SUPPLY CHAIN MANAGEMENT REVIEW
Jan/Feb 2026

Managing the autonomous era

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BRIAN STRAIGHT *Editor in Chief* bstraight@peerlessmedia.com

When tech outruns talent

AI, autonomy, and digital transformation are accelerating, but unless organizations build the skills to use them, supply chains will remain stuck in pilot mode.

The supply chain profession is standing at a crossroads. Technology is advancing faster than ever. Autonomous trucks are moving toward commercial deployment. AI is shifting from predictive to agentic decision-making. Digital transformation is giving way to self-aware systems. But the more time I spend with supply chain leaders, the more one truth seems to emerge: none of this technology will deliver on its promise unless we develop the people who know how to use it.

This issue highlights just how quickly the ground is shifting beneath us. In our cover story on autonomous trucking, Steve Tracey and Kusumal Ruamsook write that "the recent decade witnessed the rapidly evolving nature of autonomous trucking technologies, offering promises of improved logistics, inventory management, and customer service for supply chains."

Their analysis makes something else equally clear: the real opportunity isn't just driverless trucks, it's the transformation of freight planning, network design, and customer service that supply chain managers will need to orchestrate.

The same theme surfaces when the discussion turns to Agentic AI, where data, not algorithms, is emerging as the real gatekeeper of progress. Most supply chains still can't feed AI agents what they need. Data lives in silos, master records don't match, and legacy platforms refuse to talk to one another.

And even more importantly, as Gartner noted, Agentic AI "requires real-time access to contextual data across suppliers, production, logistics, and customer channels" to function effectively.

Technology may be ready, but organizations, and the people within them, often aren't.

That gap between technological capability and human capability is the defining challenge of our time.

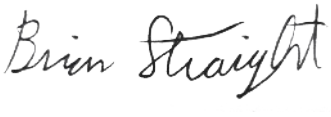
We can deploy autonomous trucks, but do our teams know how to redesign inventory strategies and facility footprints around a world of faster, more consistent transit times? We can implement Agentic AI, but do our planners know how to govern, validate, and interpret decisions made by machines? We can invest in digital transformation, but do we have the talent and the leadership vision to translate data into real competitive advantage?

Our January issue puts those questions front and center. From cocoa supply chain diagnostics to hidden cost structures in service markups to the evolving role of tuition programs in frontline training, a unifying message emerges: technology alone won't get us there. People will.

If we fail to upskill today's workforce and cultivate tomorrow's leaders, AI becomes just another expensive tool; autonomy becomes just another pilot program; and digital transformation becomes just another initiative that never reaches scale.

But if we invest in talent—deeply, intentionally, and consistently—we unlock the full value of every technological advance reshaping our industry.

That is the work ahead. And it starts now.



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Oil 2026 update: Souring on climate politics

A shifting political landscape and stalled climate commitments are reshaping oil markets, energy security, and supply chain planning in 2026.

By Larry Lapide

Dr. Lapide is a lecturer at the University of Massachusetts: Lowell and formerly an MIT Research Affiliate. He has extensive experience in industry, consulting, business research, and academia as well as a broad range of forecasting, planning, and supply chain experiences. He was an industry forecaster for many years, led supply chain consulting projects for clients across a variety of industries, and has researched supply chain and forecasting software as an analyst. He is the recipient of the inaugural Lifetime Achievement in Business Forecasting & Planning Award from the IBF. He welcomes comments on his columns at Lawrence_Lapide @uml.edu.

This is my annual update on oil that began with my first Insights column: "Is your supply chain addicted to oil?" (January/February 2007). Since, I've focused on the price of oil because freight costs are a sizable (and controllable) portion of supply chain costs. Also, because it appeared that oil prices would rise over time, it was obvious that supply chains would have to be more energy efficient and less dependent on oil. Initially, the tagline was "supply chains needed to slow down" because highly responsive chains were energy inefficient. Furthermore, once there were climate concerns, oil got a "dirty name"—as a polluting CO_2 fuel—that became another important reason to squeeze oil out of supply chains.

Update recap

The titles of my last 5 updates tell most of the story of the recent past.

1. "Oil Update: Still need fracking?" (January/February 2021)
2. "Oil Update: Where's the global energy plan?" (January/February 2022)
3. "Oil Update: We need security plans from policymakers" (March/April 2023)
4. "Oil Update: The same, for now" (January/February 2024)
5. "Oil Update: Price stability, climate change uncertainties" (January/February 2025)

Over the past several decades, shale fracking in the U.S. has played a major role in moving the oil markets away from the too-often political whims of OPEC and other major oil-exporting countries—including the rogue state of Russia. Fracking became a stabilizing factor in moving the oil market closer to a free market, largely based on supply versus demand principles. While pricing did not grow as fast as expected, it was more volatile and reacted to major economic crashes, wars, and the COVID-19 pandemic. These events caused either demand or supply to significantly change and with that, oil prices as well.

As can be noted from the titles above, climate change initiatives have dominated news cycles. Especially since Russia invaded Ukraine in early 2022. World policymakers realized that plans to primarily reduce the world's reliance on fossil fuels with renewal energy sources like wind and solar were insufficient. There needed to be three coordinated and balanced plans to achieve: 1) energy security, 2) economic security, and 3) climate security. Climate security alone was not enough, as the first two plans would deal with today's important issues while climate security focuses on 2050 and beyond.

Climate change talks became unproductive

The U.S. signed the Paris Climate Accords treaty, which covers climate change mitigation, adaptation, and finance, in 2016. It was negotiated by 196 parties at the 2015 United Nations Climate Change Conference and entered into force in November 2016. There appeared to be a mutual global strategy to move away from fossil fuels and replace them with renewables and other CO_2 non-polluting energy sources in the long term. Goals were established to reach net zero by the middle of the 21st century and keep the rise in global surface temperature to no more than 1.5 deg. C above pre-industrial levels. Also, emissions needed to be cut by roughly 50% by 2030. These turned out to be unrealistic goals for a variety of reasons.

As I write this column, the COP30 climate negotiations focused on meeting 2030 goals ended. A *Boston Globe* article (Nov. 23, 2025) summarized the results in an article titled: "Climate talks end with weak resolution" and subtitled "COP30 seen as insufficient from the outset." Evidently, the negotiations ended "with a watered-down resolution that made no direct mention of fossil fuels, the main driver of global warming." More importantly no specific plans for reducing fossil fuel emissions.

An article published by *The New York Times* (Sept. 17, 2025) titled "It Isn't Just the U.S. The Whole World Has Soured on Climate Politics," chronicled the growing disillusionment with climate change politics. Some telling excerpts are:

- "The world hasn't actually abandoned green energy, with global renewal rollout still accelerating and investment doubling."
- "But climate politics is in undeniable withdrawal, and far from ushering in a new era of cooperative global solidarity."
- "Polls show that voters don't actually prioritize decarbonization and, crucially, aren't willing to pay much to bring it about."
- "Progressives long believed that climate politics was a kind of tug of war, in which tugging harder would pull many on the other side over the line into grudging support … But it also looks a bit as if they pulled so hard they collapsed in disarray."

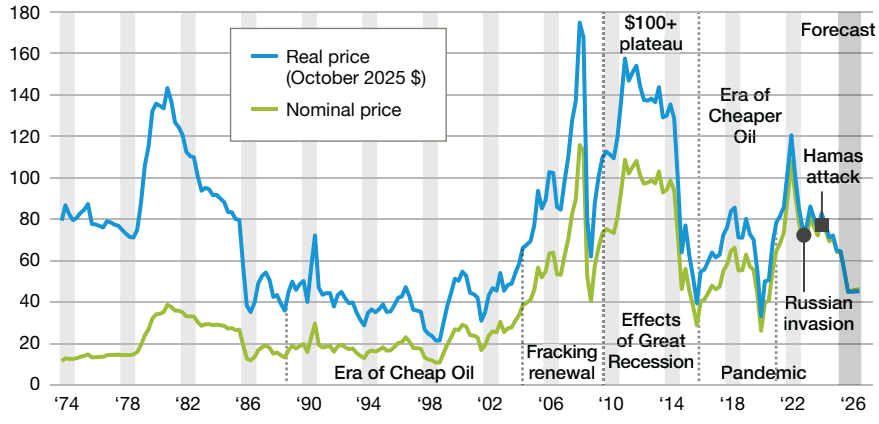
A 50-year history of oil pricing

In each oil update I've shown Figure 1, an updated historical chart depicting real quarterly imported crude oil prices since 1974. The chart shows various pricing levels through time. After the era of cheap oil ended with rising prices, the first signs of cheaper oil appeared as a precipitous drop, the result of the Great Recession of 2008, which drastically depressed worldwide economies and the demand for oil. This was followed by a three-plus-year period termed the "$100+ plateau" before receding to cheaper oil. The $100+ plateau ominously looms in the rearview mirror as a reminder of what could happen if worldwide economic and supply conditions reach the robust levels seen prior to the recession.

FIGURE 1

Quarterly imported crude oil price

dollars per barrel



Source: EIA Short-Term Energy Outlook, October 2025

Over the period of higher oil prices, U.S. oil fracking operations came online because the prices were high enough to justify the investment. U.S. frackers innovated and reached a point where operations were flexible enough to easily turn on and off as oil prices move up and down. The fracking industry made the United States the world's top oil supplier and a net exporter. In addition, fracking output caused a worldwide oversupply of oil that brought back the era of cheap oil. However, as discussed in my 2021 update, oil prices dropped to cheap oil levels when the pandemic began—prices not seen since around 2004. I questioned whether fracking was still economically justified. As seen from Figure 1, the Russian invasion triggered a spike in prices. However, it was short-lived, peaking to over the $100+ plateau for only one quarter and back down to cheaper oil—hovering around $70 to $80/barrel. It has largely remained there since last year's update. It seems that the $100/barrel of oil level is approaching a ceiling as this is the level at which frackers start to show an interest—driving up supply.

Recent news regarding climate initiatives

Generally, the world is struggling to meet COP's emission targets mainly because the thirst for energy, and in particular fossil fuels, has not subsided. Population and economic growth require growing energy use. According to a 2024 United Nation's forecast, the world population will peak in 2084 at just under 10.3 billion from about 8.2 billion today. However, despite zealous advocates pushing policymakers to develop practical plans to replace fossil fuels with renewables, no plan has yet been agreed upon. Many thought that replacing coal and oil use with more natural gas (as a bridge fuel), was one key element. In addition, wind and solar renewable sources would be aggressively relied upon, as well as all

other non-fossil fuels. However, policymakers need to serve their constituents, and nuclear, by public opinion, was deemed unsafe. Ten years of valuable nuclear development did not happen. Below are some of the policymakers' less-than-successful initiatives.

1. An over reliance on renewables growth. In a *Wall Street Journal* article (Oct. 8, 2025) titled "U.S. Renewal Energy Growth Outlook Cut," it stated that the International Energy Agency slashed the growth forecast 50% from its last annual forecast. While solar is doing okay, the weak spot for renewals is in wind because of "permitting delays, supply chain bottlenecks, and rising costs."

2. Promoting just electric vehicles (EVs), rather than hybrids as well. In "U.S. Shift Against Electric Cars Swells into Global Reversal" (*WSJ*, Oct. 15, 2025), it stated that "AlixPartners now predicts EVs will make up 18% of new vehicle sales by 2030, half of what was expected two years ago." EVs won't sell enough until there are enough electric chargers.

3. Slow gas pipeline development hampers important (and bridging) natural gas growth. In "Gas Pipeline Projects Face Hurdles" (*WSJ* May 23, 2025), it states that "Five interstate gas projects were canceled between 2013 and 2021…" In Massachusetts, we have to bring in LNG (liquid natural gas) tankers into small harbors at great expense—because we don't have enough pipeline capacity.

4. Deeming nuclear too risky was misguided. Germany's former strategy to replace all its nuclear power plants with natural gas from Russia was shown to be a bad strategy when Russia attacked Ukraine. In "Environmentalists Fight for Nuclear Plants" (*WSJ*, Oct. 10, 2025), the article is subtitled "Some activists [e.g. in Belgium] now see reactors as a source of low-carbon electricity." In other *WSJ* articles, similar thoughts were: "UK's First Nuclear Plant since 1995 Wins Approval" (July 25, 2025); and "US Bets Big on a Revival of Nuclear Power Industry" (Nov. 25, 2025). The later article points out that the U.S.'s "last big nuclear power project came in more than $16 billion over budget and seven years behind schedule." Plus, it has a chart showing electricity generation by selected sources from 2001 to the present. It shows minimal growth in nuclear, and natural gas basically replacing much of coal's declines; as well as wind rising to coal's level. High-tech firms are now projecting that their AI and future cloud computing operations are going to add substantially to the world's energy (i.e., electricity) needs. Constellation Energy "announced last year that it would restart the Three Mile Island site of the country's worst nuclear power accident to help generate electricity for Microsoft, which needs more power to fuel its artificial intelligence business," according to a *WSJ* article (Nov. 12, 2025), titled "U.S. Will Give $1 Billion Loan to Restart Three Mile Island." Google, Amazon, Meta and others are also racing to get more power in order to stay competitive.

Summary

My advice generally stays the same as the past few years. It will always be prudent to reduce the use of carbon-based energy sources by making your supply chains as energy-efficient as possible. However, I expect there will be a substantial growing demand for fossil fuels for some time. As future energy needs appear to be expanding more than needs generated via population growth.

Policymakers are having difficulties weaning their citizens away from fossil fuels. The reality has been that renewable energy, while growing rapidly, has not kept up with the still-growing thirst for fossil fuels. For policymakers, today's life challenges are getting in the way. They too often need to put climate change policies on the back burner. Generally, in the short term, humans vote for policymakers that focus on the here and now—2050 is too far over the horizon to matter much to today's voting population.

Meanwhile, don't expect much significant human action on climate change until Mother Earth strikes back with a highly catastrophic climate change event due to the higher temperatures forecast by scientists. I am optimistic, however, that future supply chain managers will adapt to the new environments, and continue to supply the goods and services needed by the human race (plus robots). After all, it's what we do for a living. •

Human-aware automation: The future of vehicle intelligence depends on understanding people

Driving automation is advancing rapidly, yet the biggest challenges ahead have less to do with sensing the road and more to do with understanding the human behind the wheel. Human-aware automation will become one of the defining features for an elevated driving experience and safe mobility.

By Dr. Pnina Gershon

Dr. Pnina Gershon is a research scientist at the MIT Center for Transportation and Logistics, director of the AWARE initiative, and director of research at the MIT AgeLab's Advanced Vehicle Technology Consortium and can be reached at pgershon@mit.edu.

Autonomous vehicles are an ambitious technological undertaking that have evolved dramatically over the past decade and are reshaping the transportation landscape. The momentum is palpable. But this progress has highlighted an important truth apparent across every level of deployment: the technical side of driving automation is advancing faster than our understanding of how humans are interacting with these systems. To reach their full potential, driving automation systems require more than advanced environmental sensing; rather, they depend on a deeper understanding of the human beings sharing control, riding inside, and moving around these vehicles. Eventually, the real differentiator between driving automation systems will not be better sensors or faster computing, it will be technologies that can interpret and respond to the human state, human behavior, and human variability. Simply put, driving automation systems need to understand people.

For years, conversations around driving automation systems centered on environmental perception: lidar, radar, computer vision, and neural networks. But as these systems have been deployed in the real world, the biggest challenges that have emerged are not just about detecting lane lines or classifying objects, they are about people: their attention, habits, trust, fatigue, reactions, and expectations. Most automated systems still operate on the implicit assumption that humans will adapt to the machine. And humans do adapt, but not always in ways designers and engineers intend or expect. Our research across multiple studies makes this clear.

What real-world driving reveals about people and automation

For more than a decade, the MIT AgeLab's naturalistic driving research program has been building one of the richest datasets available to study driver interaction with technology and driving safety. As the director of research at the MIT Advanced Vehicle Technology Consortium, and through close collaboration with industry partners and stakeholders, I work to understand how drivers use, adapt to, and behave with the most advanced automation systems currently available on the market. At the AgeLab, we study how people engage with advanced vehicle systems in both their everyday lives and across their lifespans. This work provides a rare window into directly observing and objectively quantifying the dynamics of driver behavior, vehicle kinematics, and environmental context. It offers a triad of information essential for designing intelligent driving systems.

In our studies, we look at the different ways people actually engage with automation, interact with other road users, and make decisions about whether they trust these systems. Understanding these behavioral patterns is essential for mitigating misuse and disuse, and for advancing support that future driving automation systems can offer. We see that drivers use automation fluidly, moving in and out of different levels of assistance based on moment-to-moment road conditions, traffic cues, and shifts in personal preferences. Drivers often want to do something that is beyond the automation's capabilities, or they simply prefer a different speed, lane position, or driving strategy. The result is a wide range of human–automation interactions that unfold in ways current systems cannot fully anticipate or adapt to.

