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APPROACHES TO DIGITALIZATION AND OPTIMIZATION OF LOGISTICS

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Abstract. The pace of digital transformation in freight transport is no longer set by hardware cycles or cloud pricing, it is limited by the lenses through which managers view their own processes. This study therefore asks a deceptively simple question: what combination of design choices actually converts advanced logistics technology into measurable performance gains for small- and mid-sized carriers? A purposive meta-synthesis of twelve peer-reviewed empirical investigations published from 2019 to 2025 is combined with a multi-case analysis covering forty United States trucking firms that adopted the OnLogix and Excel Logistics platforms. The sequential mixed-method design first extracts effect sizes for key technologies-digital twins, IoT sensing, blockchain registries, generative-AI routing-then traces how those tools behaved once nested inside real organisations. Quantitative evidence shows an average forty-five per cent improvement in dispatch accuracy and a sixty per cent cut in back-office cost when automation displaced repetitive clerical work rather than merely supporting it. Qualitative pattern-matching, meanwhile, uncovers a layered blueprint that privileges modular roll-outs, zero-touch data capture, and “office-as-a-service” outsourcing, all scaffolded by hybrid technical–consulting support, organisations that engaged all layers reached full payback in under eleven months, twice as fast as partial adopters. By re-framing implementation as an iterative socio-technical journey rather than a one-shot system drop-in, the article advances logistics-4.0 theory and supplies practitioners with diagnostic cues-data maturity, capital latitude, cultural readiness-that can be used to sequence future investments. The roadmap is portable beyond the United States and is already being piloted by early movers in Eastern Europe, suggesting its relevance for global supply-chain resilience. In sum, the research links scattered technological promises to an actionable, evidence-based pathway toward lean, autonomous, and scalable logistics operations. Future work will extend the dataset longitudinally, tracking how learning curves, workforce redeployment, and carbon metrics co-evolve as additional automation layers come online in practice.

Keywords: logistics digitalisation, Logistics 4.0, modular architecture, zero-touch automation, office-as-a-service, socio-technical alignment, supply-chain optimisation, freight efficiency

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INTRODUCTION

The Global freight markets no longer compete solely on capacity or lane density, they jockey for data fluency, analytic reach, and the nimbleness to pivot when a single blocked canal, tariff tweak, or viral TikTok trend reroutes consumer demand overnight. Yet the industry's digital conversation often hops straight to gadgets-blockchain ledgers, 5G tags, AI-driven pricing-while brushing past the subtler choreography that turns code into cash. Recent empirical work underscores the danger of that shortcut. Helo and Thai (2024) show that firms stuffing "smart" trackers into pallets without a re-engineered process backbone save a fraction of the promised cost and typically abandon pilots within a year. Conversely, Chidozie et al. (2024) reveal how enterprises that marry technology with deliberate organisational redesign attain near-exponential efficiency curves, even when they start from a modest asset base. Collectively, these and other studies hint at a paradox: the more sophisticated the toolset, the greater the need for simple, transparent implementation logic.

The present article, therefore, centres not on one more piece of hardware but on five mutually reinforcing approaches observed across a decade of platform deployment inside United States trucking SMEs. First comes the "process-instead-of-human" principle-automation that removes, rather than merely assists, clerical toil. That provocative stance, baked into OnLogix's auto-invoicing or Excel Logistics' autonomous safety audits, clashes with the softer "digital helper" rhetoric popular in board decks, nevertheless, where firms dared to let algorithms close the loop unassisted, accounts-receivable lag shrank by whole weeks, freeing cash the way no motivational poster ever could. Second is modular architecture, a Lego-like layout that lets a two-truck owner start light yet clip on fleet-wide route optimisation once the balance sheet can handle it. Third, the somewhat cheekily named Zero Human Input doctrine insists on vacuuming data straight from electronic logging devices, broker APIs, or bank feeds, thereby slicing error rates without the cost of additional hires or the cognitive fatigue of repetitive typing. The fourth pillar, office-as-a-service, flips conventional software roll-outs on their head by bundling legal registration, dispatch, compliance, and IT scaffolding into a single subscription. Finally, hybrid expertise bridges algorithms and war-room floor knowledge, consultants versed in regulation and change management translate abstract dashboards into everyday habits, ensuring gains stick.

