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Technological Advancements and Strategic Roles of Fourth-Party Logistics (4PL): A Systematic Literature Review

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ABSTRACT

Fourth-Party Logistics (4PL) has emerged as a critical strategic model for managing complex supply chains in the digital era. This systematic literature review analyzed 38 peer-reviewed articles (2020-2025) from the Scopus database to examine technological advancements and strategic roles of 4PL in supply chain management. Three research questions guided the analysis: optimization technologies supporting 4PL operations, strategic mechanisms improving supply chain outcomes, and cost reduction strategies enabling 4PL adoption. Findings demonstrate that advanced optimization technologies including Conditional Value-at-Risk (CVaR), stochastic programming, and reinforcement learning effectively manage transportation uncertainty and enhance operational efficiency. Strategic mechanisms such as coordinated ICT infrastructure, sophisticated matching models, and innovative financing arrangements significantly improve service quality and customer satisfaction. Cost reduction and sustainability strategies, including flexible resource management, warehouse optimization, and blockchain implementation, enable organizations to achieve cost reductions up to 38% while maintaining environmental compliance. However, implementation barriers in regulatory compliance, human resource management, and digital infrastructure remain significant challenges. The research concludes that 4PL adoption requires integrated approaches balancing technological innovation with organizational capability development. Future research should prioritize context-specific implementation frameworks for emerging markets, particularly in developing economies such as Indonesia, to address unique supply chain challenges while supporting economic growth and operational resilience.

Keywords: *Customer Satisfaction, Fourth-Party Logistics, Outsourcing Strategy, Supply Chain Management*

Introduction

Logistics services represent a component of the supply chain process that effectively plans, implements, and controls procurement, inventory management, storage, goods and services, and information from the point of origin to the point of consumption to meet consumer needs [1]. Logistics services play a role in meeting customer needs and expectations [2] and serve as a source of value creation by facilitating and streamlining the flow of goods and services, thereby becoming an integrated service that ultimately serves as a revenue source [3]. Logistics was initially a military term used before the 1950s, and by the 1970s, logistics became one of the supply functions in companies. Significant changes occurred in the 1980s, when logistics evolved into part of a system, known as Party Logistics.

Third-Party Logistics (3PL) is a service type in which companies contract with a third party to handle most or all of their logistics needs [4]. 3PL began to develop in the 1980s and has demonstrated the ability to enhance supply chain effectiveness and efficiency [5], reduce storage volume in the system [6], and overcome capacity constraints and high rates [7]. Supply chain effectiveness and efficiency are achieved through a 10-15% reduction in transportation costs, 20-25% reduction in storage levels, and operational optimization that enables companies to achieve cost savings of up to 15%. The use of 3PL also reduces storage volume in the system through the implementation of dynamic slotting algorithms while maintaining safety stock levels 23% lower [8]. This has prompted many companies to outsource from professional service providers to reduce costs [9], such as Third-Party Logistics (3PL) or Fourth-Party Logistics (4PL) [10].

Fourth-Party Logistics (4PL) has emerged as a successful model for companies worldwide to leverage resources and reduce supply chain costs [11]. 4PL is a logistics service that encompasses the management and coordination of all logistics activities through strategic logistics service provision, including 3PL management [4] and serves as a coordinator that designs comprehensive supply chain solutions by leveraging technology, knowledge, and resources from service providers and customers [12].

According to The Insight Partners, a global market firm and consultant, the 4PL market size in 2023 was US$ 71.89 billion and is projected to increase to US$ 121.63 billion in 2031, with historical data from 2021-2022 used for forecasting. The Compound Annual Growth Rate (CAGR) is estimated to increase from 2023-2031 by 6.79%. This indicates that the market has confidence in 4PL services, which offer numerous advantages. The advantages of 4PL lie in its ability to represent complex logistics systems in a structured manner [13]. 4PL service providers have proven capable of improving operational efficiency and reliability [14], while their role continues to expand and become increasingly complex [15]. Despite its advantages, 4PL continues to face various challenges in the current industrial era.

Currently, 4PL networks operate in a dynamic and disruption-prone environment [16]. Disruptions faced by 4PL include industrial accidents, natural disasters, and terrorist attacks that can cause serious operational consequences such as higher transportation costs, inventory shortages, order delays, and loss of market share [17]. In the current industrial era, 4PL also faces various challenges that require attention, such as rapid demand changes, increasingly complex logistics processes, lack of professional logistics workers, technology adoption, and information security [18]. Another challenge faced by 4PL and 3PL is the implementation of digital supply chains [19] and adaptation to cutting-edge technology, industry dynamics, and reduction of lead times [20]. In response to these challenges, e-logistics emerges as a solution to integrate various components of the digital supply chain in responding to market demands.

One sector that requires the role of e-logistics [21] and technology [22] is e-commerce. Currently, advancing technologies have prompted many manufacturers to shift from insourcing to outsourcing their logistics functions [23], such as information technology, blockchain, and artificial intelligence. Blockchain technology can enhance supply chain transparency and traceability by eliminating transaction costs and quality degradation costs in logistics systems, while artificial intelligence enables predictive analytics and intelligent automation for route optimization, inventory management, and vendor selection in 4PL services [17].