Over time, drivers also seem to learn system boundaries and safeguard sequences, becoming faster at responding to automation alerts and more adept at identifying brief "windows" where they can shift attention away from driving to engage in non-driving tasks, often accompanied by more off-road glances and more frequent hands-free driving. These findings underscore that driving automation does not remove the driver from driving, but it does change how drivers manage control and direct attention, and they do not always stay within the system's intended boundaries.

Further, our studies of driver-pedestrian interactions show that this is not just a detection-and-yield problem. These interactions are fundamentally social and far more nuanced than right-of-way rules suggest. Pedestrians rely on subtle cues—for example, how quickly a vehicle decelerates, whether it maintains speed, how long it pauses at the curb, and whether the driver acknowledges them—and these cues differ across environments and locations. These findings reinforce the dynamic nature of driver-pedestrian interactions with bidirectional communication processes that future driving automation systems should learn to interpret and replicate.

Consumer acceptance is another aspect to consider. Our longitudinal survey work demonstrates that acceptance of automation tends to be conditional, and it depends on the use case, the perceived benefit, and whether automation solves a problem that people actually face. We found that baseline willingness to use an autonomous vehicle remained cautious over the years, yet acceptance increased dramatically when framed around specific situations or cases, such as being unable to drive due to age or injury, or being assured that the vehicle is "as safe as" the human driver is. These conditional scenarios suggest that people evaluate autonomous vehicles in relative terms: *Will this be safer than me? Will it help when I can no longer drive?* Further, acceptance is not universal and varies by characteristics like age. Younger adults express higher enthusiasm for full autonomy, whereas older adults overwhelmingly prefer driver-assist features but become nearly as willing as younger adults once safety and mobility-loss scenarios are introduced.

The lesson from naturalistic driving research is simple: people are complex and variable. They adapt in unexpected ways. They bring their beliefs, context, emotions, distractions, and experiences with them into the vehicle. As such, over the next decade of vehicle automation development, the technology needs to understand people better and be able to detect, interpret, and respond to human needs, especially in the dynamic, real-world conditions of driving. Recent advances in AI, particularly in multimodal sensing, foundation models, and real-time behavioral inference, now make it possible for systems to interpret attention, workload, fatigue, stress, and intent with far greater fidelity than before. These capabilities open the door to transformative intelligent systems that apply behavioral engineering to guide drivers toward safer behaviors and mark a shift from observing and reacting to risk toward shaping the decisions and contexts that give rise to it. Driving automation designed to recognize this variability and adapt in a corrective, supportive way, guiding drivers toward the right action when it matters most, will be one of the defining features of an elevated driving experience and safe mobility.

Toward human-aware vehicle intelligence

Recognizing this need to understand human behavior better, the AgeLab developed AWARE (AI with Awareness in Real-world Environments). AWARE is built around this principle: advancing human-aware AI that senses, interprets, and adapts to human variability with the goal of supporting positive behavioral change in dynamic, real-world conditions. We envision that the vehicle of tomorrow will be more than just a mode of transportation; rather, it will serve as a platform for mobility, services, and human support.

Using multimodal sensing, behavioral modeling, and AI, AWARE develops the foundations for building systems that are not only technically capable but also human-attuned. AWARE brings together interdisciplinary research in sensing, behavior, health, and design, addressing safety issues like driver distraction, impairment, changes in mental and physical states as well as enhancing well-being and the overall driving experience.

As we look ahead, an important challenge is to develop frameworks that help us anticipate how people will actually interact with emerging intelligent systems. Different design philosophies and levels of AI embedding can lead to very different patterns of use, misuse, and disuse of these systems. To build technologies that truly support the driver, we need predictive methods that can estimate how humans will adapt to new automation features and how they will respond to behavioral-engineering interventions before these systems reach the market.

The path forward calls for a coordinated effort. Industries would benefit from shared standards for measuring and communicating the human state, along with frameworks for evaluating interactions with adaptive automation. The AWARE initiative invites partners interested in advancing human-aware intelligent systems to join us in shaping technologies that understand human engagement. By shifting toward systems that proactively support the human, AWARE positions human-centered intelligence as a foundational element of future-ready vehicles and mobility ecosystems. •

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Global Links, the next chapter: Honoring a legacy, shaping what's next

Karin Bursa is the CEO of NIRAKIO, LLC, a supply chain industry advisor, Global Links editor for Supply Chain Management Review; 2020 Supply Chain Pro to Know of the Year, and frequent podcast host. She can be contacted at kbursa@nirakio.com.

As Global Links welcomes a new editor, the focus remains clear: help supply chain leaders cut through the noise, harness AI and decision intelligence, and turn their supply chain operations into engines for growth and resilience.

By Karin Bursa

For many readers of *Supply Chain Management Review*, the Global Links column is more than a page in the magazine. It has been a trusted voice that connects innovative ideas, people, and practices from across the global supply chain community.

For years, that voice has been shaped by Richard J. (Rich) Sherman. Through his leadership of the Global Links column, and across a long career in this profession, Rich has helped thousands of executives rethink what supply chain can be—and what it should deliver.

This article marks an important moment: a passing of the torch as Rich officially retires and I have the honor of becoming the new editor of Global Links.

I am excited to step into this role. I am also deeply grateful for the path Rich helped create, and for the many ways his work has elevated the profile and impact of supply chain professionals around the world.

Honoring a trailblazer of the profession

Rich has been an influential voice in supply chain for decades. During his time with AMR Research, he helped frame and explain many of the concepts

that now feel "standard" in our field. He has been active in the Council of Supply Chain Management Professionals (CSCMP), served as a volunteer leader with the APICS Austin Chapter, and advised countless companies and professionals as they built more connected, responsive supply chains.

He has been part of many of the conversations that changed how we think about planning, logistics, collaboration, networks, and technology. More importantly, he has always focused on real-world outcomes: better service, lower risk, smarter use of resources, and more resilient businesses.

As Global Links editor, Rich created a space where different perspectives could meet: practitioners, academics, technology providers, analysts, and advisors. Under his guidance, the column has offered a balanced view of trends, challenges, and opportunities—always with respect for the people doing the work.

This transition is not about closing a chapter. It is about acknowledging the contribution Rich has made to the profession as he steps into a well-earned retirement and about building on what he started.

Rich, thank you for everything you have done to advance our profession, champion our people, and strengthen the *Supply Chain Management Review* community.

Why this transition matters now

At the same time this editorial baton is changing hands, supply chain itself is undergoing another major shift.

Leaders are being asked to do more than simply "fix problems" or "keep costs down." You are expected to:

- protect service levels in an increasingly volatile world;
- reduce working capital while serving demanding customers;
- increase resilience and sustainability without adding unnecessary complexity; and
- make sense of a crowded technology landscape, including artificial intelligence (AI), automation, and advanced analytics.

Many of you are still operating with planning tools and processes designed for a slower, more predictable era. You are also navigating a wave of new promises around AI, digital twins, and autonomous planning. Some of those promises are real. Some are just smoke and mirrors.

In this environment, a column like Global Links plays an important role. It can serve as a filter, a translator, and a guide—helping leaders understand what really matters, what is changing, and where to invest next.

Standing on strong editorial shoulders

Supply Chain Management Review, part of the Peerless Media portfolio, has long been a trusted source of insight for executives. Editors such as Frank Quinn, Bob Trebilcock, and Brian Straight have helped build a publication that balances depth with practicality, and offers a wide range of perspectives without losing its independent voice.

Global Links is one piece of that larger whole, but it has a special role. It connects global trends and local realities. It highlights innovations without becoming an advertisement. It gives practitioners a chance to see how others are tackling similar challenges.

I am honored to continue the work.

A bit about my perspective

For more than 30 years, I have worked alongside supply chain leaders across industries—manufacturing, consumer products, food and beverage, retail, life sciences, and more. I have been a practitioner, held executive roles with a

leading global supply chain solution provider, led strategy and marketing teams, and now advise both technology innovators and end-user organizations on how to turn supply chain investments into measurable business outcomes.

Over the years, I have seen the same pattern repeat itself.

- New technology arrives, often with big promises.
- Leaders feel pressure to keep up or not get left behind.
- Projects are launched in a rush, sometimes without clear goals, solid change management, or realistic measures of success.

Some initiatives deliver. Others stall. In too many cases, supply chain teams are left with more tools, more dashboards, and more alerts—but not necessarily better decisions.

My personal mission, and my goal for this column, is simple: help leaders cut through the noise, stop chasing shiny objects, and replace risky inventory with valuable insights. Technology is essential, but it's talent and leadership that deliver sustainable results.

Making AI practical for better outcomes

Artificial Intelligence is a big part of the current noise—and also a big part of the opportunity. Used well, AI can:

- turn raw data into timely, actionable insight;
- spot patterns and anomalies that humans might miss;
- simulate scenarios and recommend options when disruptions hit; and
- automate routine decisions so your teams can focus on more strategic work.

Used poorly, AI can become yet another "black box" that people do not trust, cannot explain, and eventually stop using.

In upcoming Global Links columns, we will focus on what it really takes to use AI and decision intelligence to improve supply chain outcomes. That includes the following.

- **Common business problems.** Starting with questions like "How do we reduce stockouts without over-investing in inventory?" Or: "how do we shorten response times when key suppliers are disrupted?"
- **Better decision design.** Identifying who owns specific decisions and which decisions can be automated, what inputs they need, and how to balance trade-offs between cost, service, time, risk, and sustainability.
- **Data you can trust.** Recognizing that AI is only as good as the data and context it receives—and that sometimes the most powerful move is harnessing additional market signals to augment enterprise data and increase planning precision.
- **Explainability and governance.** Making sure AI-driven recommendations can be understood, challenged, and improved over time, so your teams stay in control—even when they are moving quicker than ever.

In short, we will explore how AI can augment human expertise, not replace it. The goal is not to remove people from the process, but to give them better tools, better visibility, and more time to think.

From information overload to confident decisions

The leaders I speak with every week are not short on data. They are short on clarity. They ask practical questions such as the following.

- Which alerts really matter today, and which alerts are noise?
- Where should we hold inventory—and where can we reduce it without impacting service?

• Which customers or products should we prioritize when capacity is constrained?
• How do we connect our planning process with execution in a more seamless way?

Global Links will focus on the "decision moments" behind these questions. We will explore how to connect decisions across functions so that improvements in one area do not create new problems in another.

For example:

• How to align commercial forecasts, production plans, and logistics capacity in a way that supports more profitable growth.
• How to synchronize risk management, supplier strategies, and inventory policies so you are prepared for disruption without overreacting.
• How to bring finance, sales, manufacturing, supply chain, and IT together around a shared view of what "good" looks like.

Helping you focus on what matters most

In a world of constant change, it can feel like everything is urgent. But not everything is equally important.

In future columns, expect to see:

• Real-world stories from leaders who are modernizing planning, using AI to improve outcomes, and building more resilient supply networks.
• Frameworks and checklists you can use with your own teams to diagnose gaps and prioritize investments.
• Straightforward discussions about where technology is delivering value today—and where it still needs to mature.

The goal is not to chase every trend. The goal is to identify the few moves that will have the biggest impact on your service, cost, risk, and growth objectives.

An invitation to participate

One of the strengths of Global Links has always been its community. This column has never been a solo performance, and that will not change. I invite you to share:

• The biggest decisions your teams are wrestling with.
• The obstacles that slow you down—from data quality to siloed processes and talent development.
• The successes you are proud of, and the lessons you wish you had known sooner.

If you have ideas or stories that could help your peers, I would love to hear from you. You can reach me at kbursa@nirakio.com.

It is a great time to be in supply chain

As Rich steps into retirement, he leaves behind a strong foundation and a vibrant community of supply chain professionals who have been educated and inspired by his work.

It is a privilege to follow him as Global Links editor. My promise is to honor the independent, practitioner-focused spirit he brought to this column, while leaning into the new questions and possibilities that AI, decision intelligence, and digital transformation are creating for all of us.

The challenges ahead are real. So are the opportunities. Together, we can move beyond noise and complexity to build supply chains that are smarter, faster, and more resilient—supply chains that truly serve as engines of value for our organizations and the customers who rely on us. •

About Global Links

Global Links appears in each issue of *Supply Chain Management Review*. Karin L. Bursa, CEO of NIRAKIO, LLC, supply chain industry advisor, Global Links editor, and 2020 Supply Chain Pro to Know of the Year, serves as the Global Links column editor and collaborator. If you are interested in participating in the column, she can be reached at kbursa@nirakio.com.

Supply chain and logistics management in the emerging age of autonomous trucking

By Steve Tracey and Kusumal Ruamsook

The recent decade witnessed the rapidly evolving nature of autonomous trucking technologies, offering promises of improved logistics, inventory management, and customer service for supply chains.

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Ground-based autonomous vehicle (AV) technology has been rapidly evolving in recent years. Broad-scale implementations of autonomous vehicles are expected to bring several benefits such as reduced drivers' stress, decreased vehicle accidents, and reduced fuel consumption. While much of the AV attention thus far has concentrated in passenger transportation, the consensus among industry experts is that the promise of AV technology will be sooner realized in the freight transport setting due to its less complex driving environment.

Indeed, the invention of AV technology is increasingly perceived to potentially mark an epoch in the history of freight transportation, making the potential impact of autonomous vehicles particularly relevant to supply chain and logistics (SC&L) organizations. Among various settings for AV applications—such as closed venues like those in agriculture and mining, and yard operations like those in port terminals, rail yards, and warehouses—the transformative magnitude is notable for road transportation due to its dominant role in freight movements.

Certainly, the widespread deployment of autonomous trucks (AT) in road freight transportation has yet to come, but when autonomous trucking becomes mainstreamed, its implications for SC&L organizations will extend far beyond the freight transport operations themselves. Not only is transportation the largest cost component in business logistics expenditure, but it also critical to demand fulfillment and has significant influence on supply chain network design.

Given the rapidly evolving nature of AT technologies and their compelling potentials in road freight transportation, this article draws insights from research conducted at Penn State Center for Supply Chain Research. It discusses potential deployment scenarios and explores, through the lens of the logistics triad, possible changes in SC&L management as a result of its broad-scale deployments.

Getting the lay of the autonomous-truck land

To provide an essential understanding of AT technologies and set the scene for subsequent discussions, AT technology and the current state of AT development are highlighted as follows.

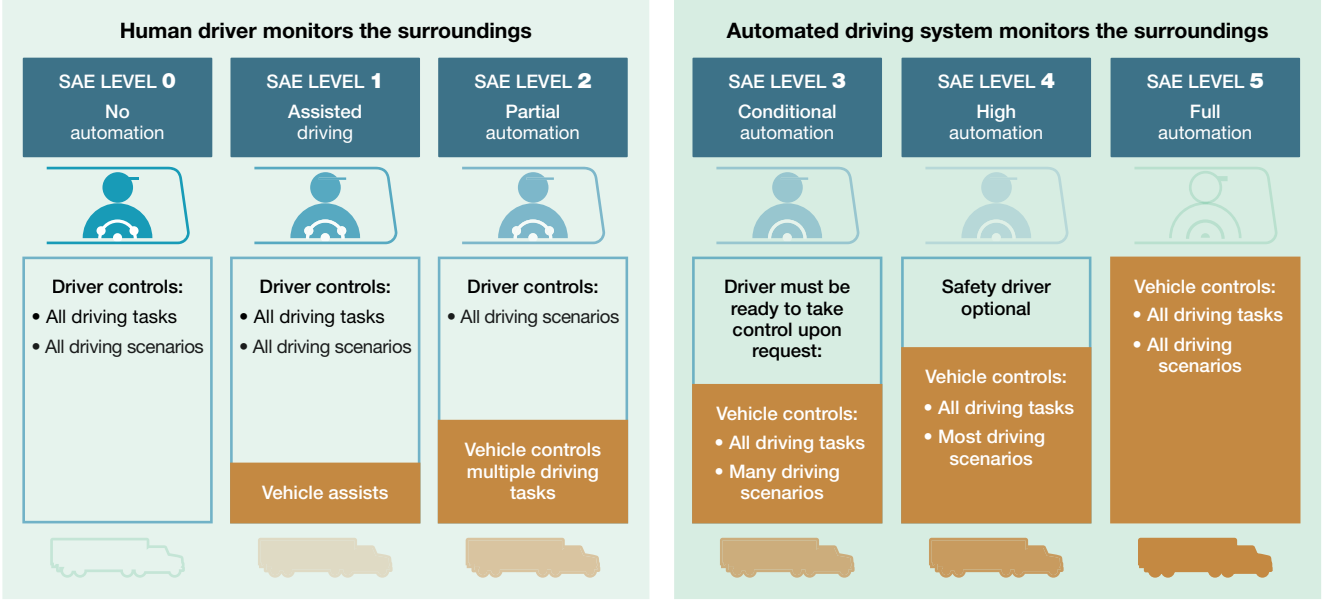
Levels of vehicle automation: Automated vehicles versus autonomous vehicles

The progression in AV technology is echoed in the widely accepted taxonomy of vehicle automation developed by the Society of Automotive Engineers International (SAE).