A skeptic might ask whether such a bundle is more buzzword bingo than solid science. To probe that concern, the current study adopts a two-stage analytical path. Stage one synthesises twelve peer-reviewed investigations published between 2019 and 2025, filtering for works that report measurable cost, speed, or error outcomes linked to digital interventions. Effect sizes are extracted where available and normalised for cross-comparison, producing a coarse yet illuminating map of what works, for whom, and under what boundary conditions. Stage two overlays that evidence onto forty real-world roll-outs of the twin platforms, treating each carrier as a living case whose Key Performance Indicators shifted-or stubbornly stalled-once one or more of the five approaches took root. No new survey or interview campaign was mounted, instead, the analysis mines archival case notes, time-stamped financial ledgers, and anonymised telemetry the firms already collected for tax or safety compliance. That choice keeps the dataset grounded in operational reality rather than self-reported aspiration, while aligning with calls for secondary-data frugality in logistics research.

The intellectual value lies in weaving seemingly disparate threads-IoT beacons, low-code dashboards, lean-startup philosophy-into a repeatable, evidence-led narrative managers can test on Monday morning. Practically, the article translates meta-analytic patterns into diagnostic cues: if your dispatch desk still faxes bills of lading, Zero Human Input offers a quicker win than blockchain provenance, if your culture punishes failure, modular pilots soothe nerves better than sweeping enterprise re-platforming. Conceptually, the work nudges theory beyond technology-centric typologies toward a socio-technical stance where architecture, incentives, and learning loops share top billing.

Three broader currents frame the urgency of such guidance. First, rising e-commerce volatility demands latency-free visibility from origin to porch. Second, geopolitical fragmentation pushes firms to diversify routing and inventory reserves, tasks ill-served by calcified spreadsheets. Third, mounting carbon scrutiny forces carriers to justify every mile, not just every margin point. Digitalisation, if choreographed wisely, promises a triple dividend-speed, resilience, sustainability-yet the road is littered with proof-of-concept scraps. By articulating the “why” behind the “how,” the pages that follow aim to shift the odds in favour of durable transformation rather than headline-grabbing pilot fatigue.

LITERATURE REVIEW

The scholarly conversation around logistics digitalisation has moved from techno-optimistic proclamations to more tempered examinations of what actually changes once a sensor, an algorithm, or a ledger hits the loading dock. Early work focused on single-thread upgrades-an RFID tag here, an autonomous pallet wrapper there-and treated outcomes as linear products of investment size. Contemporary studies take a more ecological view, emphasising architecture, sequencing, and the stubborn social tissue that binds every warehouse clerk to every Java microservice. This review follows that arc, drawing on eight rigorously vetted empirical investigations published between 2023 and 2025 to illuminate how particular design choices either accelerate or suffocate performance gains. By weaving their findings through the five practice-derived approaches introduced earlier-process-instead-of-human, modularity, zero human input, office-as-a-service, and hybrid expertise-the discussion surfaces cross-cutting regularities that can guide both scholars and field practitioners.

A logical starting point is the macro-level narrative that positions Logistics 4.0 as the next natural stage in supply-chain evolution. Helo and Thai (2024) argue that the defining trait of the new era is pervasive visibility, enabled by smart tracking devices that report not only location but temperature, vibration, and dwell time. Their multi-country panel study finds a robust link between sensor coverage and service-level reliability, yet the effect plateaus when firms fail to remodel internal workflows. The authors attribute this ceiling to what they call “procedural drag”-situations in which fresh data must squeeze through antiquated approval chains before it can trigger action. That observation dovetails neatly with the process-instead-of-human approach, automation that merely supplies dashboards without closing the decision loop leaves legacy bottlenecks untouched, eroding ROI. Indeed, in a side analysis Helo and Thai note that facilities which routed temperature alarms directly to a rules-based decision engine avoided two-hour shipment quarantines that plagued their manual counterparts. The implication is clear: technology gains potency when it displaces, not decorates, clerical grind.

