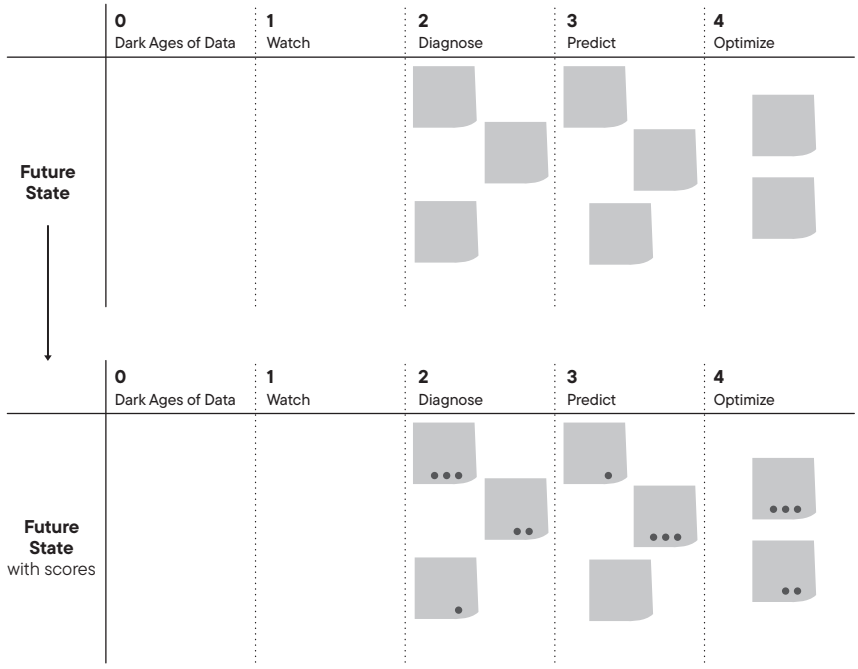


Figure 9.3: Future State and Future State with Scores

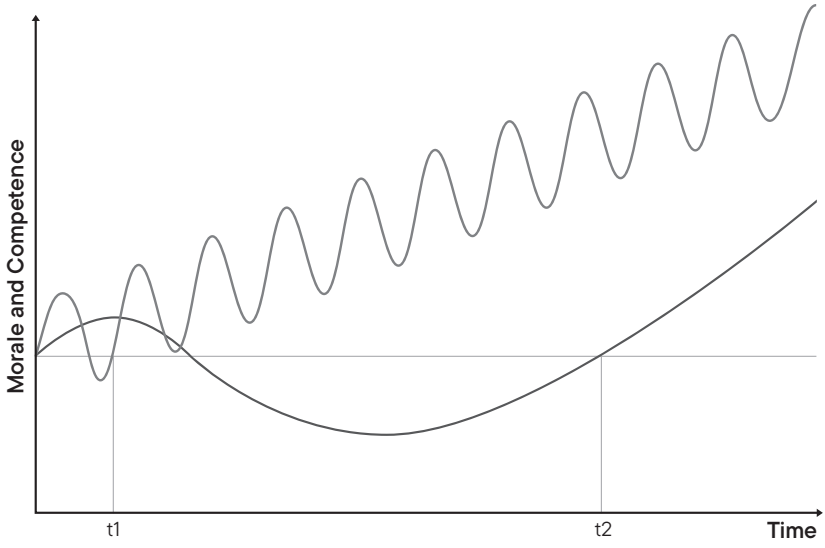


Figure 9.4: Big-Bang Project (Bottom Line) vs. Small Steps (Top Line)

Jonathan Smart, "Want to Scale Agile? Don't. Descale the Work First. Achieve Big Through Small." Medium, August 18, 2018. https://medium.com/sooner-safer-happier/want-to-scale-agile-dont-descale-the-work-first-achieve-big-through-small-7bdd09962540.