Figure 1 depicts SAE's five levels of vehicle automation—with human-driving engagement ranging from "all time" at Levels 0-2, "certain time or certain driving environment" at Levels 3-4, to "none" at Level 5. In the United States, vehicles with Levels 3-5 automated systems are termed "highly automated vehicles" and are focused scopes of the U.S. Department of Transportation's Automated Vehicles Comprehensive Plan released in January 2021.

FIGURE 1

Taxonomy of vehicle automation



Note: Adapted and discerned from DHL n.d.; Graf and Anner 2021; Horizon 2018; Rana and Hossain 2023

Source: Center for Supply Chain Research, The Pennsylvania State University

Connected vehicles, connected autonomous vehicles, and truck platooning

Another vehicle technology concept that is frequently discussed together with AV technology is connected vehicle (CV) technology that enables bidirectional communication between vehicles, and between vehicles and infrastructure. While the two technological categories may be implemented separately and connectivity is not a required feature of autonomous vehicles, the synergistic effects between them give rise to the development of connected autonomous vehicles (CAVs), which incorporate both AV and CV technologies (see Figure 2).

An application of CAV technology, *truck platooning* systems leverage different levels of SAE's vehicle automation and can be distinguished into three generations as follows:

- **First-generation truck platooning:** Fully manned platoon (at least SAE's Level 3 automation required). Drivers are behind the wheels of both leader and follower trucks forming the platoon. The leading-truck driver is the main agent and is constantly in control, while drivers in following trucks either rest, perform driving operations, or monitor autonomous driving mode.
- **Second-generation truck platooning:** Hybrid platoon (at least SAE's Level 4 automation required). Only the leader truck is manned, while the following trucks operate autonomously without a human driver onboard.
- **Third-generation truck platooning:** Driverless platoon (SAE's Level 5 automation required). There is no driver behind the wheel of any truck forming the platoon. All trucks operate autonomously without a human driver onboard.

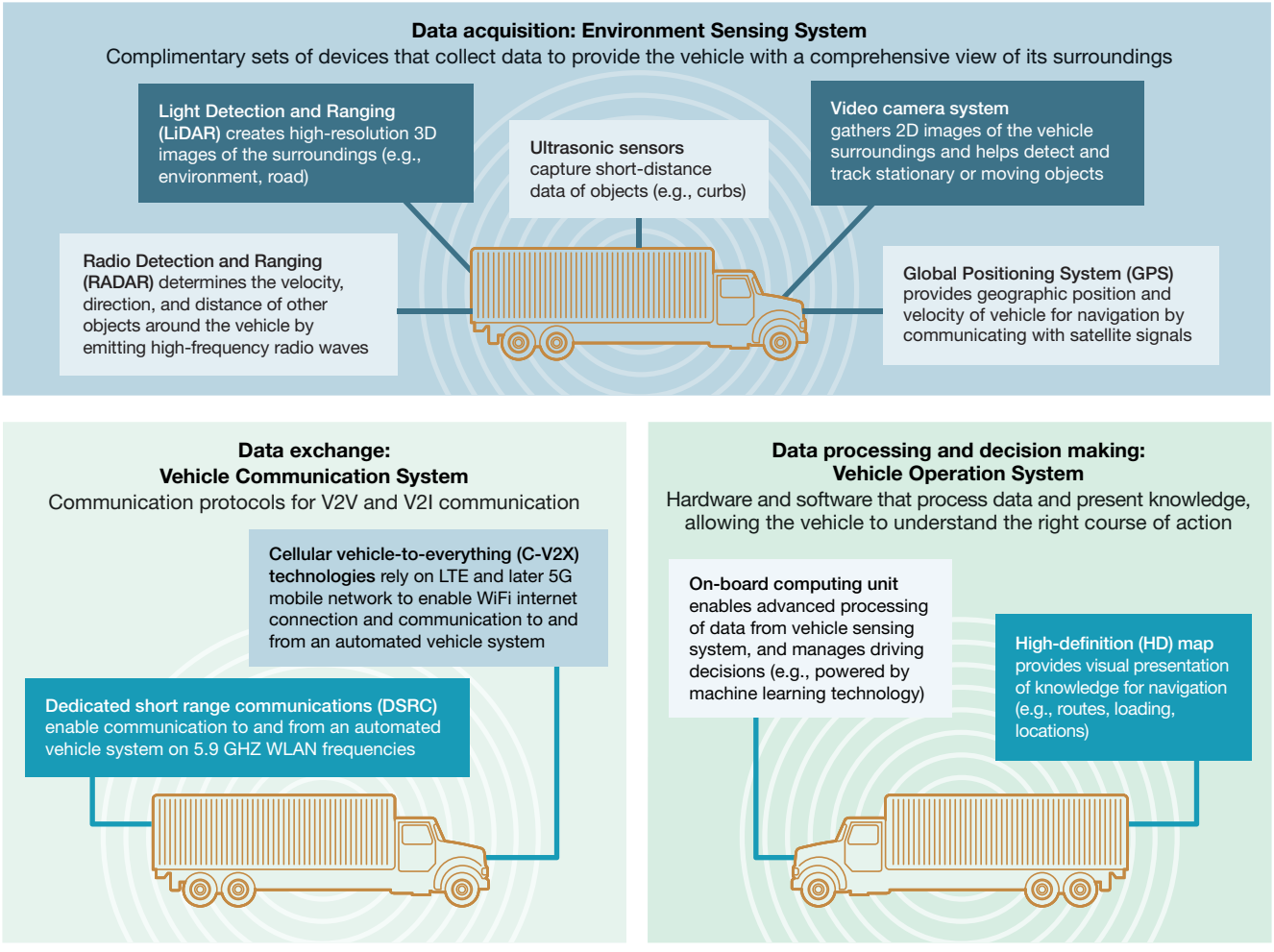
The state of the art: En route to Level 4 automation, focusing on commercialization of Class 8 trucks

As of this writing, AT technology developers are largely targeting SAE's Level 4 autonomous trucks while the heavy-duty classes have increasingly garnered attention as the primary target for AT commercialization, particularly Class 8 dry van trailers. In terms of AT operations, although a safety driver is optional, the majority of these developers currently operate with a human driver onboard.

It is also anticipated that Level 4 autonomous trucks deployment will proceed incrementally, starting on highways in selected lanes where weather, regulations, and road infrastructure meet certain conditions. These initial deployments would likely be in the southwest states, particularly, Texas, Arizona, and New Mexico where weather issues are rare and the regulatory atmosphere is favorable. In fact, the majority of the testing and demonstration activities to date has taken place in these states.

FIGURE 2

Basic components of connected autonomous vehicle technology



Note: Discerned from Bathla et al. 2022; CISA 2021; Faisal et al. 2019; Graf and Anner 2021; Horizon 2018; Kidambi and Simonetti 2021; Machado 2019; Slowik and Sharpe 2018; Wishart, Skavroneck, and Beiker 2020.

Source: Center for Supply Chain Research, The Pennsylvania State University

Emerging autonomous trucking scenarios

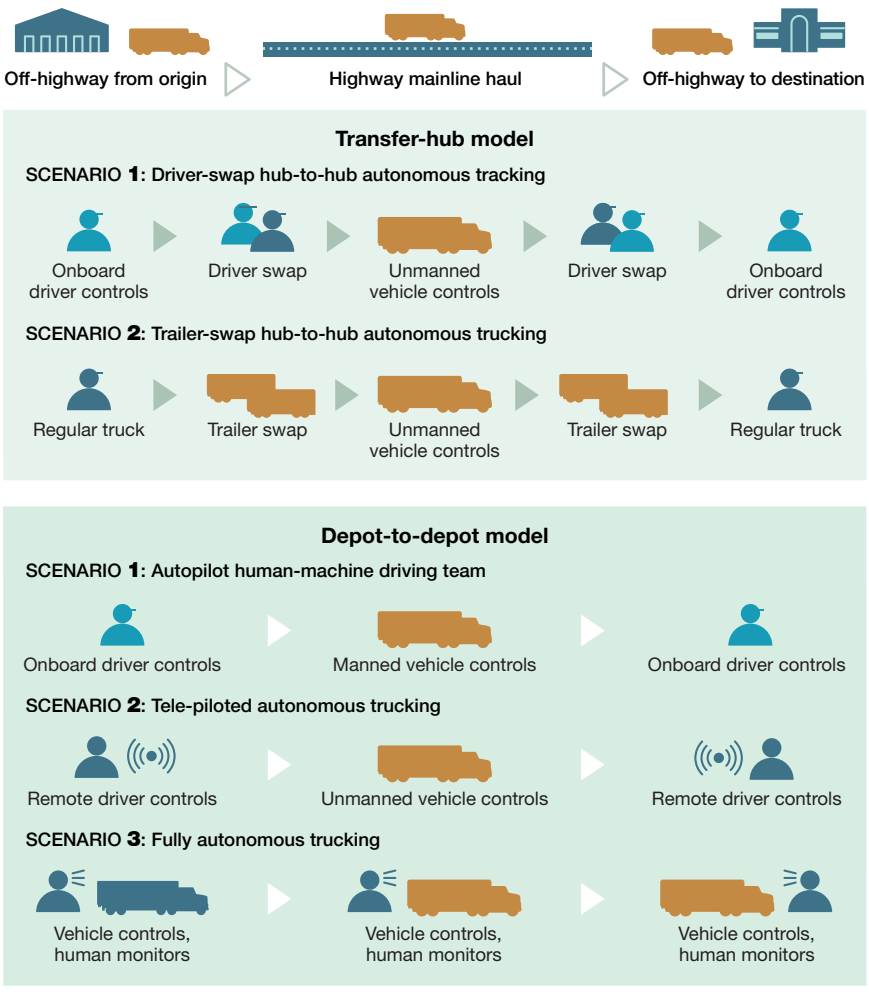
Given the state of AT technology, extant opinions accord that the initial commercial deployment of Level 4 autonomous trucks on public roads will center on *long-haul trucking*. In turn, a number of potential scenarios for AT implementations have been posited. A snapshot of these emerging AT scenarios is depicted in Figure 3. Essentially, potential long-haul AT implementations can be broadly categorized into two operating models, namely *transfer-hub model* and *depot-to-depot model*, as highlighted below.

Transfer-hub model scenarios. Also referred to as *exit-to-exit* model and highway-focused model, this operating model leverages a transfer hub through which an autonomous truck is deployed either alone or in conjunction with a regular truck to complete an origin-to-destination haul.

Depot-to-depot model scenarios. This operating model enables autonomous trucking without the need to leverage a transfer hub in which a self-driving truck is deployed to complete an origin-to-destination haul, either with or without direct human intervention.

FIGURE 3

Emerging autonomous trucking scenarios



Note: an autonomous truck may run solo or as part of a convoy/platoon.

Source: Center for Supply Chain Research, The Pennsylvania State University

Among these implementation scenarios, the *transfer-hub model* is currently adopted by the majority of AT technology providers (such as Embark, Kodiak, Torc Robotics, Waabi, and Waymo Via) to commence the first wave of AT deployment for long-haul transportation. Human oversight and remote assistance through *teleoperations* are also shared practices among AT players. Such approaches allow AT providers and users to deploy Level 4 autonomous trucks early, before transitioning to fully autonomous depot-to-depot applications when AT technology

becomes more mature and its surface-street driving capabilities improve. Nevertheless, some experts opine that while teleoperations will be required during the transition period, remote human oversight may be a permanent element of autonomous trucking, even when it becomes fully autonomous.

Supply chain and logistics implications of autonomous trucking: A logistics-triad perspective

Potential SC&L implications of the wide-scale AT deployment depend to a large extent on application scenarios and levels of vehicle automation employed. Here, we explored potential impacts on SC&L management in reference to the following application scenario of focus:

Level 4 autonomous trucks for long-haul freight transportation—including largely individual truck operations with possible hybrid truck-platooning implementations—under the transfer-hub model with human supports through teleoperations.

A logistics-triad perspective—involving shippers, transport service providers, and receivers—was adopted in this examination. The logistics-triad perspective underscores the intertwined relationships involved in both the *exchange of goods* and the *exchange of transport services*, stressing the embeddedness of transport activities in a broader supply chain network. Potential SC&L implications are summarized in Table 1 and further discussed subsequently.

AT implications on the exchange of transport services

When autonomous trucks take to long-haul highways, a number of implications for transport service providers can be perceived from two key aspects of the exchange of transport services, namely *operating costs* and *service performance* of trucking services provided.

Implications on operating costs

Top-three operating cost components for typical trucking services include driver costs, fuel costs, and truck costs, respectively. They constitute approximately 80% of total operating costs, about half of which pertains to driver costs, according to experts. The remaining 20% of total operating costs constitutes maintenance and repair (M&R), insurance premiums, tires and tolls, and licenses and permits. AT services under the transfer-hub model will significantly *alter the structure* of these conventional cost components, while bringing to the rank *new operating cost elements* associated with transfer hub facilities and teleoperations.

TABLE 1

SC&L implications of long-haul autonomous trucking under transfer-hub models

Implications on transport service exchanges

Trucking services operating costs

- **Changes in top-three operating cost structure:** Reduced share of driver costs, with costs of fuel and autonomous trucks making up larger shares
- **Savings in insurance and accident management:** Improved safety performance
- **Total maintenance and repair (M&R) cost:** Depend on direct cost of M&R activities and indirect cost of availability loss
- **New operating cost elements:** Incremental costs associated with transfer hubs and teleoperations

Trucking service performance

- **Increased trucking service capacity:** Unconstrained by hour-of-service (HOS) regulation and human physiological capabilities
- **Improved time performance:** Reduced lead-time length
- **Improved dependability performance:** Improved lead-time consistency and safe delivery
- **Improved in-transit visibility:** Real-time, highly precise positioning data

Implications on goods exchanges

Inventory requirements

- **Reduced inventory requirements:** Reduced in-transit and cycle inventory (shorter trucking lead time); reduced safety-stock inventory (lower lead-time variability, and safer trucking)

Number and location of facilities

- **Fewer facilities for comparable order fulfillment performance:** Increased delivery radius of a single facility, rebalancing tradeoff between inventory costs and transport costs
- **New facility location factor:** Proximity to AT transfer hubs as a location decision factor

Source: Center for Supply Chain Research, The Pennsylvania State University

1. Changes in operating cost structure

Autonomous trucking's largest cost impacts entail the two largest components, driver costs and fuel costs. In terms of driver costs, under transfer-hub AT services, the need for highway drivers is eliminated, limiting driver costs only to those related to off-highway operations. Concurrently, fuel cost savings can be achieved due to more fuel-efficient driving of an automated driving system, which can be programmed to follow best driving practices.

The degree of these two largest cost savings will depend largely on the relative portion over the entire trucking route that is machine-operated (highway driving between transfer hubs) versus human-operated (off-highway driving inbound to and outbound from each transfer hub). That is, the larger the share of highway automation, the larger the potential savings. Also, by implementing a hybrid truck-platoon, potential fuel savings can be further enhanced for following trucks in the platoon as the front truck will reduce aerodynamic drag friction, rendering the followers the benefits of less air resistance.

Overall, decreased driver costs result in cost structure changes where the other major cost components—costs of fuel and autonomous trucks—will constitute larger shares of the total AT operating costs. The upfront capital costs of autonomous trucks can be significant since modern tractors, additional sensors, and a host of other CAV systems required could add $25,000 or more to the cost of a truck, according to industry experts. These costs, however, are generally decreasing with time as the technologies become more mature.

2. Mixed pictures on M&R costs, insurance and accident-related costs

As for cost components outside the top three, M&R costs as well as insurance and accident-related costs are widely recognized as areas potentially affected by AT implementations. Better safety performance of an automated driving system helps to assure safer operations and reduce risks of truck accidents caused by human errors. Consequently, savings in insurance and accident management can be achieved for AT service providers.

In terms of M&R costs, AT implications are not as straightforward, especially when both *direct cost of M&R activities and indirect cost of availability* loss are considered. On the one hand, advanced AT technologies can create M&R cost savings because mechanical wear and tear from driving and chances of accident-related damages are lessened by more optimized driving practices and better safety performance of autonomous trucks. Moreover, sensing technology and intelligent algorithms enable real-time information and more advanced fault diagnosis, providing more accurate information for maintenance planning.