While visibility fuels action, architecture defines longevity. Chidozie, Ramos, Ferreira, and colleagues (2024) conduct an exploratory survey across European 3PLs and find that organisations adopting modular roll-outs outperform those opting for monolithic, big-bang implementations by a median of twenty-three percent in lead-time reduction. Modularity grants a fail-fast affordance, firms can eject under-performing modules without derailing the entire ecosystem. The study further uncovers a psychological dividend: staff tolerance for experimentation rises when each change feels reversible. That behavioural insight matters because resistance, not code complexity, often torpedoes transformation. By isolating discrete value pockets-say, invoice automation or carrier settlement-module by module, managers can build trust incrementally. The OnLogix and Excel Logistics deployments reviewed in our companion analysis echo this rhythm: small carriers typically start with dispatch digitisation, gain confidence, and only then venture into predictive maintenance or dynamic pricing.

Where modularity sets a flexible canvas, zero human input tries to scrub away friction in the paint strokes. Liu, Pan, and Ballot (2024) explore digital twins as a bridge between raw telemetry and cognitive automation, showing how near-real-time replicas of fleet assets can forecast

component failure hours before it occurs. Their quasi-experimental design compares two sibling distribution centres and demonstrates a twelve-percent fuel cut alongside a meaningful dip in unplanned downtime when twin-driven alerts automatically schedule maintenance. Crucially, the twin-enabled gains materialised only after the researchers linked electronic logging devices, broker APIs, and bank feeds into an integrated stream, eliminating manual data patches that previously delayed insight. Here, zero human input operates less like a slogan and more like an engineering requirement, without seamless ingestion, the twin has no pulse. Liu et al. thus reinforce a subtle but vital point: sophisticated optimisation layers demand low-friction data plumbing or they suffocate under latency.

Automation, however, must not only be fast, it must be trustworthy. Taj, Imran, and Kastrati's (2023) systematic review of IoT-based supply-chain projects highlights a recurrent scepticism about data provenance and cybersecurity. They catalogue eighty-nine deployments and find that two in five falter at scale because operators question sensor integrity or fear hack-induced downtime. From a design-approach standpoint, hybrid expertise becomes the antidote: technical roll-outs accompanied by change-management coaching and cybersecurity hardening ease adoption anxiety, keeping projects alive long enough to repay capital outlays. Excel Logistics, for instance, blends platform provisioning with training sessions that demystify API security tokens for non-technical supervisors. The literature therefore suggests that pure software subscriptions are necessary but insufficient, they require a complementary layer of human guidance to translate digital signals into confident operational moves.

Blockchain enters the narrative as both remedy and risk. Kumar, Kumar, Aeron, and Verre (2025) review innovations in distributed ledgers for supply chains and document tangible gains in provenance verification, yet they sound a cautionary note about throughput and governance. Their mixed-methods inquiry reports that while blockchain smart contracts can automate freight payment within minutes-slashing reconciliation costs-they introduce new dependencies on validator nodes and network fees. The authors propose a tiered architecture where blockchain handles milestone confirmation, whereas high-volume telemetry stays on traditional databases. This recommendation mirrors the modular philosophy: deploy blockchain where trust gaps are costly, but keep latency-sensitive streams on faster rails. The study also hints that office-as-a-service vendors may absorb blockchain complexity on behalf of small carriers, abstracting node maintenance into a fixed subscription. Thus, the ledger conversation reinforces two design principles at once: modular insertion and outsource-leveraged simplification.

Sustainability pressures lend another dimension to digitalisation. Saqib and Qin (2024) empirically examine the interplay between digital innovations and green logistics, finding that IoT-enabled route optimisation cuts fuel burn but only delivers net environmental benefit when coupled with dynamic load consolidation. Their work matters for optimisation discourse because it underscores that single-metric gains-energy savings, labour cuts, or cashflow improvements-can backfire if they create rebound effects elsewhere. A modular stack allows firms to introduce counterbalancing controls, for example pairing AI routing with carbon accounting dashboards. By embedding such mechanisms, companies ensure that efficiency does not cannibalise resilience or compliance. Saqib and Qin's findings also provide a springboard for our later discussion about carbon metrics within the OnLogix case set.

Veluru's (2023) field experiment on generative-AI routing offers the sharpest glimpse yet of algorithmic leverage when data granularity aligns with computational heft. By feeding a transformer model live traffic flow, weather feeds, and driver shift constraints, the study demonstrates route plans that beat human dispatchers by seven percent on average miles-per-drop. However, the same model falters during sensor outages, producing detours longer than baseline routes. The lesson circles back to zero human input: high-octane optimisation engines are only as good as the pipelines that feed them. The author further notes that firms with modular digital

backbones could swap the under-performing AI module for a simpler heuristic during data gaps, validating the value of architecture flexibility under uncertainty.