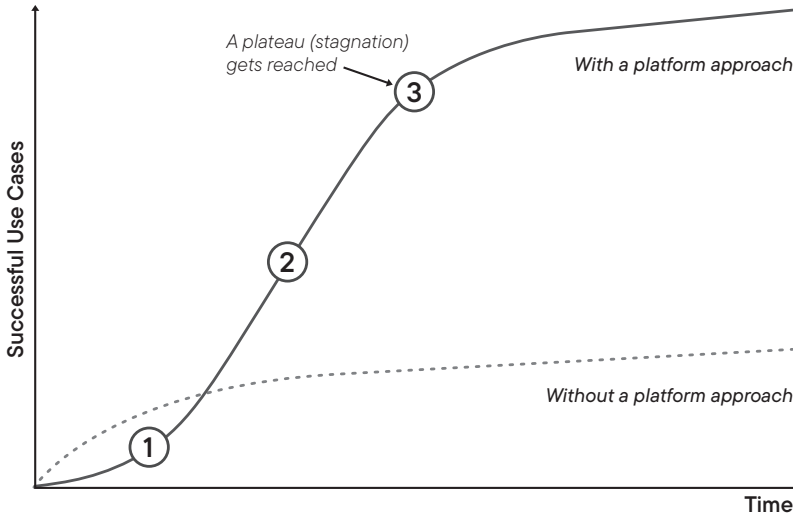


Figure 9.5: Productivity Plateau

A first productivity plateau gets reached after successfully stepping over the tipping point.

Conclusion

BUILDING TOWARD ONE TEAM

Remember that printer from the preface? The one that refused to cooperate late at night, triggering a full-blown war room, nearly bringing a global supply chain to a halt? We started this book with that story because it captures the messy reality of digital transformation in manufacturing: the people, the pressure, the physical world, the patchwork of systems, and the fact that cooperation between IT and OT can make or break you when it matters most.

That's what this book has been about. Not just the technology but how people, systems, and decisions connect. We structured the journey around a three-step framework that reflects the real work ahead:

- **Understand:** Why IT and OT evolved separately, how their goals and mental models differ, and what data convergence now demands. You can't build bridges without understanding the terrain on both sides.
- **Cooperate:** How to expand the common ground between IT and OT—not by forcing convergence but through deliberate organizational patterns that make working together the natural way to solve shared problems.
- **Scale and sustain:** How to move from pilots to production, build platforms that compound value, and recognize when you've hit the plateau that signals it's time for the next transformation loop.

The framework isn't linear—it's a continuous cycle. Each iteration deepens understanding, strengthens cooperation, and expands scale. This is how transformation actually happens: not all at once but through repeated cycles that build capability over time.

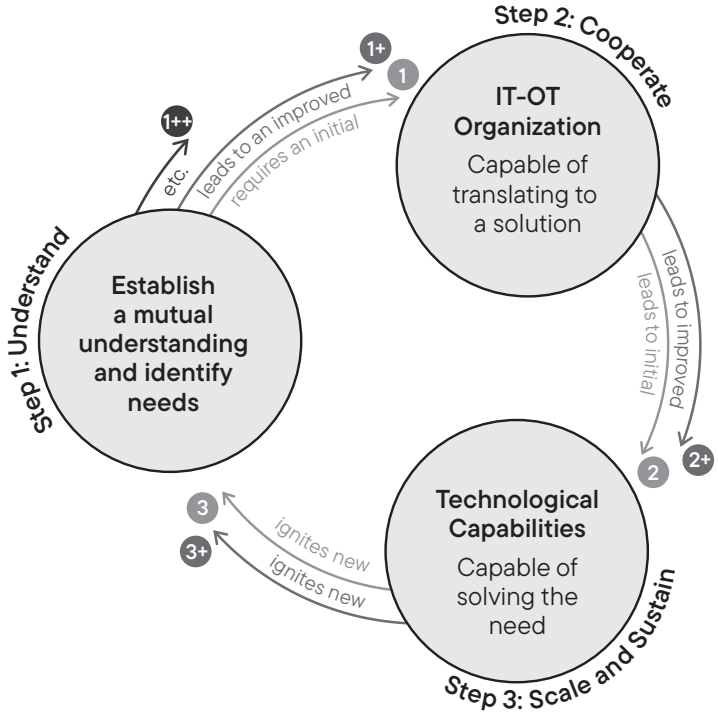


Figure C.1: Adapted Three-Step Framework with Continuous Learning and Adaptation

Better Cooperation Isn't the End Goal

Throughout this book, IT and OT remained separate identities. Even in the most advanced cooperation patterns, they stayed distinct. Working together, but never truly merging. Pattern 7 (Product Teams) still had people sitting in either IT or OT. Halifax Water's success came from aligning IT and OT under one Technology leader, but the identities persisted.