On the other hand, new challenges and associated implications on M&R costs also arise due to increased truck utilization, complexity of AT technologies, and absence of a driver on the road. Since unmanned autonomous trucks are not required to follow federal HOS rules, they can be used more intensively, close to 24/7 continuous operating time. Hence, they would likely require more frequent maintenance, while simultaneously reducing time windows for

planned maintenance. Due to this paradox, more unplanned maintenance could result, increasing uncertainties of direct maintenance costs and limiting the utilization of the truck (indirect costs of availability loss). Meanwhile, the absence of onboard drivers can further increase the need for predictive maintenance to minimize in-trip failures that would be difficult to address without a human driver. Also, the new, complex AT technologies might increase M&R costs as more skilled M&R workers and new or upgraded equipment are needed. All of these new challenges could offset any savings gained and negatively contribute to total M&R costs.

3. Key new operating cost elements: Transfer hubs and teleoperations

New incremental costs will be incurred in the provision of AT transport services, notably *transfer hub costs* and *teleoperation costs*. A transfer hub, which must be located in proximity of highway junctions, is a key feature in the emerging long-haul AT operations. It performs the crucial task of transshipment between autonomous highway hauls and non-autonomous off-highway hauls, and, when truck platooning is implemented, it can also perform the task of platoon formation. Furthermore, a transfer hub provides *traditional* terminal services such as refueling, on-site inspections and maintenance, as well as *non-traditional* AT data services related to data transfer offload for processing and storage. These transfer hubs will require labor, process coordination, and a relatively large space for parked trailers that have been decoupled from a truck platoon and are awaiting pickup, or for those trailers that await service on the tractor unit. The utilization rate and performance of transfer hubs will significantly influence the cost competitiveness of AT service operations.

Another key new operating cost element, teleoperation costs can be quite stiff. Compared to a traditional fleet command center, a remote AT center requires IT infrastructure and high-performance communication networks that enable the collection, processing, and sharing of autonomy-related data. It also requires more skilled operators who must possess a good understanding of AT technologies and how to use operating systems to, for instance, monitor autonomous trucks, update path planning, and initiate recovery behaviors to ensure that driverless trucks on the road are operating properly. These teleoperation costs, however, are expected to decrease over time as AT technologies become more mature. Besides, industry experts suggest that a skilled operator will be able to oversee as many as 10 to 30 trucks at a time from an office space—a sharp contrast to the number and work environment of human drivers required on the road to operate a similar size of truck fleet.

Implications on trucking service performance

Transport service providers generally aim to reduce the lead-time length (*time performance*), improve lead-time consistency and safe delivery (*dependability performance*), provide visibility of shipment status (*communications performance*), and offer service flexibility in such terms as routing and delivery times (c*onvenience performance*). AT operations can potentially improve transport service performance in all of these dimensions.

At present, long-haul trucking operations

are constricted by hours-of-service (HOS) regulations and the physiological capabilities of human drivers, limiting driving time to at most 70 hours and roughly 3,000 miles per week. Consequently, an average truck spends only 40% of its time carrying freight in the provision of services. In contrast, autonomous trucks are not compelled by these limitations, potentially allowing them to double the total distance covered in one day from around 400 to 600 miles to 800 to 1,200 miles. The productivity gained from increased truck utilization not only reduces operating costs, but also *increases service capacity* that avails more hours per day and more days per year of services for customers, provided that the trucks are properly maintained.

In effect, autonomous trucks not only can operate for longer hours without a need for a rest stop, but also includes the days of week and times of day that would otherwise be undesirable for human drivers to spend on the road—allowing them to travel farther, faster, and more flexibly in a given amount of time than a human-driven truck. Results are shorter delivery lead times, more *consistent delivery lead times*, and *more flexible availability of services*. Moreover, reduced traffic accidents due to the better safety performance of automated driving systems would greatly *reduce service disruptions*, while also ensuring reliable and s*afe delivery of goods.*

Additionally, because autonomous trucks are connected in real time with highly precise positioning data required to safely navigate on public roads, *in-transit visibility* of the location and status of a shipment would also improve. Service performance can, hence, be enhanced by providing transport service buyers with *accurate shipment tracking and access to real-time data* about their shipments. Such visibility not only helps them better plan and manage loading/unloading tasks and other interfaces with the arriving truck, but would also make it possible for them to make timely and informed decisions in response to problems that may arise.

AT implications on the exchange of goods

To fulfill customer orders, shippers must make a series of interrelated logistics decisions and network design to effectuate the firm's distribution strategies. The goal is to achieve efficient order fulfillment while creating satisfactory service levels for customers. Since transport services are the key influencer of order delivery performance, it is palpable that such a goal will be affected by AT implementations. Here, important strategic interactions in the distribution network that must be considered are *transportation, inventory, and number and location of facilities.*

Implications on inventory requirements

The inventory levels that a firm maintains at a facility in its distribution network impact the availability of goods it can dispatch to support order fulfillment. Typically, a shipper holds more inventory in order to shorten order cycle time. Meanwhile, transport services used for order shipping can differ in terms of transit-time lengths, transit-time variability, and damage rates; therefore, affecting both the *absolute*

length and *variability of order cycle time*. By using faster and more reliable transport services, usually at a higher rate charged by transport service providers, inventory requirements and associated costs can be reduced.

However, AT long-haul services could *rebalance the tradeoff* between transport costs and inventory costs since not only do trucking services costs reduce, but time and dependability of the services also improve. The shorter transit time of order delivery would allow more frequent and smaller shipments that help to reduce both in-transit inventory and cycle inventory. Equally, more reliable transit time and safer delivery make it possible to reduce safety-stock inventory required to buffer against stockouts caused by lead-time uncertainties and unforeseen problems such as damage shipments.

Implications on number and location of facilities

The number of facilities in a distribution network can range from one large facility in centralized operations to several geographically dispersed facilities in decentralized operations. Generally, it is more economical to operate fewer, larger facilities due to the economy of scale, but firms must contend with the major drawback related to longer distances to customers, and resulting longer lead times and higher transportation costs. In contrast, having a larger number of facilities located regionally or locally allows firms to be closer to customers, enabling them to reduce order delivery costs and provide faster delivery. However, the value of better services gained are at the expenses of the additional costs of operating more facilities and costs of carrying more redundant inventory across the distribution network.

So far, to maintain suitable service levels, many firms have employed more decentralized distribution operations. However, as discussed earlier, with the coming of AT services, the one-day transit distance could dramatically increase and could double the delivery radius of a single facility. Such improvements would allow a firm to provide a comparable level of service, but with fewer facilities required. Another implication, given the transfer-hub model of AT services, is that proximity to AT transfer hubs could become a part of decision factors for facility locations to capitalize on the advantages of AT services.

Closing remarks

The recent decade witnessed the rapidly evolving nature of AT technologies that were once regarded as a conceptual envision but could soon become a reality. Prospectively, the first wave of commercial AT implementation is characterized by a transfer-hub model that leverages autonomous highway-driving supported remotely through teleoperations. Under such implementations, AT transport providers could potentially achieve significant operating cost reductions and service performance improvement that, in turn, provide SC&L managers with viable mechanisms to better effectuate freight transport, order fulfillment, and customer service. To this end, notwithstanding various barriers to broad-scale deployment—ranging from high initial investment, technological and infrastructural immaturity, to regulation inconsistency—AT potential benefits and revolutionary impacts on SC&L management are too great for businesses to afford indifference. •

Not-so-sweet spots: Diagnosing cocoa supply chain woes using FMEA

By Senali Amarasuriya, Ph.D.

A proactive approach using Failure Mode and Effects Analysis can help the cocoa and candy industry reduce waste, improve product quality, and strengthen supply chain resilience through collaboration and innovation.

The global cocoa industry forms the backbone of the chocolate and candy manufacturing sector but it faces serious risks and inefficiencies in its chain. Any failure in any of the stages such as farming, processing after harvesting, storage, transportation, and manufacturing, contributes to poor product quality, operational delays, and increased costs.

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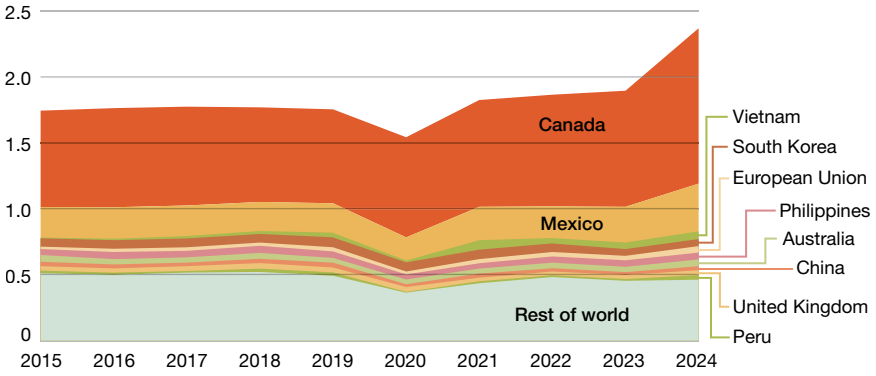
Cocoa is the ingredient that accounts for the highest value of chocolate products, and supplying high-quality cocoa is quite important, with increasing demand for chocolate and candy bars occurring around the world. Total export value of chocolate and cocoa products in the United States in 2024 was $2.36 billion with a compound average growth of 3.1% from 2015 to 2024 according to U.S. Department of Agriculture data (see Figure 1).

FIGURE 1

Chocolate and cocoa exports in the U.S.

Billion USD



Source: USDA

Still, this industry faces many challenges, from environmental risks affecting the quality of cocoa beans, to logistics in hauling beans to the manufacturers. Candy manufacturers must ensure consistency in the quality of their products and also manage disruptions in the supply chain (Figure 2).

By identifying at the outset possible failure points in each step of the cocoa supply chain and candy production process, companies are in a position to minimize waste, reduce operational downtime, improve product quality, and have healthy relations with suppliers and customers.

The following article describes the application of Failure Mode and Effects Analysis (FMEA) to cocoa farming, the supply chain, post-harvest handling and transportation, and candy manufacturing processes. It points out the usual risks during every process, develops examples of failure modes, and shows how this approach may contribute to better risk management and higher-quality products for the candy manufacturing industry.

Understanding Failure Mode and Effects Analysis (FMEA)

FMEA is a structured, systematic approach using a risk assessment tool to identify and evaluate a process, product, or system for possible failure modes. It is an excellent method for prioritizing risks according to their seriousness, occurrence, and detectability; thus, organizations can concentrate resources on the realization of corrective actions before problems arise. FMEA, first developed in the aerospace industry, has been applied in various other industries since, including automotive, healthcare, and food manufacturing.

Failure Mode and Effects Analysis originated in the United States military in the late 1940s as a systematic approach to identify and mitigate potential failure modes in complex systems and is now a core part of Six Sigma methodology.

Initially, FMEA was employed to classify failures based on their impact on mission success and personnel safety. In the 1960s, NASA adopted FMEA for the Apollo missions, underscoring its significance to enhance reliability and safety in aerospace applications. The automotive industry recognized its value in the late 1970s, with Ford Motor Company

FIGURE 2

Major processes in the cocoa supply chain

Source: Author

implementing FMEA to address safety and regulatory concerns, particularly following the Pinto model issues. Over time, FMEA has been integrated into various industries, including semiconductor processing, food service, and healthcare, becoming a cornerstone in quality and risk management practices.

FMEA becomes highly valued in industries that rely on complex processes, like those of farming cocoa and manufacturing candies, since many variables could influence the quality of the products. For such industries, FMEA allows stakeholders to identify modes of failures that could lead to impairment in product quality or delay; evaluate the potential consequences of each failure mode on product quality, production timelines, and costs; and prioritize risks through the Risk Priority Number (RPN), which is the product of the severity, occurrence, and detection ratings. It then helps to develop corrective actions to reduce or eliminate high-risk failure modes that increase reliability and consistency.

Key elements of FMEA

The methodology of FMEA comprises a number of key elements.

- **Failure mode.** The way or mode in which a procedure or system can fail. Taking the cocoa supply chain for example, a failure mode would be a delayed shipment of beans because of poor logistics.
- **Effect.** The impact that would result from a certain failure mode on the product or process. In this regard, delayed shipment of supplies might disrupt production schedules therefore creating a shortage of key ingredients needed for candy bars.
- **Cause.** It defines the possible cause for such failure. The cause, in this case, may be anything from poor storage to poor transportation networks.
- **Severities (S).** A ranking for the estimated effect of a failure on the final product or process. The higher the severity score, the more critical the failure.
- **Occurrence (O).** This is a ranking of the estimated likelihood of occurrence of each failure mode.
- **Detection (D).** This is a ranking of estimated likelihood that the failure will be detected by current controls before it reaches the final product. The less detectable it is, the higher the score, indicating higher risk.

The RPN is calculated by multiplying the scores for Severity, Occurrence, and Detection:

RPN = Severity (S) × Occurrence (O) × Detection (D)

After the RPNs are calculated, the failure modes with the highest RPNs are prioritized, and corrective actions are developed to mitigate these risks.

Application of FMEA to the cocoa supply chain

There are a few key steps in the supply chain for cocoa, each of which may contain its own possible failure points. Understanding the stages and common failure modes helps manufacturers proactively understand risk and improve quality (Figure 3).

1. Cocoa farming: risks and failure modes

Farming is the first step in the supply chain of cocoa, and it is where the quality of the

FIGURE 3

Major processes of cocoa farming and production selected for FMEA

Source: Author

beans is determined. However, cocoa farming faces many challenges, especially from environmental factors and the nature of smallholder farming.

Failure modes:

- **Poor soil fertility.** When the soil is poor, yields are low, and the quality of the beans will be poor, which could affect the flavor of the final product.
- **Pests and disease infestation.** Cocoa trees are susceptible to certain pests, like the cocoa pod borer and diseases such as black pod rot, which could result in high crop losses.
- **Poor planting.** Planting with poor-quality seedlings or in poor conditions often leads to weak trees with low yields.

Mitigation strategies:

- Farmers could adopt soil management practices that would improve soil fertility, for example, the use of organic fertilizers and crop rotation.
- Insects and other animals can also be used in integrated methods of pest control, like using natural predators and utilizing resistant varieties.

2. Processing and storage after harvesting

After cocoa is harvested, fermentation and drying develop the beans' flavor and quality—critical steps post-harvest. This practice would, however, encourage off-flavors and development and could be contaminated with mold if done wrong.

Failure modes:

- **Irregular fermentation.** Bad timing for fermentation and turning provides negative uniformity in flavor quality.
- **Poor drying of cocoa**. Beans dried too quickly and without a good environment preserve additional moisture, which would enable mold to grow.
- **Contamination.** Contact with foreign materials such as sand, wood, or other contaminants, can result in the deterioration of quality.

Mitigation strategies:

- Farmers will use fermentation boxes that allow for temperature control and turning to ensure uniform fermentation.
- Adequate drying racks with proper ventilation systems can easily reduce moisture content and thus prevent mold formation.

3. Cocoa transportation and storage

After processing, the beans are warehoused and shipped to the manufacturers. This is a very vulnerable phase in supply, where delays, contamination, and spoilage occur easily.

Failure modes:

- **Moisture contamination.** Poor packaging or humidity exposure during transport may cause mold and mildew growth on the beans.
- **Delayed shipments:** This disrupts manufacturing schedules, hence delaying production.
- **Infestation.** Poor or unsealed package invites the pests that cause infestation to the beans.

Mitigation strategies:

- Package the beans in sealed, moisture-tight containers and ship them in controlled climates to avoid moisture damage.
- GPS and shipment monitoring shall be installed for real-time tracking.
- Transportation with pest-resistant packages that are sealed and packed well can minimize the possibilities of contamination with pests.

4. Candy manufacturing

Once the beans reach the processing plant, they are processed into the various ingredients such as cocoa liquor, cocoa butter, and cocoa powder that go into candy bars. Each step in the processing chain brings with it opportunities for things to go wrong.

Roasting. Roasting is a very basic process in candy bar manufacture to develop the distinctive flavor of the cocoa. Disruption in this process usually brings out

flavors that will not please the customer connoisseur and may reduce the quality of the product generally.

Failure modes:

- **Over-roasting.** Roasting at too high a temperature or for too long increases the possibility of burned beans and bitter smells.
- **Under-roasting.** Under-roasting can make the taste of the beans raw, at the expense of full flavor development.

Mitigation strategies:

- Automatic roasting systems with proper temperature control ensure that beans are consistently and evenly roasted.
- Regular calibration and maintenance of roasting equipment can avoid any variation in temperature that leads to uneven roasting.

Grinding. After roasting, cocoa beans are ground into a variety of products such as cocoa liquor, cocoa butter, and cocoa powder. Not properly controlling grinding may result in a gritty particle that produces an unpleasant mouthfeel when chewing chocolate.