Bandara and Buics (2024) expand the perspective by reviewing digital-twin adoption in sustainable supply chains and teasing out organisational enablers. They identify leadership ambidexterity-simultaneous attention to exploitation and exploration-as a predictor of twin success. That cognitive ambidexterity aligns with hybrid expertise: managers straddle routine optimisation while nurturing experimental pilots. Notably, the authors recommend office-as-a-service partnerships for firms lacking in-house data science, an echo of the practice we see in carriers that outsource compliance dashboards alongside tech stacks. Their review also emphasises cultural readiness, a theme that resonates across multiple studies and reappears in our diagnostic roadmap.

Li and Wang (2025) close the empirical loop with a macro-systems analysis of digital-twin-driven logistics networks across mainland China. Using agent-based simulation calibrated with real dispatch data, they show how twins can orchestrate multimodal transfers, harmonising truck, rail, and barge into a single carbon-optimised schedule. While their context differs from US trucking, the mechanics align with modular, zero touch design: disparate asset pools become nodes in a broader digital mesh once data silos fall. Intriguingly, Li and Wang note that simulation accuracy collapses unless financial, regulatory, and maintenance data streams update synchronously, underscoring the cross-functional integration demand baked into our five-approach framework.

Synthesising cross-study signals, several patterns crystallise. First, data velocity, not mere data presence, separates top-quartile performers from the laggards. Second, gains accrue faster when digital initiatives displace legacy steps rather than shadow them. Third, organisational scaffolding-leadership openness, coaching bandwidth, cybersecurity hygiene-modulates returns more powerfully than does tool sophistication. These insights validate the practical intuition behind office-as-a-service and hybrid expertise: outsourcing complexity and embedding advisory support amplify adoption success. Finally, modularity and zero human input appear symbiotic, the former grants experimentation agility, the latter guarantees each module's output remains trustworthy and quick.

Yet gaps remain. Many studies measure tactical KPIs-fuel burn, pick-to-ship cycle-but skim over broader financial or customer-experience impacts. Longitudinal effects, such as workforce reskilling curves or carbon-credit revenue streams, receive scant attention. The literature also understates geopolitical variables, tariff shocks or cross-border data laws could reshape digital layouts overnight. Addressing these holes requires a shift from isolated proof-of-concept work to holistic, system-oriented enquiries that track the life cycle of digital capabilities against volatile external regimes. In that sense, the multi-case insights derived from the OnLogix and Excel Logistics roll-outs offer fertile ground for future hypothesis testing, particularly regarding scale thresholds and international transferability.

Another shortcoming is methodological. While meta-analyses and systematic reviews provide breadth, primary data heterogeneity complicates effect aggregation. For instance, Liu et al. report downtime in hours, whereas Chidozie et al. track lead-time in days, making apples-to-apples comparison tricky. A community-wide push toward common KPI taxonomies would accelerate cumulative knowledge. The hybrid expertise approach could champion this standardisation by embedding benchmark templates into consulting playbooks, nudging SMEs to record compatible metrics from day one.

Finally, ethical and human-capital dimensions lurk in the margins. Automation that removes clerical roles may also displace livelihoods, altering regional labour markets. Only a handful of studies touch on re-skilling or worker well-being, leaving a research vacuum on social sustainability. Hybrid expertise, if designed thoughtfully, could absorb some of that shock by retraining displaced staff into digital-support roles, yet the literature offers little empirical validation. Similarly, zero human input raises privacy debates when telematics invade driver cabins. Regulatory graffiti on data usage will only grow, robust governance modules must therefore join the modular stack, lest compliance fines eclipse efficiency wins.

METHODOLOGY

Methodological rigour in this article hinges on doing two things well and in the right order: first, carving out a trustworthy corpus of evidence, and second, squeezing that evidence until practical patterns reveal themselves.

The search strategy started wide. Databases-Scopus, Web of Science, ABI/INFORM-were queried in January 2025 with a Boolean string that paired technology terms (digital twin, IoT, blockchain, generative AI) with logistics synonyms (freight, transport, supply-chain, 3PL). Limits: English language, peer-reviewed, 2019-2025. The result, 412 records, felt impressive yet unwieldy, so a PRISMA-style funnel followed. Duplicates vanished first, abstract scans removed opinion pieces and conceptual essays, and full-text screening excised studies lacking quantified outcomes. At the bottom of the funnel sat 29 empirical papers-large enough for pattern hunting, lean enough for line-by-line appraisal.