This was a deliberate choice. We wrote this book for the here and now—practical patterns you can implement within current organizational constructs without requiring your CEO to restructure the entire company. But let's also be clear about where this is really headed.

The word "cooperate" implies two separate entities working together—IT helping OT, OT accommodating IT. That's progress from silos, but it's not the end state.

But what if IT and OT weren't identities at all?

What if they were skill pools instead of organizational homes? What if team identity aligned to value streams instead of technical domains? What if you had an MES team—a long-lived, multidisciplinary group with IT skills, OT skills, and Operations expertise, all serving the same business outcome? Not "IT people" cooperating with "OT people" but one team where those distinctions become irrelevant. Their identity isn't IT or OT. It's the MES. The value stream. The business outcome they collectively own.

Halifax Water didn't just align IT and OT—they created one Technology organization with shared incentives under one leader. DevOps didn't just improve cooperation between Dev and Ops—it merged them into teams where you own what you build. You get called at 2 a.m. to support your own code, not to fix someone else's problem. When your survival depends on the person next to you, understanding their perspective stops being a virtue and becomes a reflex.

Shared incentives make cooperation real. Without them, "cooperate" is just a word on a slide.

The most successful transformations we've seen are the ones where IT and OT gradually became less relevant as identity constructs—where teams organized around value, the asset management platform, the quality system, the production optimization capability, with whatever mix of skills the outcome required—and someone's background in automation or enterprise architecture mattered less than their commitment to shared success. That's the future this work is building toward: value-aligned, long-lived teams where the only question is how to solve the problem, because it belongs to everyone in the room.

The Journey from Here

Most organizations aren't ready to dissolve IT and OT identities tomorrow—organizational inertia is real, reporting structures exist for reasons, and restructuring faster than people can adapt is a reliable way to achieve neither.

That's fine. Start where you are.

Use the patterns. Build facilitation capability (Pattern 4) if you're still in silos. Create cross-functional Project Teams (Pattern 6) when complexity demands it. Evolve toward Product Teams (Pattern 7) when you have the capability and the mandate. Each pattern builds the trust, vocabulary, and shared understanding the next pattern requires.

But keep the bigger vision in mind. Every time you create a cross-functional team, you're practicing the future. Every time you align incentives across IT and OT, you're weakening the identity boundaries. Every time someone says "we" instead of "they," you're moving toward value-aligned teams.

The cooperation patterns are the bridge, not the destination. They're how you get from here (siloed identities) to there (value-aligned teams) without breaking everything along the way. Use them deliberately. But don't mistake the bridge for the other side.

What This Requires from You

Near term: Take the practical steps this book outlined. Recognize which pattern you're operating in. Understand when your current pattern hits its limits. Build the cooperation capability your complexity demands. Create platforms that make data accessible and reusable. Iterate: understand, cooperate, scale, repeat.

Long term: Challenge the identity constructs themselves. When you create that next digital transformation initiative, ask: Does this really need to be an "IT project with OT involvement"? Or could it be a value stream team that happens to need IT and OT skills? When you reorganize, ask: Are we optimizing for domain expertise (IT, OT) or business outcomes (asset reliability, production optimization)? When you set incentives, ask: Are we rewarding silo success or shared success?

The biggest mistake we see? Trying to skip the journey. Declaring "we're one team now" without building the trust, capability, and incentive structures that make it real. That's how you get cynicism, not transformation.

But equally dangerous: stopping at cooperation. Building beautiful bridges between IT and OT, then treating those bridges as the end goal.

Transformation is when the bridges become unnecessary because there's nothing left to bridge. When IT and OT aren't identities people protect but skills people contribute. When teams organizing around value and identity

comes from shared outcomes, not technical domains. When "cooperate" becomes a meaningless word because there's only one team to begin with.

Final Thoughts

We've seen what's possible. We've helped make it happen. The organizations that move fastest aren't the ones with the best technology or the biggest budgets. They're the ones that figured out how to align people, incentives, and structures around shared success.

The gap between IT and OT isn't only technical; it's human and organizational. This book gave you tools to bridge that gap within current constructs. But don't stop there. Use those tools to build toward something bigger: organizations where IT and OT are skills, not identities. Where teams align to value. Where cooperation is so deeply embedded it becomes invisible.

Thank you for taking this journey with us. Now go build the teams that your transformation needs.

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