Failure modes:

- **Inconsistent grinding.** If the grinding process isn't uniform, cocoa particles may be too coarse, resulting in a gritty texture.
- **Excessive heat generation**. While grinding, temperature is invariably generated; if not carried out properly, the free cocoa butter that separates out will result in nonuniform texture and consistency in the chocolate.

Mitigation strategies:

- Inconsistency can be avoided by employing a precision grinding machine that would provide the possibility of regulation in particle size distribution.
- Employing water-cooled grinding equipment can offer control of the temperature in grinding.

A summary of this information is given in Table 1, which demonstrates an example of FMEA on cocoa farming and production.

The Failure Mode and Effects Analysis (FMEA) given in Table 2 systematically evaluates potential risks across critical stages of cocoa farming and processing, emphasizing Risk Priority Numbers (RPN) to identify and prioritize failure modes. The table outlines each process step alongside corresponding failure modes, potential effects and causes, and proposed mitigation strategies. To illustrate the practical application of FMEA, hypothetical Severity, Occurrence, and Detection ratings were assigned at the author's discretion, resulting in RPN values presented purely for demonstrative purposes. These randomly assigned ratings yield RPN values calculated as the product of the three factors, arranged in descending order to effectively illustrate how high-risk failure modes are prioritized within a typical FMEA framework. For instance, pest and disease infestation during the pest management stage of cocoa farming—assigned an illustrative RPN of 432—demonstrates a high-priority risk scenario warranting immediate attention. Similarly, mold due to improper drying (RPN=280) and poor yields resulting from poor soil fertility (RPN=224) exemplify other significant risks. While the actual RPN scores presented herein do not reflect empirical data, their use effectively demonstrates the methodology and benefits of FMEA in systematically identifying, prioritizing, and mitigating risks within cocoa farming and processing.

Managerial recommendations

Strengthen farmer partnerships. This could be achieved through training at the point of origin regarding best practices in planting, fermentation, and drying for improved quality from the start. Supportive equipment like fermentation boxes and drying racks promotes consistency in quality, minimizing post-harvest losses.

Leveraging technology. IoT sensors could monitor temperature and humidity conditions in real-time at various points in the fermentation and drying process, thus creating a consistent product quality standard. Applying blockchain for traceability would bring transparency into sourcing and add to the integrity of the cocoa bean down the value chain.

Implement regular audits. Routine quality inspection, auditing, and FMEA review at every stage of the supply chain could help in ascertaining emerging risks and opportunities for improvements.

Promote sustainable practices. From a sustainability standpoint, these recommended interventions align closely with global environmental, social, and economic sustainability objectives. Promoting sustainable agricultural practices such as the use of organic fertilizers, crop rotation, and integrated pest management reduces environmental degradation, preserves biodiversity, and enhances long-term soil fertility. Investments in standardized infrastructure, like improved fermentation boxes and drying racks, not only decrease post-harvest losses but also minimize resource wastage and environmental impact. The adoption of technology such as IoT sensors contributes to energy efficiency and optimized resource utilization, while blockchain-driven transparency supports ethical and responsible sourcing.

TABLE 1

Example of FMEA table for cocoa farming and production

Process step	Failure mode	Potential effects	Potential causes	Mitigation strategies
Planting and cultivation	Poor soil fertility	Low yields, poor bean quality, reduced flavor	Poor soil quality, lack of nutrients	Use organic fertilizers, crop rotation, soil management practices
	Poor planting	Weak trees, low productivity	Poor-quality seedlings, improper planting conditions	Proper farmer training, quality seedling selection
Pest management	Pest and disease infestation	Crop damage, reduced yields	Cocoa pod borer, black pod rot, inadequate pest control methods	Integrated Pest Management (IPM), natural predators, resistant plant varieties
Harvesting and post-harvest processing	Irregular fermentation	Poor, inconsistent flavor, off-flavors	Improper fermentation timing and method	Use fermentation boxes, regular turning, temperature control
	Poor drying	Mold growth, contamination	Rapid drying, poor environmental conditions	Adequate drying racks, proper ventilation
	Contamination	Unsafe product, reduced quality	Foreign materials (sand, wood, dirt), poor handling	Proper hygiene training, secure handling practices
Transportation and storage	Moisture contamination	Mold growth, bean spoilage	Poor packaging, exposure to humidity during transit	Moisture-tight, sealed containers, controlled climate transportation
	Delayed shipments	Production delays, disruption in manufacturing	Logistical issues, poor shipment tracking	GPS shipment monitoring, real-time tracking systems
	Infestation	Product loss, quality deterioration	Poor or unsealed packaging	Secure, sealed, pest-resistant packaging
Candy manufacturing–Roasting	Over-roasting	Burned, bitter flavors, poor product quality	Excessively high temperature, prolonged roasting time	Automated roasting systems, temperature control, equipment calibration and regular maintenance
	Uneven roasting	Inconsistent flavor, customer dissatisfaction	Equipment malfunction, inconsistent roasting conditions	Regular equipment calibration consistent equipment maintenance
Candy manufacturing–Grinding	Inconsistent grinding	Uneven texture, reduced product quality	Lack of precision control, inadequate equipment	Precision grinding equipment, particle-size regulation
	Overheating during grinding	Separation of cocoa butter, texture problems	High grinding temperature, lack of cooling system	Water-cooled grinding equipment, temperature control

Source: Author

TABLE 2

FMEA table with RPN values

Process step	Failure mode	Potential effects	Potential causes	Mitigation strategies	Severity (S)	Occurrence (O)	Detection (D)	RPN
Pest management	Pests and disease infestation	Crop damage, reduced yields	Inadequate pest control methods	Integrated Pest Management (IPM)	9	8	6	432
Harvesting and post-harvest	Mold due to improper drying	Spoilage, mold growth	Rapid drying, poor environment	Proper drying racks, ventilation	8	7	5	280
Planting and cultivation	Poor yields	Reduced productivity	Poor soil quality, lack of nutrients	Organic fertilizer, soil management	8	7	4	224
Planting and cultivation	Poor planting	Weak trees, low productivity	Poor-quality seedlings, bad planting conditions	Training, quality seedlings	7	6	5	210
Harvesting and post-harvest	Irregular fermentation	Inconsistent, off-flavors	Improper fermentation timing	Controlled fermentation boxes	7	6	5	210
Transportation and storage	Moisture contamination	Mold growth, spoilage	Poor packaging humidity	Sealed containers, controlled climate	7	6	5	210
Harvesting and post-harvest	Contamination	Unsafe product, quality reduction	Foreign materials, poor handling	Proper hygiene training, handling	8	6	4	192
Roasting	Over-roasting	Bitter, undesirable flavors	Excessive roasting temperature or time	Automated roasting control	8	6	4	192
Transportation and storage	Pest infestation	Quality deterioration, product loss	Poor packaging methods	Sealed, pest-resistant packaging	7	5	4	140
Grinding	Inconsistent grinding	Uneven texture, gritty chocolate	Lack of precision control	Precision grinding equipment	7	5	4	140
Grinding	Overheating during grinding	Cocoa butter separation, texture issues	High grinding temperature	Water-cooled grinding systems	7	5	4	140
Transportation and storage	Shipment delays	Production delays	Logistics issues, tracking failure	GPS tracking, monitoring systems	6	5	3	90

Source: Author

Furthermore, strengthening farmer partnerships through training and capacity-building initiatives encourages fair trade practices, equitable economic opportunities, and increased farmer resilience, thereby addressing key social sustainability goals. Collectively, these strategies reinforce a comprehensive sustainability framework within the cocoa industry, fostering environmental stewardship, economic stability, and social well-being across the entire supply chain.

Conclusion

Both farming cocoa and manufacturing candies are very complicated processes, carrying risks at every step of the supply chain. Application of FMEA helps the stakeholders identify in advance, prioritize, and mitigate the risks to arrive at better product quality with reduced cost, thereby bringing efficiency in the overall supply chain.

FMEA has proved to be a reliable, systematic method of controlling risks and making the chain sustainable, given the rise in global demand for high-value chocolate, coupled with increased complexities facing the cocoa industry. Stronger collaboration, more intensive use of technology, and building sustainable resilience within processes all play their role in ensuring the final product meets consumer and investor expectations, as well as those of the regulating bodies. •

SEEING THE FULL PICTURE

Why service markups are the missing link in cost, quality, and workforce stability

By Sylvia Hernandez

Most companies track bill rates, but few understand the hidden markup forces driving cost overruns, turnover, and supplier performance risk.

In today's increasingly service-driven supply chains, many organizations have robust strategies for analyzing material costs, logistics spend, and supplier performance. Yet one of the most impactful and misunderstood elements of service procurement remains largely invisible: the service markup.

In time-and-materials contracting, most leaders focus on the bill rate or the projected total cost of the project. Because these numbers appear straightforward, the factors beneath them are rarely questioned. Many assume markups are simply the supplier's profit. Others believe they are too technical to dissect or too standardized to matter.

This mindset leaves organizations blind to critical dynamics affecting operational continuity, workforce quality, and total cost of ownership. In a market where skilled labor is scarce, turnover is rising, and service spend is increasing year over year, overlooking the markup is no longer sustainable.

This article explains what a service markup truly represents, why it has been historically overlooked, and how a transparent understanding of markup components can transform the way procurement leaders evaluate supplier value.

Why service markups are overlooked—and why they matter

In time-and-materials service contracts, purchasing managers tend to focus on two familiar figures: the bill rate and the total project cost. Because those numbers appear straightforward, the underlying elements that make up the bill rate—collectively known as the service markup—are often ignored. Many assume the markup is simply the supplier's profit, or that the details behind it are too technical or irrelevant to sourcing decisions. Others believe that as long as total cost of ownership seems reasonable, the composition of the rate does not require scrutiny.

This common mindset leads buyers to overlook one of the most insightful indicators of supplier reliability, employee stability, and long-term service quality.

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Why service markups are often ignored

Despite their significance, service markups routinely go unexamined. There are several common reasons.

1. Bill rates appear simple, but are not. Executives see a single rate—$90/hour—and assume it reflects skill level, market conditions, and supplier profit. In reality, that rate conceals multiple financial and workforce decisions.

2. Markups are confused with profit. Many purchasing managers believe markup equals margin. Most of the markup, however, funds statutory taxes, benefits, hiring costs, safety programs, and employee support, not profit.

3. The breakdown is rarely requested. Unlike material costs, where line-item visibility is expected, service cost transparency is often treated as optional or intrusive. Suppliers therefore default to a single blended hourly rate.

4. The workforce behind the rate is "invisible." Executives know the deliverables they expect, but not the people performing the work. Markup details bring the workforce into view, highlighting the employee experience driving service quality.

5. Leaders prioritize speed over understanding. When projects move quickly, many teams simply compare bill rates, assume similarity equals fairness, and proceed. The hidden costs emerge later in turnover, overtime, and delays.

The irony is that the often-ignored markup contains some of the most useful information about supplier performance, stability, and long-term value.

What a service markup actually is

A service markup is the portion of the hourly bill rate that is not paid directly to the worker. It funds four primary categories:

1. Statutory costs. These include mandatory employer taxes such as Social Security and Medicare (FICA), Federal unemployment tax (FUTA), and state unemployment tax (SUTA). These typically total 10% to 12% of wages but vary based on wage caps, turnover, and state unemployment ratings.

2. Employee benefits. These include employer-funded items such as paid time off (holiday, vacation), medical and dental insurance, retirement contributions, training and certifications, benefits influence retention, skill level, and worker continuity.

3. Supplier overhead. These are operational costs required to employ and support workers, including hiring and background checks, safety programs and PPE, supervisory labor, scheduling and workforce management, equipment and administrative overhead, supplier profit, and the actual margin (often the smallest component of the markup).

Put simply:

Bill rate = base wage + markup

Markup = statutory + benefits + overhead + profit

This structure reflects not only the cost of labor, but also the investment a supplier makes in its workforce.

Why markups matter, and why they should be evaluated early

Transparent markups give procurement leaders deep insight into a supplier's ability to deliver consistent, high-quality work. They reveal the "health" of the workforce behind the service.

1. Wages signal turnover risk. If base wages are significantly below market:

- the best workers leave;
- new workers require ramp-up time;
- teams lean on overtime to maintain schedules; and
- productivity declines.

All of these increase the buyer's cost.

2. Benefits predict workforce stability.
Suppliers offering holidays, PTO, medical, and retirement have:
• lower turnover;
• greater workforce continuity;
• better safety performance; and
• higher overall service quality.

3. Statutory costs reveal operational health.
For example:
• inflated FUTA may indicate late tax payments;
• high SUTA may signal poor safety performance or high turnover; and
• understated statutory percentages may mean compliance issues.

4. Overhead shows investment in safety and capability.
Suppliers may be differentiated not by wages, but by:
• training programs;
• certification pathways;
• safety culture;
• supervisor-to-worker ratios; and
• hiring and background check rigor.

5. Profit levels reflect sustainability. A supplier with a razor-thin margin may under-invest in talent or support, or may not survive challenging market conditions.

The broader impact of markups on service quality

Because services are intangible and vary widely by provider, a simple price comparison rarely tells the full story. Expertise, responsiveness, training, and employee well-being all shape the value delivered. Understanding what sits behind a bill rate helps determine whether a supplier can consistently meet the organization's expectations.

This is why analyzing markup components is so important. They show not only how costs are allocated, but also whether the supplier invests in its workforce or cuts corners in ways that may harm project outcomes.

Many buyers compare bill rates alone and choose the lowest number. But similar bill rates can mask very different underlying wage structures and overhead models.

Why bill rates alone are misleading: A realistic example

Consider five suppliers bidding on the same scope of work. Their bill rates for Craft 2 range from $98 to $105 per hour—a difference small enough to suggest equivalent value. At face value, Supplier 3 appears cheapest. But when we examine the wage-to-markup breakout, a different story emerges.
• Supplier 2 pays the lowest base wage
• Supplier 5 pays the highest
• Markup percentages vary from 62% to 72%

These differences reflect:
• varying statutory obligations;
• different benefits packages;
• different levels of overhead and investment; and
• different turnover risk profiles.

This information is essential for evaluating long-term value, not just immediate cost. Low wages or minimal benefits may yield short-term savings, but often lead to:
• high turnover;
• increased overtime;
• frequent retraining;
• project delays; and
• quality issues.

Ultimately, the buyer pays for these problems, even if the bill rate appears competitive.

Markup as a percentage: The real transparency

Markup percentages highlight how much of the bill rate is allocated to statutory obligations, benefits, and other costs. Statutory taxes typically average around 11% to 12% of wages nationally. Benefits vary but significantly

influence retention. Other costs represent overhead, hiring, training, safety, and profit. Every percentage in the markup tells a story about a supplier's workforce and operational health.

A transparent markup allows buyers to evaluate:

- Wage competitiveness and retention risk.
- Accuracy and appropriateness of statutory tax allocations.
- Benefit levels and employee participation rates.
- Reasonableness of "other" costs.
- Supplier financial discipline and stability.

A modern approach: Using markups to assess supplier value

Progressive supply chain organizations now use markup structures as a strategic sourcing tool. Here is how leading companies leverage these insights.

1. Benchmarking supplier investment in people.
Organizations evaluate:

- market competitiveness of base wages;
- benefits provided;
- worker retention metrics; and
- participation rates (e.g., % enrolled in medical or 401(k)).

2. Identifying hidden financial red flags.
Markup transparency reveals:

- cash flow strain;
- poor tax compliance;
- weak safety performance;
- underfunded benefits; and
- unsustainable pricing models.

3. Evaluating supplier operational maturity.
Higher "other" markups often include:

- safety programs;
- quality management systems;
- supervisory support; and
- service infrastructure.

4. Strengthening total cost of ownership analysis.
Instead of using the bill rate alone, organizations incorporate:

- estimated turnover;
- ramp-up costs;
- overtime usage;
- safety incidents; and
- rework and delay costs.

5. Negotiating based on logic, not pressure.
When buyers understand each markup component, negotiations evolve from "lower your rate" to "help me understand your SUTA rate;" "walk me through your benefits structure;" and "explain your hiring and safety investments."

How procurement should approach markup evaluation

You can implement markup transparency with a clear, repeatable process. Follow these steps.

Step 1: Always request a markup breakdown.
Required minimum components:

- base wage;
- statutory percentage;
- benefits percentage;
- supplier insurance;
- overhead; and
- profit.

If a supplier will not provide transparency, that in and of itself is a signal.

Step 2: Compare base wages to market data.
Evaluate whether wages are:

- below market (risk);

• at market (acceptable); and
• above market (potential stability advantage).

Step 3: Assess benefits relative to project duration.
Short-term roles may not require robust benefits. Long-term or recurring work absolutely does.

Step 4: Examine statutory rates for red flags.
These include:
• FUTA greater than 2%;
• unusually high SUTA; and
• statutory totals below 10%.
Each indicates potential risk.