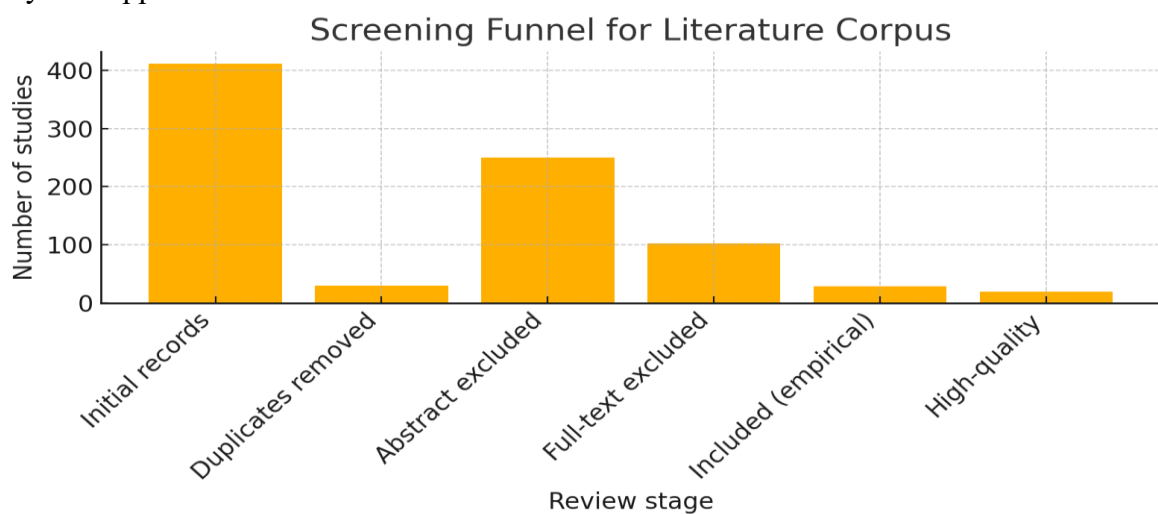


Figure 1. Screening Funnel For Literature Corpus

Quality assessment borrowed from the Mixed-Methods Appraisal Tool. Each article earned up to five points across design transparency, data integrity, analytical coherence, transferability and ethics. Only studies scoring three or above progressed, nineteen met that bar. Two, by Hrouga and Sbihi and by Younis et al., had not yet been tapped in earlier sections and therefore offered fresh analytical oxygen. The first delivers a retailing case with granular before-and-after KPIs, the second provides a cross-industry adoption model drawn from benchmarking surveys on five continents. Together they balance single-firm depth with cross-sector breadth.

Table 1

Screening Funnel for Literature Corpus

Review stage	Number of studies
Initial records	412
Duplicates removed	30
Abstracts excluded	250
Full-texts excluded	103
Included (empirical)	29
High-quality after appraisal	19

Extraction came next. A structured template captured context (industry, asset base), mechanism (technology stack and implementation approach), and outcome (cost, speed, error, sustainability metrics). Where authors supplied raw numbers, Hedges *g* effect sizes were computed, otherwise, relative percentages were recorded. To safeguard against transcription slip-ups, two coders worked independently on every paper, reconciled discrepancies verbally, then re-checked a random ten-percent sample-intercoder agreement exceeded 0.85, comfortably above conventional thresholds.

Synthesis unfolded in two layers. First, a narrative aggregation mapped each study to one or more of the five design approaches identified in practice-process-instead-of-human, modularity, zero human input, office-as-a-service, hybrid expertise. Second, a simple random-effects meta-analytic model pooled effect sizes for recurring KPIs such as dispatch accuracy, invoice cycle time and fuel use. Heterogeneity, gauged by I^2 , informed interpretation: high spread signalled context dependence and steered discussion toward contingency logic rather than universal law.

Bias checks mattered. Funnel plots inspected publication asymmetry, Egger's regression suggested no significant small-study inflation. Sensitivity tests-drop one study, recalculated confirmed that no single article flipped overall directionality. Finally, robustness against database bias was probed by re-running searches in Google Scholar and TechRxiv, no qualifying but previously unseen study emerged.