This research presents innovation by combining a focus on e-commerce with the application of technologies such as blockchain and artificial intelligence in the context of 4PL-based supply chain management. The research aims to demonstrate the impact of 4PL technology implementation on supply chain performance. Additionally, the governance and trust aspects between clients and 4PL providers are thoroughly analyzed to explain collaboration mechanisms and risks in managing integrated logistics services. The context of developing countries such as Indonesia also becomes a primary focus to fill the literature gap that has been dominated by studies from developed countries. This research explores the combination of multi-technologies and their impact on supply chain efficiency and competitiveness, while integrating sustainability dimensions through the application of green logistics principles in the strategic role of 4PL.

This research establishes three main research questions: (RQ1) What optimization and risk management technologies support 4PL strategic operations during 2020-2025?; (RQ2) How do 4PL optimization models and strategic mechanisms (matching, pricing, contract design) improve supply chain outcomes (efficiency, service quality, customer satisfaction)?; and (RQ3) What cost reduction and sustainability strategies enable 4PL adoption and operational efficiency in supply chains?. The synthesis results connect supporting technologies with the strategic role of 4PL.

Research Methods

Systematic Literature Review (SLR) is a methodology or analytical tool employed to process and collect a number of research studies, which are then identified and analyzed [24]. SLR research is conducted for various purposes, including identifying, examining, evaluating, and interpreting all available research within a specific field of topic that is of interest, guided by particular research questions that are relevant. This research employs the Systematic Literature Review (SLR) method following the PRISMA framework (Preferred Reporting Items for Systematic Reviews) to consolidate various scattered evidence related to 4PL and to directly address the research questions that have been formulated.

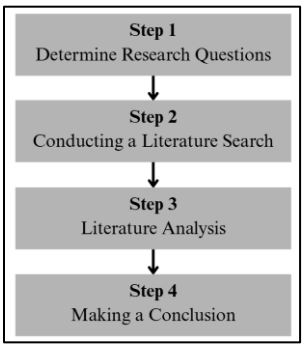

Figure 1. Research methodology

The stages of Systematic Literature Review (SLR) research consist of four steps: problem formulation, literature searching, analysis of scientific articles, and drawing research conclusions. In the first step, the researcher formulates the research questions that will be discussed in depth. These questions are developed based on the topic requirements selected by the researcher, namely: (1) What optimization and risk management technologies support 4PL strategic operations during 2020-2025?; (2) How do 4PL optimization models and strategic mechanisms (matching, pricing, contract design) improve supply chain outcomes (efficiency, service quality, customer satisfaction)?; (3) What cost reduction and sustainability strategies enable 4PL adoption and operational efficiency in supply chains?

The second step involves conducting a search for relevant articles. This literature study is a summary or synthesis determined based on a predetermined theme. The literature search was conducted in July 2025. The data used in this research is secondary data obtained not from direct observation, but rather from studies that have already been conducted or prior research. The database used is Scopus for cross-disciplinary coverage. Below are the inclusion and exclusion criteria for the literature search.

Table 1. Inclusion and exclusion criteria

Include	Exclude
Using the keywords "Fourth Party Logistics" and "Technology 4PL"	Article with no related to subject area of "Fourth Party Logistics" and "Technology 4PL"
Only using article document type	Based document type such as Conference Paper, Review, Book Chapter, Retracted, Note, Erratum, Conference Review, Book
Articles written in English	Based language type non-English
Articles published between 2020-2025	Articles published before 2020

The literature search process was conducted systematically by targeting titles, abstracts, and keywords using the query TITLE-ABS-KEY ("Fourth Party Logistics") OR TITLE-ABS-KEY("4PL"), which yielded 439 articles published from 2001 to 2025 before screening and deduplication were performed. To maintain relevance with current research focus, the screening process was then limited to English-language journal articles published between 2020 and 2025. The SLR design was selected because previous research on 4PL remains scattered across various perspectives, including technology, operations, and governance, without comprehensive and integrated synthesis. The Scopus database was used as the primary source in the SLR design because it has extensive coverage of prestigious and peer-reviewed international publications in the fields of engineering, management, and operations. A summary of the number of articles from the identification stage through the inclusion stage is presented in the following figure.

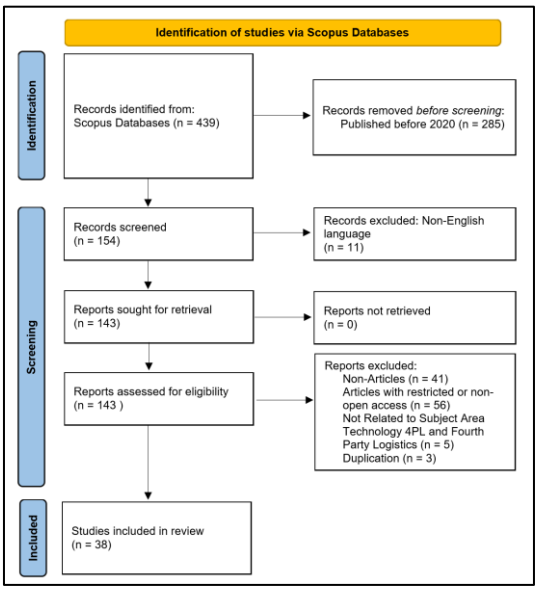

Figure 2. Systematic literature review using prisma.