Step 5: Interpret "other" overhead carefully.
Costs here often fund:
• training;
• safety;
• certification; and
• supervisory coverage.
Rather than cutting these costs, buyers should understand their value.

Step 6: Evaluate profit for sustainability.
Healthy, reasonable margins support:
• credible staffing;
• low turnover; and
• continued investment.
Unsustainably low profit is not beneficial to the buyer.

The strategic payoff: Better outcomes and lower total cost of ownership

Organizations that adopt markup transparency report significant benefits, including the following.

1. Lower turnover. Better wages and benefits attract stable, skilled workers.

2. Higher productivity. Continuity reduces learning curves and rework.

3. Better safety outcomes. Suppliers investing in training and oversight see fewer incidents.

4. Reduced overtime and schedule risk.
Fewer workforce gaps mean fewer last-minute labor shortages.

5. More trustworthy supplier relationships.
Transparency builds alignment and reduces conflict during renegotiations.

6. True cost savings over time.
When buyers value workforce stability as much as bill rate, they achieve lower total cost of ownership—even when the lowest bill rate is not selected.

Conclusion: The case for elevating markup transparency

Service markups have long been overlooked in sourcing, dismissed as technical or irrelevant. Yet they contain powerful insights into supplier capability, financial stability, workforce quality, and long-term risk. In an era defined by labor shortages, supply disruption, and rising service complexity, ignoring markup structures is a liability.

The organizations that excel in service procurement are those that understand the human, financial, and operational factors hidden within a billable rate. They make decisions grounded in visibility, not assumptions, and they build supply chains that are more resilient, cost-effective, and strategically aligned.

Service markups are more than an accounting detail. They are a window into supplier value. And for supply chain leaders, they are an advantage waiting to be leveraged. •

FROM PERK TO STRATEGY:

Rethinking tuition programs for supply chain success

By Corrine Chen

Traditional tuition benefits often fail frontline workers. But smarter design and consistent messaging can help fix the supply chain talent crisis.

Supply chain executives know all about problems related to employee turnover; but now it is especially critical. Consequences in operational effectiveness, competitive advantage, and business development are dramatic. Companies counteroffer with tuition aid programs (TAPs) as the "golden ticket" to increase retention and workforce development. On paper, the formula is simple: invest in educating your people, and they will stick around. But reality is another matter.

What's going wrong? For most supply chain professionals, the actual chasm is not availability but accessibility and equity. Upfront expenses, process barriers, and managerial judgment keep career development out of reach for exactly the frontline talent supply chains need most. Leaders too frequently miss structural barriers that render a potentially appealing perk a lost cause. Suppose the supply chain career realm is to thrive amidst current volatility. In that case, tuition assistance has to shift, from a one-size-fits-all benefit to a powerful, equitable talent strategy.

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The supply chain talent challenge

Organizations today struggle to bridge a growing gap between business expectations and workforce realities. A recent summary of Gartner research via Supply Chain Digest reports that 31% of supply chain professionals indicate they intend to leave firms within a year. Yet, chief supply chain officers identify only 40% ranking talent attraction and retention as a near-term priority this year, versus 56% in the past year's survey (Kim & Variyam, 2024), an alarming drop in a time of existing disruptions, a shortage of workers, and growing demand for frontline logistics professionals.

On the surface, many companies tout tuition benefit programs (TAPs) as a solution to turnover. Such programs are known to work against declining employee attrition rates even during crisis periods like the COVID-19 pandemic (Little et al., 2024). However, TAPs' effectiveness is actually relatively narrow: less than 10% of the eligible workforce make use of TAPs, and only about 2% utilize such programs to continue

studies despite the working population's strong interest (Hundrev, 2024; InStride, 2024).

These gaps are not just theoretical; they have daily operational consequences. With lagging retention, companies pay ongoing training costs, operational losses, and the possibility of losing institutional knowledge. Frontline staff point to dissatisfaction and disengagement: In 2022, more than 60% of logistics staff viewed their jobs as long-term employment, but 40% considered resigning that same year because they were poorly paid and didn't feel valued enough (Mizell-Pleasant, 2024).

Instead of being strategic tools, most tuition programs become lost opportunities handicapped by barriers, making them accessible to only a few advantaged individuals. Talent's greatest challenge is not a paucity of programs but an inability on the part of those who need them most to participate and progress.

Barriers to tuition assistance access

Despite the universal presence of TAPs in supply chain organizations, participation rates remain exceedingly low due to a plethora of convoluted, permanent barriers. Such barriers are no minor issue; instead, they widen inequalities between roles and divisions, thus hampering career growth of frontline personnel upon whom supply chains draw most heavily. These barriers include:

Financial barrier. Most TAPs ask workers to pay out-of-pocket tuition expenses and apply for reimbursement upon completion of courses. This is often too expensive for many (37% of American adults reported not having any savings to cover a $400 emergency, according to a 2022 Federal Reserve report). In logistics and frontline work, where pay is often low and personnel already feel underpaid, advancing via education becomes a financially unreachable goal (Mizell-Pleasant, 2024).

Procedural ambiguity and managerial bias. Gaining approval for tuition reimbursement is often subjectively rather than objectively evaluated. Employees have to navigate a rugged terrain of managerial discretion where considerations such as "business alignment" or "readiness for promotion" shape ultimate decisions. Commenting upon Krieger's (2023) views, a lack of transparent and consistent evaluation criteria creates a "hoops mentality" and leads to a lot of dissatisfaction. Application processes often entail numerous levels of managerial approval and thus reinforce consequences of bias or favoritism. In many institutions, higher-level personnel receive approval for MBA studies while equally qualified frontliners hit roadblocks to entry-level certifications (Bramoullé & Huremović, 2020).

Awareness gaps. TAPs within the company are often tucked away in HR portals and only cursorily mentioned during onboarding. Though 80% of workers report interest in ongoing education, a paltry 40% even know that their employer has tuition benefits available, according to InStride's 2024 research. Through failing to aggressively promote and physically walk individuals through these TAPs, least of all within shift or work-from-home workforces, frontliners rarely even know these life-changing opportunities exist (InStride, 2024).

Organizational justice and trust. The cumulative effect of these barriers goes beyond abstract statistics; it erodes trust and diminishes a culture of inclusion. Disparities in access and non-transparency around decision-making make professional development appear hyper-exclusive, viewed as a privilege granted only to those already within networks of management. By Gallani and colleagues' (2020) account, the apparent shallow impact of reward systems is often overtaken by the "opportunity effect," wherein those prevented from gaining these benefits face declines in engagement and performance.

Without a major redesign, tuition assistance programs risk doing more harm than good. Financial obstacles keep frontline workers out, subjective approval processes invite discrimination, inept communication leaves a large section of employees unaware of available opportunities, and transparent decision-making erodes trust. What's supposed to level playing fields ends up entrenching existing inequalities, locking out those same workers whose supply chains require them most. The ultimate impact is lost potential, disengagement, and avoidable turnover that acts against retention at its core.

Lessons from leading companies

Some organizations have gone beyond traditional limits inherent in tuition aid programs by designing programs that are easily accessible, financially equitable, and consistent with organizational missions. Rather than treating educational benefits as simple symbolic rewards, these firms have eliminated financial obstacles, streamlined eligibility, and focused on supporting frontline staff who often fall outside mainstream designs. The results are impressive: improved employee retention rates, fast-tracked promotion counts, and tangible gains in mobility in the workforce. Table 1 compares three leading programs: Target, Amazon, and Chipotle exemplify how immediate grants, quick eligibility, and a focus on frontline personnel can generate tangible business benefits.

TABLE 1

Benchmarking leading tuition assistance programs

	Target	Amazon	Chipotle
Upfront funding	100% at >40 institutions	95%, prepaid	100%, upfront (select)
Speed of eligibility	First day of employment	90 days	120 days of part-time work
Core beneficiaries	90% frontline	Operations/frontline	Store-team, hourly
Notable outcomes	70% lower turnover, 3x higher promotions	250,000+ operations staff upskilled	Boosts mobility, increases retention

Source: Author

Target: Democratizing opportunity from day one. Target's "Dream to Be" program offers 100% upfront tuition at more than 40 accredited colleges and universities, and eligibility begins on the employee's first day of employment for part-time and full-time employees (Target, 2023). This inclusive model eliminates financial and accessibility constraints, without out-of-pocket costs or prior tenure requirements. Remarkable outcomes ensue: Target reduced turnover among involved hourly team members by 70% and tripled promotion rates. Interestingly, an impressive 90% of participants in the program have been frontline team members, demonstrating a rarity in accessing often-overlooked talent within conventional TAP designs (Loeb, 2023).

Amazon: Prepaying for progress and retention. According to researcher Connie Chen (2025), Amazon's Career Choice covers 95% of tuition and related fees upfront for logistics, IT, and in-demand skills degrees and certifications. It's eligible after 90 days of employment, a notable extension beyond traditional reimbursement methodologies. Over 250,000 Amazon staff around the globe have benefited since it launched in 2012. This method calls out both retention and mobility explicitly, enabling professional development beyond leaders to include lower-wage and hourly staff.

Chipotle: Immediate access with no-strings funding. Chipotle's Cultivate Education program partners with Guild Education to offer 100% upfront tuition for more than 75 degree programs, some of which become accessible to workers after having worked part-time for only 120 days (Sanborn, 2022). It covers a wide range of institutions and disciplines, eliminating the financial hurdle while facilitating development on any scale. What's notable about it is that

it helps in excess of 80 master's programs with partial reimbursement. Its overall impact is a happier employee base, higher internal mobility, and a stronger employer brand (Gerut, 2025).

Shared features of best-in-class TAPs

• Direct-bill or upfront payments remove financial hardship as a barrier.
• Eligibility begins early, not after years of service or managerial approval.
• Frontline and hourly workers are core beneficiaries, not afterthoughts.
• Programs are clearly communicated, transparent, and promoted internally.

Major players such as Walmart, Liberty Mutual, and TEL Education have embraced comparable strategies, underscoring that equity and accessibility in tuition efforts foster retention, progress, and innovation (Lobell, 2021).

Actionable solutions and recommendations

To transform tuition assistance from a missed opportunity into a source of supply chain resilience and equity, companies need to reconsider structure and delivery rather than grant blanket benefits. Most successful designs speak directly to frontliners' and lead leaders' barriers to five proven actions.

1. Eliminate financial barriers

• Adopt direct-bill arrangements where tuition is paid directly to educational institutions, obviating employee burdens to pay out-of-pocket and be reimbursed.
• Provide financial stipends to help offset associated expenses, including textbooks and technology materials, to prevent associated costs from hindering attendance.
• Explore income-share agreements or deferred tuition models for high-impact, hard-to-fill frontline roles.

2. Standardize transparent criteria

• Create clear, merit-based eligibility standards tied to business goals and talent development, instead of promotion expectations.
• Pre-approve a wide range of relevant courses, degrees, and certifications so employees know exactly what's covered.
• Remove vague requirements such as promotability or subjective business alignment constraints.

3. Decentralize approval authority

• Replace outmoded and subjective gatekeeping processes with cross-functional review committees, including HR, operations, and finances, to remove unevenness and subjectivity.
• Employ software or analytics tools to monitor and flag demographic disparities in TAP approvals and usage.

4. Democratize program awareness

• Integrate TAP information into onboarding and ongoing employee communications beyond HR portals.
• Utilize mobile messaging and push notifications to keep the opportunity front-of-mind both for shift-based or distributed teams.
• Regularly showcase success stories and outcomes from front-line employees who have advanced through the program.

5. Audit and rebalance regularly

• Track participation, completions, and finish rates by job function, department, and demographic segment.
• Redistribute investment proactively to underserved locations or divisions with minimal participation, bridging gaps in closing.
• Link bonuses for people managers and executives to progress on equity metrics in education benefit access.

By converting TAPs into business-oriented talent strategies, supply chain companies can attract, build, and keep the people they require while maintaining opportunity accessible to all. These steps can be taken

and tested, and they have already been tested by industry leaders who have reaped rewards.

The strategic payoff

When organizations move from beyond selective and siloed investment in tuition to fair-based performance-oriented programs, rewards extend beyond those considered in conventional return on investment (ROI) analysis. Organizations that reimagine tuition aid within broader-based overall talent management notice phenomenal increases in employee retention rates, flexibility, and brand strength.

Stronger retention and internal mobility. Companies such as Target, Amazon, and Chipotle have substantiated the business case: Target's program reduced hourly turnover by 70% and tripled promotion rates within frontline workers (Loeb, 2023). Amazon's Career Choice has allowed more than 250,000 operations workers to develop skills for promotion and growth within and across the firm (Chen, 2025). These outcomes indicate that fair TAPs can significantly mitigate churn that is draining supply chain performance.

Beyond traditional ROI: Measuring what matters. While some institutions have reported astonishing returns on investment in tuition programs, such as Accenture's 353% and Cigna's 129%, both analysts and researchers in business caution against focusing solely on financial gain (Nicastro, 2020). Actual value is reflected in indicators such as workforce stability and growth, including participation rates, retention figures, and promotion outcomes. A skilled and dependable supply chain workforce offers a long-term competitive advantage, enabling a company to pursue strategic initiatives and withstand ongoing disruptions, a point highlighted by Birou and Hoek (2022) and Tenpas et al (2023).

Agility and innovation through learning. TAPs reinforce concepts in Adaptive Learning Theory such that workers can perform optimally in changing contexts upon gaining flexible mindsets and desirable competencies (Ihichr et al., 2024; Mmom, 2022). Workgroups with readily available continued education exhibit higher flexibility levels, improved process improvement, and better adaptation to technology changes, compared to those where only a few are efficiently upgraded.

Employer brand magnetism. Tuition programs are also great attractors of talent. A recent survey carried out by InStride, as reported by Hundrev (2024), reported that 84% of workers at Fortune 500 companies regard tuition help as a deciding factor in selecting a workplace, and 71% cite it, right after healthcare, as a highly valuable benefit. Such education support has become table stakes in attracting and keeping supply chain professionals. Organizations such as Chipotle have reshaped not only turnover but also their image, generating enthusiasm among job hunters and boosting intracompany movement (Gerut, 2025). Amazon, too, positions Career Choice as a stepping stone to long-term career development internally or externally (Chen, 2025).

Ultimately, organizations that design tuition benefit programs that are equitable, communicated well, and tied to performance position themselves as true employers of choice. By minimizing obstacles and expanding access, they not only build trust and commitment but also enhance retention, mobility, and brand equity. The payoff is greater than short-term ROI: these plans future-proof talent streams, create a more adaptive workforce, and imbue supply chains with resiliency and flexibility to thrive within a more disrupted global environment.

Leadership and implementation takeaways

For supply chain leaders, equal tuition aid is not only an HR policy but a business imperative of corporate strategy that demands transparent, evidence-driven, and multi-functional initiatives. To make TAPs a reality as true accelerators of talents, leaders and managers need to:

Lead from the top with transparency and example. Senior leaders must promote open eligibility, openly discuss their own career development histories, and make attendance at TAP a transparent component of corporate culture. Open expressions of executive approval suggest that growth and development are valued highly throughout all levels, not only for those within promotion range.

Break down silos with cross-functional teams. Implementation success relies on energetic collaboration between operations, HR, and finance to keep TAPs current and relevant to frontlines' needs. With this mutual monitoring, gatekeeping is averted and programs are aligned with shifting organizational strategy.

Focus on metrics that matter. Go beyond minimal return-on-investment metrics. Measure TAP participation, retention rates, and upward mobility across departments, functions, and demographic groups. Use data to uncover and address gaps in access and celebrate those departments that excel in inclusive development.

Over-communicate policies and pathways. Clear and frequent communication, through onboarding, mobile technology, and team meetings, ensures that all associates know what is available and how to begin. Highlighting success stories about frontline associates can create broader use and reinforce faith in leaders' commitment.

Confront bias and hold leaders accountable. Regularly running analytics will be necessary to identify denial rates or imbalances in any demographic region that are disproportionate. Tie part of executive and manager compensation to verifiable progress toward equity and use of TAP, ensuring permanent accountability for change.

By instilling these values in day-to-day leadership and program management, supply chain organizations can transform tuition assistance from an exchange-based benefit to a growth-oriented strategic driver. Leaders who espouse equity, track meaningful results, and take ownership of responsibility ensure that TAPs become drivers for innovation, engagement, and lasting workforce stability that emboldens both the people who power supply chains and the institutions that serve them.

Conclusion: Call to action

Treating education benefits as merely a perk or checkbox is no longer an advantage, especially when talent unpredictability can both snap and craft the supply chain. Access to education on a fair basis is no longer a nicety; it's a strategic resilience switch for innovation and future-proofed growth. The proof is in the pudding: transparent, performance-based, accessible programs drive retention, productivity, and employer brand.