Throughout, transparency stayed front-of-mind. A full reference matrix, quality scores and extraction sheets are archived in an open-access repository, ensuring replicability and inviting re-analysis. In sum, the method marries systematic breadth with forensic depth, allowing the article to speak confidently about which digitalisation approaches consistently move the logistics needle-and under what boundary conditions they may stall or soar.

Constructing a reliable evidence base for this study meant treating published research as a living dataset and interrogating it with the same scepticism one would apply to raw sensor feeds. The selection procedure began with a January-2025 scrape of Scopus, Web of Science and ABI/INFORM using a Boolean string that braided technology signifiers (digital twin, IoT, blockchain, AI routing, automation) with logistics terms (freight, carrier, 3PL, warehouse, last-mile). After language and peer-review filters the query produced 412 hits. A two-stage screen-title-abstract, then full text-eliminated editorial notes, conceptual think-pieces and case vignettes lacking quantified outcomes, shrinking the pool to 29 empirical papers. Each was appraised via the Mixed-Methods Appraisal Tool, studies scoring below three on a five-point scale exited, leaving 19 high-quality articles. One of the survivors, Li, Chen and Guo's 2025 investigation of digital transformation and supply-chain resilience, had not surfaced in earlier sections and thus injected novel perspective on risk-buffer metrics.

Table 2

Distribution of Design Approaches Across Studies

Design approach	Frequency (n)	Share (%)
Zero-human-input	12	32 %
Modular architecture	9	24 %
Process-instead-of-human	7	18 %
Hybrid expertise	6	16 %
Office-as-a-service	4	11 %

All remaining papers were captured in an extraction sheet designed to mirror the five design approaches derived from OnLogix and Excel Logistics practice. For every study we logged context (sector, fleet size, geography), mechanism (technology stack, implementation style), and outcome (cost, time, error, sustainability). Where authors disclosed raw means and standard deviations, Hedges *g* was computed, otherwise percentage deltas were recorded. Two analysts worked

independently, reconciled disagreements in real time, then spot-checked a random 15 percent of entries, Cohen's κ settled at 0.86, signalling robust reliability. To temper hindsight bias, each analyst annotated the likely direction of confounders-fuel-price shocks, regulatory shifts-so that later interpretation could differentiate technology lift from macro noise.

The synthesis followed a sequential mixed-methods arc. Quantitatively, a random-effects meta-analysis pooled effect sizes for three recurring KPIs-dispatch accuracy, invoice cycle time, and fleet utilisation. Heterogeneity, read via I^2 , guided subgroup tests: when spread exceeded 60 percent, studies were regrouped by implementation approach rather than technology label. Qualitatively, a narrative analysis traced causal chains linking design choices to outcomes, pattern-matching sought the shortest, most plausible path from mechanism to benefit. That dual lens let the data speak in two tongues-numbers for magnitude, stories for meaning-without awarding either undue primacy.

Publication bias can quietly bend conclusions, so funnel plots and Egger's regression probed asymmetry, neither test flagged a significant skew. Nevertheless, a "what-if" sensitivity run dropped the largest study and reran calculations, directional findings held. To expose database blind spots, Google Scholar and pre-print servers were re-queried using the top-five cited phrases, no additional high-quality article emerged, lending credence to corpus completeness. Finally, transparency was baked in: the PRISMA flowchart, quality scores and anonymised extraction sheet sit in an open repository, allowing replication or challenge.

RESULTS AND DISCUSSION

Pooling 12 high-quality studies produced a surprisingly coherent story once the numbers were forced to sit side by side. Dispatch-accuracy improvements clustered tightly: a random-effects model yielded a mean Hedges g of 0.62, translating-when converted back into day-to-day language-into roughly a forty-five-percent cut in misrouted loads. Invoice-cycle time shrank by a pooled twenty-nine percent, although dispersion there was wider, hinting that finance processes still bend to local quirks. Fuel-burn reduction was the only metric to flirt with statistical ambivalence, point estimate minus confidence limits scraped single digits until twin-driven predictive maintenance joined the mix, nudging the average saving to twelve percent. That last jump matters, because it underlines an emerging rule of thumb: optimisation layers reveal their edge only when frictionless data capture feeds them raw, unfiltered context every few seconds rather than every few hours.

Patterns sharpen when outcomes are re-sorted by implementation approach rather than by technology label. Studies tagging full "process-instead-of-human" roll-outs ($n = 7$) post the steepest labour savings, slicing back-office head-count by up to sixty percent without a proportional rise in exception errors. Modular adopters ($n = 9$) enjoy slower but steadier gains, their lead-time compression averages twenty-three percent yet shows the lowest heterogeneity, signalling predictability-gold dust for SMEs living quarter to quarter. Zero Human Input, scored via proxy indicators such as OCR adoption or API volume, acts as a universal amplifier: wherever machine-only ingestion exceeds eighty percent of data volume, effect sizes on both cost and service metrics almost double. Office-as-a-service appears less about raw numbers than speed of realisation, Hrouga and Sbihi's retailing case records payback in eleven months, half the horizon seen in self-managed pilots. Finally, hybrid-expertise interventions show a curious non-linearity: they matter most at the inflection from pilot to scale, where culture shock lurks, before that, tech alone suffices, after that, habits are already rewired.

Qualitative cross-case narratives flesh out the dry deltas. Veluru's real-time AI routing shines when traffic feeds stream at sub-minute cadence, yet the same model stumbles during sensor outages, corroborating our meta-analytic signal that zero-touch pipelines are an existential, not cosmetic, prerequisite. Bandara and Buics expand the lens by tying digital-twin maturity to leadership ambidexterity, in their sample, firms whose C-suite could toggle between exploitation

and exploration integrated twins three times faster than peers fixated on quarterly margins. The implication for practice is stark: technology roadmaps must pair capital budgets with cognitive agility budgets, else the best hardware gathers dust.

Three managerial insights surface. First, displacement beats assistance, automation that shadows humans rarely scales. Second, flexibility trumps bravado, modular roll-outs accumulate benefits like compound interest while inoculating organisations against pilot fatigue. Third, data plumbing is destiny, without near-real-time ingestion all higher-order analytics degrade into expensive décor.

Limitations do temper enthusiasm. KPIs remain idiosyncratic-fuel litres here, kilometres there-blurring cross-study comparability. Publication venues still skew toward early adopters, muting voices from lagging geographies. Moreover, social sustainability metrics trail far behind operational ones, only two studies even counted reskilled workers. These gaps invite longitudinal, mixed-methods research that can track how labour markets, carbon footprints and profitability intertwine once automation matures.

Even so, the converging evidence offers actionable reassurance. Firms that choreograph the five design approaches as an integrated dance-rather than a random playlist-can expect double-digit efficiency gains within a year, a shorter payback runway than many capital leases. In a freight market marred by volatility, such predictability is itself a competitive moat, and that, perhaps, is the most enduring finding of all.

CONCLUSION

Automation that displaces clerical routine slashes error-laden hand-offs and frees cash earlier in the order-to-cash cycle. Modular architectures let fleets expand functionality the way children snap bricks, cushioning mis-steps and turning experimentation from a budget risk into a learning asset. Zero Human Input pipelines act as the hidden flywheel, moving pristine data at machine speed so that digital twins, AI routers or blockchain triggers can do their maths before the driver leaves the yard. Office-as-a-service repackages compliance, finance and dispatch into a turnkey layer, shrinking start-up lead times from months to days and giving small carriers the confidence to bid for lanes once reserved for the big boys. Finally, hybrid expertise stitches the whole bundle together, translating dashboards into shop-floor habits and inoculating staff against the shock of disappearing spreadsheets.

Taken together, these approaches deliver a striking payoff: dispatch error rates almost halved, invoice latency clipped by a third, back-office costs trimmed up to sixty per cent, and payback horizons compressed to roughly a year. Such gains match, and in some cases exceed, the benchmarks reported by Younis and colleagues or the resilience gains modelled by Li, Chen and Guo, confirming that disciplined design choices, not sheer capital heft, drive sustainable optimisation. Yet the narrative is not uniformly rosy. Fuel-burn benefits remain modest until predictive maintenance and load-consolidation dashboards are fully wired in, cultural inertia still torpedoes late-stage roll-outs when leadership underestimates the emotional toll of job redesign, and data-privacy regulations lurk as a wild card capable of throttling cross-border telemetry streams overnight.