Leaders must move swiftly to break down entrenched barriers, reorient eligibility and approval, and incorporate education benefits into the fabric of their culture. This entails leading by example, monitoring outcomes rigidly, and holding supervisors, executives, and everyone in between accountable for equitable access and development outcomes. Now is the moment to turn tuition assistance into a true differentiator. By doing so, supply chain executives will not only reduce turnover but also unleash hidden potential, toughen their people, and gain a powerful advantage in a world where disruption is unforgiving. •

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The new logistics playbook for consumer and retail growth

Organizations that view logistics as an evolving system, rather than a fixed set of assets, position themselves to respond more effectively to these pressures and to capture the benefits that come with a more flexible and resilient network.

By Korhan Acar, Steven Cunix, and Roy Kamar

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Logistics has evolved from a back-office function to a strategic lever for growth, profitability, and customer loyalty. The companies winning today treat supply chain performance as inseparable from commercial success, placing it on par with marketing or product innovation.

This shift coincides with a new wave of technology. Agentic AI has matured beyond experimental pilots and is now being embedded into everyday workflows. The following dynamics show where execution challenges are emerging most quickly and how operators are adapting.

1. Last-mile complexity is the new normal

Customer expectations are diverging into two extremes, with some shoppers prioritizing ultra-fast delivery and others seeking the lowest possible cost. This shift has accelerated the rise of "buy online, pick up in store" (BOPIS) and "buy online, return in store" (BORIS), as retailers increasingly rely on store networks as fulfillment nodes. As stores take on this role, networks designed for bulk shipments must now handle more frequent, smaller, and faster runs. These tighter delivery windows change how inventory moves and create a daily rhythm that is very different from traditional operations.

Store-based fulfillment also moved inventory closer to customers, which increases the demand for domestic transportation, staging space, and labor. The model tends to work well in dense urban markets where stores are near large customer bases. However, it

becomes significantly more costly and complex in suburban and rural areas where distances are longer and fulfillment density is lower.

Relying on a single carrier is no longer viable. Leading retailers are now managing a mix of national, regional, and gig partners, each with different service level agreements (SLAs) and tracking capabilities, making visibility and performance management harder. Add tariffs into the mix, and logistics organizations are dealing with declining small-parcel imports while trying to scale bulk and store fulfillment simultaneously.

The new playbook

- **Delivery and fulfillment strategy.** Make reliability your edge by prioritizing consistency, reserving ultrafast delivery for high-conversion SKUs, and using a service-tier P&L to flag unprofitable options and enforce pricing.
- **Store network operations**. Define a clear role for each store location: fulfillment-first, experience-first, or build-to-order; then staff and equip each location according to its primary function, not a one-size-fits-all model.
- **Technology and optimization.** Deploy AI to optimize routing and batching in real-time, merging orders and re-sequencing deliveries as demand shifts. Use dynamic algorithms to adjust delivery windows and carrier selection based on live signals.
- **Supply chain agility.** Treat import lanes and node networks as flexible, not fixed, and adjust them as trade policies and tariffs evolve. Build the capability to rebalance between small-parcel, bulk, and store fulfillment channels quickly.

2. Working capital pressure is reshaping daily planning

The operational intensity reshaping last-mile logistics is also transforming working capital management. Higher interest rates have elevated carrying costs for every unit of inventory, making excess stock a direct hit to budgets and forcing capital velocity to drive daily decisions. Legacy planning systems struggle with large SKU counts, tariff volatility, and inconsistent lead times, resulting in inflated stock levels, poor visibility, and persistent margin pressure at distribution centers. To address this, operators are embedding intelligent agents into warehouse and transport management systems to accelerate product movement, reduce dwell time, and release cash tied up across facilities.

Traditional network designs optimized for lowest unit cost rather than inventory velocity, but each additional day of inventory now carries measurable cost. Tariff fluctuations trigger overbuying that locks up capital, while fragmented inventories across channels obscure waste and prevent efficient allocation.

Flow-based models offer a solution. By leveraging cross-docks, rapid-transit points, and synchronized transportation, these approaches minimize idle inventory and keep goods moving. Retailers using AI-supported flow planning have reduced safety stock by double-digit percentages and freed substantial working capital, demonstrating that velocity—not just volume—now defines competitive advantage in logistics.

The new playbook

- **End-to-end visibility.** Connect forecasting, transport, and warehouse data to spot rising inventory and shift it early, supported by simple dashboards showing turns, dwell time, and tied-up capital.
- **Intelligent planning agents.** Use AI to read demand and automate transfers while agents

help supervisors right-size safety stock and reduce manual replanning.

- **Dynamic policy design**. Replace fixed rules with flexible guardrails and set clear thresholds for tightening or loosening safety stock to manage liquidity actively.
- **Scenario-based decisioning.** Bring finance and operations together to model shifts and use weekly scenarios to speed alignment so managers adjust plans quickly.

3. Personalization is pushing secondary manufacturing into logistics operations

Consumer expectations for personalized and seasonal variations—from Snapple variety packs to TikTok-inspired limited editions—are accelerating innovation cycles across beauty, beverage, snack, and household categories. Teams now support frequent launches and line extensions throughout the year, which has shifted secondary manufacturing from production lines into logistics sites. Displays, multipacks, and promotional packs require extra touches inside warehouses and cross-docks, while planogram resets have moved from annual to quarterly or even monthly schedules, increasing facility workload.

This shift creates steady pressure on logistics capacity by adding labor, interrupting flow, and consuming space not designed for light assembly. Centralized sites deliver consistency but extend lead times, while regional sites accelerate demand response at the cost of higher labor and overhead. The operational complexity compounds quickly: automation struggles to adapt to rapid SKU changes, quality checks create additional touchpoints, and faster SKU turnover expands working capital requirements as inventory moves through more steps. Together, these factors drive up the cost-to-serve across the network.

The new playbook

- **Workload placement.** Build a framework to identify products suited for regional secondary work, balance speed with site costs, and shift low-variability items upstream to reduce strain.
- **Automation and AI support.** Apply automation where SKU churn is manageable, use AI to sense demand and guide customization, and use vision and generative tools to accelerate pack and planogram design.
- **Labor, flow, and inventory coordination.** Use agent tools to manage spikes and labor, as better forecasting and coordination reduce idle stock and keep personalization efficient.

4. Retailer and supplier collaboration is becoming a daily operational requirement

Consumers expect constant product availability, requiring retailers and suppliers to operate from synchronized demand signals. Retailers monitor real-time point of sale (POS) trends, online traffic, and inventory levels, yet suppliers often receive this information with significant delays that result in missed sales and margin pressure. The consequences compound quickly, in the form of redundant storage, duplicated inventory, and misaligned transport plans, which in turn raise cost-to-serve and slow recovery when demand shifts. Data silos and inconsistent formats delay integration, forcing teams to maintain higher safety stock simply to protect service levels.

Misaligned incentives widen these operational gaps, making coordination difficult even when both parties recognize the problem. Emerging solutions are helping to bridge this divide. Data clean rooms enable secure information sharing without compromising competitive data, while digital twins create shared visibility across partners. Advanced modeling links inventory and transport planning, allowing suppliers and retailers to respond to demand changes in concert and systematically reduce buffer stock requirements.

The new playbook

- **Joint scenario planning.** Run planning sessions to test demand, supply, and transport shifts, then use insights to cut redundancy, refine safety stock, and align service.
- **AI-supported reconciliation.** Use agent tools to spot mismatches, propose reallocations, and shrink reconciliation cycles, enabling faster team adjustments.
- **Simulation and testing.** Use digital twins to test inventory pooling, consolidation, and routing so teams improve availability while reducing cost.

5. AI agents are becoming the operators behind daily retail execution

AI is moving from limited pilots to tools managing operational workflows at scale. Consumer shopping agents now influence demand patterns, while retailers deploy agents for customers, suppliers, employees, and developers, including platforms such as Walmart's Sparky and Marty.

Agentic AI supports critical logistics tasks, including lane forecasting, carrier discovery, contract and rate management, bid evaluation, and freight audit. When these agents integrate ERP, TMS, procurement platforms, and market data, they close information gaps and accelerate decision cycles. Forecasting and inventory models must adapt to algorithm-driven demand signals, requiring tighter ERP-level connectivity with suppliers to maintain replenishment stability as automation scales. However, productivity gains depend on clean data and consistent change management across teams.

Early adopters demonstrate measurable impact. One global shipper automated $400 million in freight audits across 350,000 annual invoices, achieving a 93% first-time match rate. Another company managing $6 billion in freight spend improved charter air visibility by 35%, raised first-time match rates by 53%, and reduced leakage by more than 30%.

The new playbook

- **System integration.** Link suppliers at the ERP level to boost reliability and free capital, starting with high-volume or long-lead partners for fast ROI.
- **Modular agent deployment.** Deploy agents through knowledge graphs for sourcing and rate improvements, beginning with simple high-volume tasks and scaling as teams gain confidence.
- **Governance and oversight.** Let teams prioritize partner strategy and risk as agents manage execution within strict approvals, exception rules, and data-quality guardrails.
- **Process and workflow design**. Redesign roles and workflows so AI fits naturally into sourcing and planning, map manual touchpoints to guide adoption, and align performance metrics to reward effective collaboration.

Preparing for what comes next

Logistics teams are navigating converging pressures that require faster pivots, tighter coordination, and greater precision across daily operations. As trade policies shift, demand patterns evolve, and automation advances, competitive advantage will increasingly favor networks that can adapt with speed and consistency. This adaptability grows when logistics teams integrate earlier with commercial and product planning, since early alignment reduces reactive firefighting and creates more room for proactive decision-making.

At the same time, Agentic AI is beginning to shorten the path from issue identification to resolution, which gives operators clearer signals and a more stable foundation for daily execution. Organizations that view logistics as an evolving system, rather than a fixed set of assets, position themselves to respond more effectively to these pressures and to capture the benefits that come with a more flexible and resilient network. •

TODAY'S DIGITAL SUPPLY CHAINS: On the road to maturity

Gaining ground while refocusing on business drivers.

By Marisa Brown, APQC

Marisa Brown is the senior principal research lead for Supply Chain Management at APQC. She leads APQC's supply chain team that conducts research to provide insights into benchmarks, best practices, and process improvements in supply chain planning, procurement, logistics, manufacturing, product development, and innovation. Marisa is a leader in supply chain with almost 30 years' experience in business, research, writing, speaking and consulting.

The term "digital supply chain" has evolved over the years, from an initial vision of radically transformed companies using cutting-edge technologies to a more realistic view that focuses on solving business challenges. It now includes not only the implementation of advanced technologies, but also foundational aspects like process standardization and data management. APQC recently collected data from 2,500 organizations from a variety of industries to identify what business problems drove them to digitize, what they include in their digital supply chains, and the availability of critical data.

Bottom line: Despite the adoption of numerous technologies, many organizations still have a way to go in developing their digital supply chain maturity.

Making the case for transformation

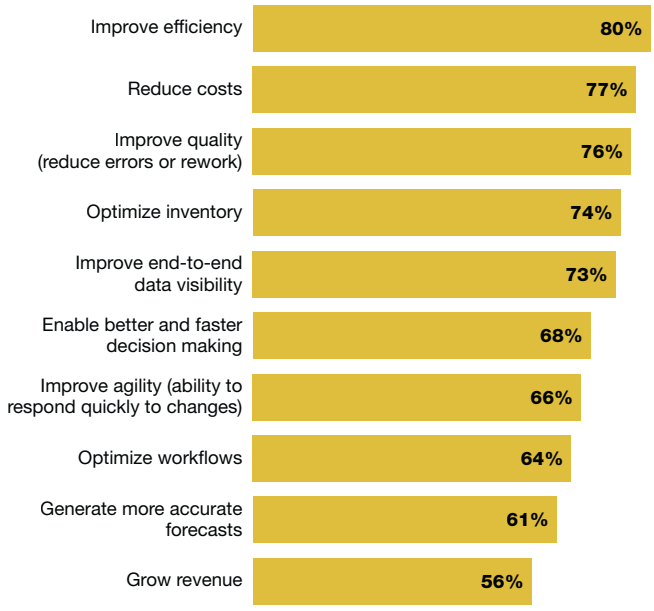
The first question APQC wanted to answer was why companies embraced moving to a digital model for supply chain. Although a common refrain is that organizations digitize to keep up with the technology developments of their peers and competitors, APQC's data shows that the reasons are more business focused.

As shown in Figure 1, the top drivers in organizations' business case for supply chain digital transformation are to improve efficiency, reduce costs, and improve quality. These are familiar reasons as they are the business challenges behind so many organizations' investments in both technology and process improvements: faster, better, cheaper. For supply chains, the drivers also include challenges such as the need to optimize inventory and improve agility.

The promise of digital supply chains has not disappeared, but the focus has changed over time. Organizations now look for a return on investment from transformation that delivers value by targeting specific business needs, signaling a more realistic and directed approach toward technology adoption. Companies are connecting the capabilities of digital supply chains with the very real enterprise goals of maximizing investment and efficiency. In this way, organizations tie digital transformation to business strategy.

FIGURE 1

Top 10 critical drivers in the business case for supply chain digital transformation



Source: APQC

Scope of transformation

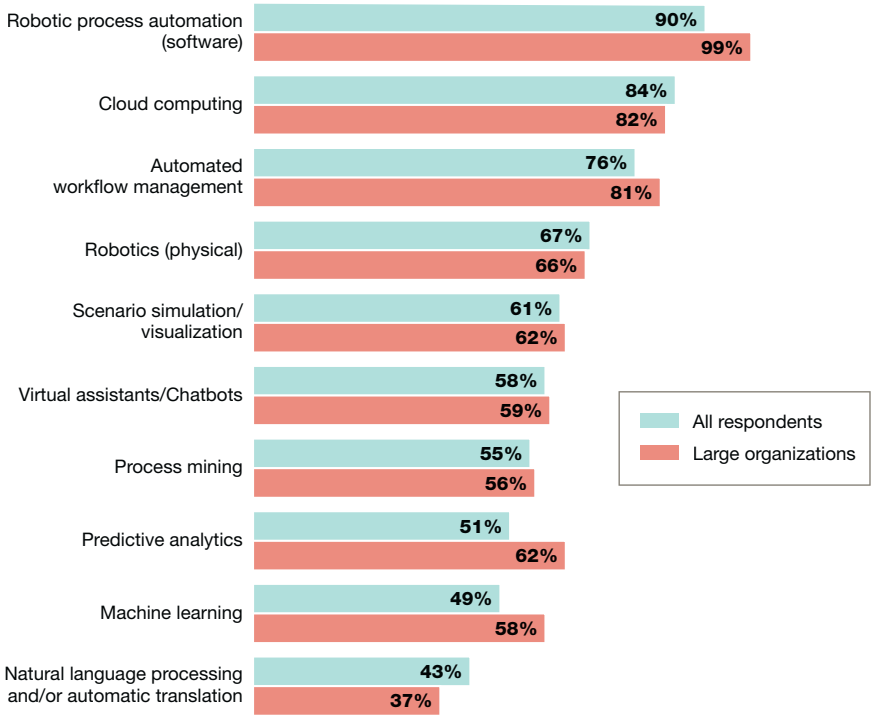
Organizations are not limiting their transformations to only one kind of technology for their digital supply chains. In fact, they are using a combination of software, cloud computing, and physical technology such as robotics. Figure 2 shows the top 10 technologies that organizations include as part of their digital supply chains. Despite the attention currently paid to AI, it is not explicitly listed among the top 10 elements noted in Figure 2. However, supply chains are using machine learning, which is a subset of AI, and AI is the engine under the hood of some of the other technologies.

Interestingly, there are a few differences in technology adoption to note when comparing all the respondents in APQC's research against only organizations with a revenue of $500 million or more (noted as large organizations in Figure 2). For example, nearly all of the larger organizations (99%) use robotic process automation. This is an essential investment for many companies as it enables them to automate repetitive tasks and reallocate staff to more strategic work.

More of the larger organizations have also improved their supply chain operations with predictive analytics, machine learning, and automated workflow management when compared to the entire group of respondents. Complex supply chains need technologies like predictive analytics and machine learning to keep their operations flexible in a changing environment.

FIGURE 2

Top 10 elements of digital digital transformation



Source: APQC

Availability of data

For an organization to fully digitize its supply chain, information must be freely available across systems. In its research, APQC examined the level of visibility for several key types of supply chain data. For organizations with the highest level of maturity in this area, real-time data is accessible both across the enterprise and across their ecosystem of suppliers, partners, and customers. At the lower end of the maturity scale, organizations have no or limited operational data visibility.

The results paint a complex picture. As shown in Figure 3, availability varies depending on the type of data.