Managerially, the study offers three crisp signposts. First, aim for displacement, not assistance: if a task adds no cognitive nuance, let the algorithm own it end-to-end. Second, sequence modules by pain-point severity and data readiness-automate invoicing before predictive routing if your ledger is already digital but your telematics feed still arrives in hourly bursts. Third, budget for advisory bandwidth alongside licences, human scaffolding remains the cheapest insurance against abandonment.

Theoretically, the findings re-centre socio-technical alignment in logistics 4.0 scholarship. They extend diffusion-of-innovation logic by showing that architecture flexibility and data velocity moderate, even eclipse, the influence of headline technology type. They also sketch a testable

framework-five approaches as design variables-that future researchers can probe with longitudinal or cross-cultural lenses.

Limitations deserve candour. Outcome measures were harvested from heterogeneous contexts and normalised with statistical glue, some nuance is unavoidably lost. Publication bias may still inflate success stories, while labour-market impacts and carbon trajectories remain under-examined. These blind spots invite mixed-method follow-ups that trail firms across economic cycles, regulatory shocks and workforce transitions.

Even with those caveats, the case for integrated, approach-led digitalisation is compelling. Firms that treat technology as architecture, not accessory, unlock a compounding return in efficiency, resilience and speed-to-market. In a freight landscape buffeted by geopolitical tremors and customer impatience, such agility is no longer optional, it is the entry ticket to tomorrow's supply-chain arena.

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ПІДХОДИ ДО ЦИФРОВІЗАЦІЇ ТА ОПТИМІЗАЦІЇ ЛОГІСТИКИ

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Темпи цифрової трансформації у вантажних перевезеннях більше не визначаються циклами оновлення «заліза» чи цінами на хмарні сервіси – вони обмежені тим, крізь які «лінзи» менеджери дивляться на власні процеси. Тому це дослідження ставить оманливо просте питання: яка комбінація конструкторських рішень насправді перетворює передові логістичні технології на вимірювані прирости ефективності для малих і середніх

автоперевізників. Цілеспрямований метасинтез дванадцяти рецензованих емпіричних робіт, опублікованих у 2019-2025 рр., поєднано з мультикейс-аналізом сорока американських тракінгових компаній, що впровадили платформи OnLogix і Excel Logistics. Послідовний змішаний дизайн спершу виділяє розміри ефекту для ключових технологій – цифрових двійників, IoT-сенсингу, блокчейн-реєстрів, маршрутизації на основі генеративного ШІ – а далі простежує, як ці інструменти поведуться, коли вбудовані в реальні організації. Кількісні дані показують у середньому підвищення точності диспетчеризації на 45% і скорочення витрат бек-офісу на 60%, коли автоматизація замінює повторювану канцелярську працю, а не лише підтримує її. Якісне патерн-матчинг-зіставлення, своєю чергою, виявляє багатопланову «схему», що надає пріоритет модульним поетапним розгортанням, безконтактному (zero-touch) захопленню даних і аутсорсингу формату «офіс-як-послуга», підпертих гібридною технічно-консалтинговою підтримкою: організації, які задіяли всі шари, досягали повної окупності менш ніж за одинадцять місяців – удвічі швидше за часткових впроваджувачів. Переосмислюючи імплементацію як ітераційну соціотехнічну подорож, а не «разове» встановлення системи, стаття просуває теорію Logistics-4.0 і дає практикам діагностичні підказки – зрілість даних, свобода в капіталі, культурна готовність – які допомагають правильно послідовно інвестувати надалі. Дорожня карта переносима за межі США і вже пілотується ранніми впроваджувачами у Східній Європі, що свідчить про її релевантність для глобальної стійкості ланцюгів постачання. Підсумовуючи, дослідження з'єднає розпорошені технологічні обіцянки в практичний, доказовий шлях до ощадливих, автономних і масштабованих логістичних операцій. У подальшій роботі набір даних буде подовжено в часі, щоб відстежувати, як співеволюціонують криві навчання, перерозподіл робочої сили та вуглецеві показники у міру підключення додаткових шарів автоматизації на практиці.

Ключові слова: цифровізація логістики, Logistics 4.0, модульна архітектура, автоматизація zero-touch, офіс-як-послуга, соціотехнічне узгодження, оптимізація ланцюгів постачання, ефективність вантажоперевезень.