At the highest level of maturity, more organizations have real-time data accessible across the ecosystem for customer order and shipment status (13%), as well as inventory levels (11%). Yet even for these types of data, fewer than 20% of organizations have widespread availability. Far more organizations have data visibility restricted to specific departments or internal groups. In fact, half of organizations (50%) have their manufacturing data in silos. This makes it hard for companies to have a complete understanding of the impact from risks posed by changes in geopolitical issues that may require considering dramatic action such as relocating manufacturing facilities.

Silos also impact an organization's ability to react quickly to natural disasters. Should a facility become

unavailable, companies lose valuable time when they do not have access to real-time data about the extent of damage or to aid in recovery.

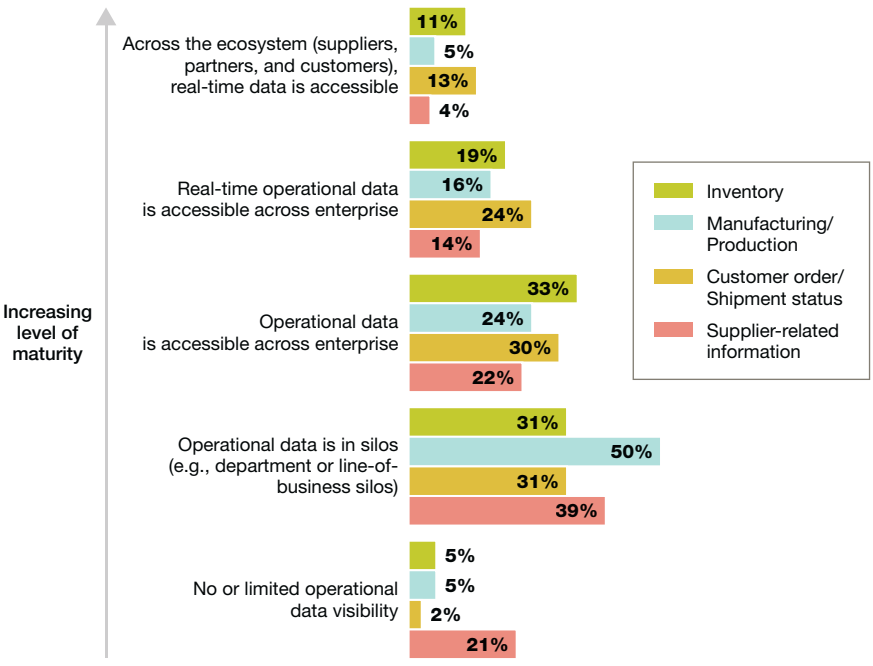
Maturity of digital supply chains

We can also understand digital transformation initiatives using a maturity scale. As Figure 4 shows, there is still room for growth for the majority of organizations, as only 10% have reached the highest level of maturity by extending their initiatives to include their ecosystem partners. As you move down the scale to the next level, automation helps 11% of organizations take action on the outputs from predictive analytics, AI, and machine learning. By contrast, at the lowest level of maturity, 23% of organizations have implemented little digital transformation in their supply chains. The largest group of organizations (30%) is lower on the scale, having only digitized their data and processes.

As with information accessibility, digital transformation initiatives vary in maturity across different parts of the supply chain. Figure 5 shows that demand planning and forecasting/scenario analysis and planning tends to lead the other parts of supply chain in digital maturity. A small group of organizations has reached the highest level of digital maturity in this critical area by extending beyond the enterprise to include ecosystem partners. Transportation, on the other hand, is the area with the lowest level of digital transformation maturity.

FIGURE 3

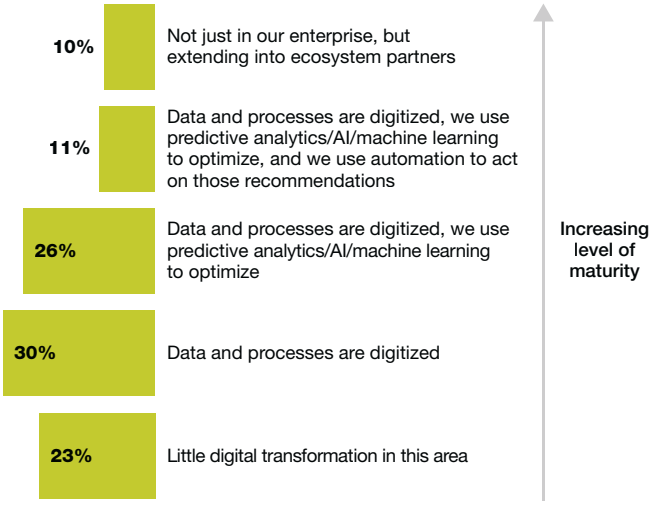
Maturity of supply chain information availability



Source: APQC

FIGURE 4

Maturity of digital transformation initiatives in supply chain

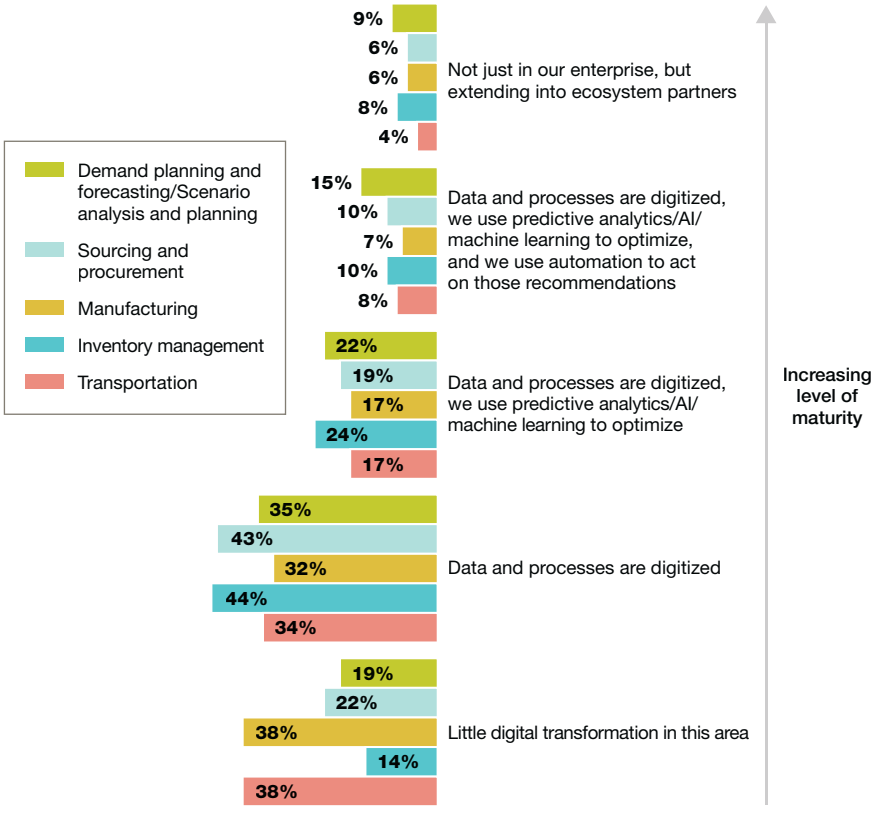


Source: APQC

FIGURE 5

Supply chain digital transformation maturity

Core areas



Source: APQC

Make data widely available

Digital transformation is a multifaceted undertaking. Organizations have made progress over the last decade in embracing digital transformation and tying it to business goals and challenges. Digitization has aligned with technologies that correspond to business drivers of increasing efficiency, reducing costs, and improving quality.

Yet the maturity of many digital supply chains is still in the early stages. A major factor for this is the availability of information. If information is held in silos, organizations are undermining their own efforts. It is no longer enough to ensure data is shared across departments. To provide maximum flexibility and speed, companies need to make their data available in real time cross-functionally.

Factors such as an organization's industry and size can certainly influence which types of data it prioritizes for digital transformation. But ultimately, all data types should be at least digitized and preferably made available for predictive analytics and to ecosystem partners. This maximizes the organization's ability to make informed predictions that lead to effective decision making and greater maturity. •

Data in this content was accurate at the time of publication. For the most current data, visit apqc.org.

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APQC (American Productivity & Quality Center) is the world's foremost authority in benchmarking, best practices, process and performance improvement, and knowledge management (KM). With more than 1,000 member organizations worldwide, APQC provides the information, data, and insights organizations need to support decision-making and develop internal skills. Learn more.

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A SPECIAL SUPPLEMENT TO:
SUPPLY CHAIN MANAGEMENT REVIEW

Navigating Disruption, Driving Innovation

Technology, automation, and software advancements shape this year's conversations on the future of logistics.

By Bridget McCrea, Contributing Editor

Supply chains are moving faster than ever, and the technology designed to support them is racing to keep up. Companies are navigating constant shifts in demand, tighter delivery requirements, and operations that leave little room for error. That pressure is pushing AI, modern software platforms, automation, and robotics deeper into daily workflows as organizations look for tools that can keep goods moving and help their teams make better decisions in real time.

At the same time, the industry is paying closer attention to systems that improve visibility, tighten processes, and strengthen the connections across complex networks. Together, they're helping teams respond faster, run more efficiently, and keep pace with the demands of modern logistics. The continued push into software, automation, and robotics is giving operators clearer insight into their networks and more practical ways to manage the daily pressures of the job.

With their finger on the pulse of the industry, the editors of Logistics Management and Supply Chain Management Review present the 2025 Supply Chain Outlook Virtual Summit. The event centers on the tech tools and automated solutions shaping today's operations, with sessions that offer practical guidance on how to evaluate, implement, and use these systems to streamline work, strengthen networks, and prepare teams for what's ahead.

Here's a look at each presentation and the key messages that stand out.

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KEYNOTE

Intelligent Logistics Systems: How AI Will Transform the Way We Move, Store, and Deliver

SPEAKER: Matthias Winkenbach, PhD, *Principal Research Scientist, Massachusetts Institute of Technology (MIT); Director of Research, MIT Center for Transportation & Logistics*

As supply chains grow more complex and fast-moving, many organizations are finding that conventional approaches can't keep pace with those changes. In his keynote session, Matthias Winkenbach, Ph.D., director of research at the MIT Center for Transportation & Logistics, outlines how AI is reshaping the way companies move, store, and deliver goods.

Winkenbach explains how AI is connecting functions that once operated in silos, giving teams faster insight into sourcing, inventory, transportation, and warehouse activity and helping them make decisions with greater accuracy and confidence. He also walks attendees through the next wave of AI innovation, from agentic systems that coordinate work across functions to Edge AI embedded in warehouses, vehicles, and IoT devices.

"Everyone is aware that there's a certain level of hype to the discussion around AI and machine learning and what it might do to our society and industries," Winkenbach says. He points to the level of customer-centricity that modern e-commerce platforms are offering buyers and the resultant pressure onto the supply chains and distribution networks to deliver the related services.

Winkenbach also discussed how formulating logistics design and solving planning problems are no longer as simple as writing down a cost function in a world where organizations must balance multiple, potentially-competing objectives. "Logistic systems are complex," he adds, "and are therefore harder than ever to plan and optimize."

SESSION 1 TRANSPORTATION MANAGEMENT

34th Annual Study of Logistics and Transportation Trends

Bridging the Great Disconnect: Turning Management Awareness into Action

The 34th Annual Study of Logistics and Transportation Trends examines the gap between what logistics leaders know needs to happen and what actually happens inside their operations. This "Great Disconnect" shows up in familiar places: underused AI; stalled talent development; undervalued credentials; reactive strategies; and technology that never reaches its potential.

For the study, the research team drew insights from more than 280 industry professionals, most with 15+ years of experience. "We feel really good about the perspectives and insights that we gained and that it's coming from what professionals are actually experiencing in the industry today," says Christopher Boone, Ph.D., of Mississippi State University.

The session speakers emphasize that awareness isn't the problem, and say most logistics and transportation professionals understand the tools available to them. The hard part is finding the time and stability to put those tools to work. Respondents pointed to pressure from the Great Freight Recession, ongoing labor shortages and shifting tariff policies that make long-term planning difficult and keep teams focused on immediate problems instead of long-term improvements.

The research team also touches on AI's influence on talent and the uncertainty around skill development that continues to slow progress. They noted that companies still struggle to retain workers and often don't give employees a clear path for building AI skills.

Without that direction, workers don't know what to focus on and the technology may not ever realize its potential. The researchers say closing this gap will be key for any organization that wants to move forward in today's increasingly complex supply chain environment.

SESSION 2 SOFTWARE

SCM Software in Action: Driving Smarter, Faster Decisions

Modern supply chain management (SCM) software has become the backbone of daily operations, giving companies the tools they need to plan, execute, and adjust in real time. Howard Turner, director, supply chain execution systems at St. Onge Co., opens his session by outlining how platforms like WMS, TMS, and YMS now support everything from tracking inventory to managing transportation and coordinating labor.

Turner notes that mature systems like WMS and TMS still anchor most networks. A WMS handles high volumes of order and inventory data inside the four walls, he explains, while a TMS coordinates shipments and transportation tasks. Both have been standard tools for years, but advancements in computing power and software design are expanding these platforms' capabilities. "Companies are now using software for tasks that would've seemed out of reach just a few years ago," he says.

Turner also underscores the need for clearer visibility across distributed operations. With multiple facilities in play, he says companies need one view of the network to see performance, automation capacity and potential bottlenecks. As software platforms become more flexible and scalable, they give operators a clearer view of what's happening across sites and help them adjust before issues escalate into major problems.

SESSION 3 THIRD-PARTY LOGISTICS (3PL) SESSION

Maximizing 3PL Partnerships in a Complex Shipping Landscape

As the tariff uncertainty continues and e-commerce volumes climb, shippers face growing complexity across transportation, fulfillment, warehousing and reverse logistics. Third-party logistics providers (3PLs) play a crucial role in this evolving landscape, which is why choosing the right one is so important.

In a marketplace filled with global, regional, and tech-enabled newcomers, shippers must evaluate 3PLs not only for cost efficiency but also for innovation, visibility, and the ability to scale with evolving demand.

In this session, Herman Guzman, subject matter advisor in logistics and transportation at Accenture, discusses how companies can strengthen their 3PL relationships, benefit from the emerging trends shaping 3PL partnerships, and stay agile as customer expectations and global trade patterns evolve.

Guzman tells attendees that shippers and 3PLs are facing a wider range of pressures than they have in past cycles, and that those conditions are pushing both sides to rethink how they work together. He says the most effective relationships are built on partnership, with shippers and providers sharing plans, improving system integration and approaching disruption as a joint responsibility rather than a handoff.

Compliance is also gaining attention as shippers work to keep documentation and product details accurate across their networks. “As the industry changes,” he adds, “companies need stronger partnerships with their 3PLs to build the resilience they’re looking for.”

SESSION 4 AUTOMATION

2025 Warehouse/DC Automation & Operations Study

Automation Investment Accelerates

In this session, Norm Saenz, partner and managing director at St. Onge Co., walks attendees through this year's Warehouse/DC Operations Survey and says the findings match what his team is seeing in the industry right now.

One of the biggest shifts, he notes, is the move toward fewer but larger buildings. Companies that once spread operations across several sites are consolidating, which increases volume under one roof and makes it easier to justify automation.

He also points to changes in building design. Clear heights in new construction continue to climb, giving companies room to add vertical storage systems like crane-based AS/RS and pallet shuttles. Dock space is another focus area according to Saenz, who says inbound congestion remains a persistent challenge. Smart operators are looking for ways to speed up receiving and putaway to keep the rest of the building moving.

Interest in automation is strong across the board, Saenz reports, with AMRs and AGVs finding their places both in warehouses and on production floors. These automated options are taking on work traditionally done by forklifts. In some operations, they're even starting to replace elements of pick modules.

"It really matches what we're seeing with our own customers," Saenz says. "There's a lot of focus on being efficient, controlling labor, and figuring out where automation makes the most sense."

SESSION 5 ROBOTICS

The Future of Robotics in Logistics and Supply Chain Operations

Robotics and automation are gaining new attention as warehousing, logistics, and e-commerce operations face heavier demand and tighter expectations. The technology has become more capable, and interest is rising across the industry. In this session, Alex Shikany, EVP at the Association for Advancing Automation (A3), discusses current market data, A3 member feedback and examples of how robotics is showing up on warehouse floors today.

Shikany describes 2025 as a year that opened with optimism for the robotics sector after a difficult stretch marked by weak demand and a softer manufacturing environment. That early confidence didn't hold, he says, as uncertainty across global markets continued to influence planning and investment decisions.

He also addresses the surge of attention around humanoid robots, highlighting the wave of videos featuring systems like Tesla Optimus, Figure, and Digit, along with early trials in automotive plants and at GXO. These are all early-stage deployments, he says, but the interest in them reflects just how quickly the market is exploring new options.

Shikany closes out the session with a look at how AI will shape the next phase of automation. "We're entering a new world when it comes to what's possible with AI," says Shikany. "This is the worst the technology is ever going to be in our lifetimes and it's already pretty good at a lot of different tasks." •

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