The third step is the stage of analyzing literature results to answer the research questions established in step 1. The final step involves understanding the search results that have been summarized in the analysis stage. At this stage, the researcher draws research conclusions, which are brief statements about the results of descriptive analysis derived from facts or logical relationships and contain answers to the questions posed in the problem formulation section. All answers focus solely on the scope of the research questions and the number of conclusions is tailored to the existing problem statements.

Results and Discussion

Literature Review

A 4PL serves as a coordinator that designs and manages end-to-end supply chain solutions, drawing on the combined knowledge, capabilities, and assets of logistics providers and customers [25]. As an assetless logistics service provider, 4PL embodies a novel and transformative organizational arrangement [26]. A 4PL provider also functions as a technology service provider, equipped with adequate intellectual capital and robust IT infrastructure [27]. In this context, a neuro-informed collaborative multi-criteria decision support system improved decision accuracy and stakeholder alignment [28].

Fourth-Party Logistics providers are classified into four models: Metronome, Architect, Nostalgic, and Minimalist, according to relationship reliance and service involvement [29]. To support provider evaluation, various decision-making frameworks have been developed. The integrated FAHP–FMARCOS model provides a robust and adaptable framework for selecting the best 3PL provider, validated through a case study, sensitivity tests, and comparisons with other MCDM methods [30]. Similarly, a systematic 4PL selection framework effectively ranks 4PL candidates and is robust across methods, validated by the Thailand case study [31]. A hybrid decision-making framework is also proven robust and effective in evaluating and selecting the best fourth-party logistics providers [32]. In addition, PTC-BOCR enables robust, sustainable, and cost-effective 4PL decision-making [33].

Beyond provider selection, performance evaluation frameworks have also been widely studied. The performance measurement framework and its implementation procedure can be effectively used by users as part of the strategic management process of their organizations [34]. A performance measurement methodology and framework for non-profit fourth-party reverse logistics demonstrates its effectiveness through expert validation and total performance index calculations [35]. Furthermore, a structural performance measurement system for fourth-party logistics (4PL), developed using the Plan–Do–Check–Act (PDCA) cycle and evidence-based management (EBM), consists of five performance dimensions and 32 key indicators. Within this framework, service quality, social and environmental performance, and inter-organizational relationships are found to positively influence financial performance and efficiency [36]. The efficiency of worldwide retail supply chains depends significantly on optimized container shipping [37].

Overall, the reviewed literature demonstrates that 4PL functions not only as an assetless coordinator but also as a technology enabler, a performance evaluator, and a developer of robust decision-making models. The diversity of models, frameworks, and performance measurement approaches establishes a solid conceptual foundation for understanding the strategic roles of 4PL. These insights provide the basis for the subsequent Findings section, where the thematic synthesis further explores how such frameworks translate into practical applications and value creation.

Finding

Descriptive Mapping of The Corpus

The search yielded 439 records (2001–2025), from which 38 journal articles (2020–2025) were included after screening (Figure 1 in Method). The escalating publication trajectory from 2021-2025 signals a critical inflection point in 4PL research, reflecting a fundamental shift in how global supply chains respond to post pandemic challenges and digital transformation imperatives. This acceleration particularly pronounced from 2023 onwards, is not merely quantitative growth but reflects the field's maturation from theoretical exploration to practical implementation frameworks, driven by e-commerce expansion, supply chain disruptions, and the urgent need for integrated logistics solutions. The momentum observed suggests that 4PL has transitioned from a niche logistics model to a strategic imperative, with scholarly discourse increasingly focused on operationalization of optimization technologies and risk mitigation mechanisms in complex, distributed networks (see Figure 3: Quantity of publications).

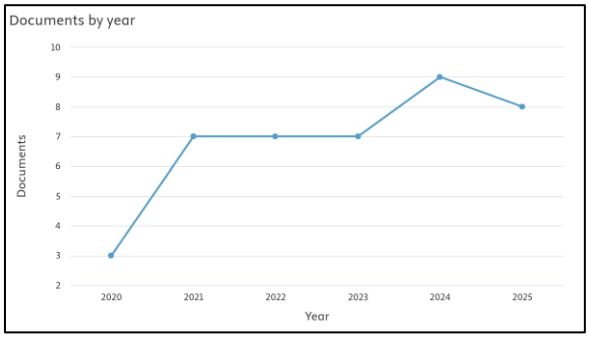

***Figure 3**. Quantity of publications (2020-2025)*

China's dominance in 4PL research reflects its massive e-commerce sector and infrastructure investments, where coordinated logistics networks are critical for competitive advantage. Meanwhile, strong participation from the U.S. and Europe indicates different research priorities, these regions tend to focus on governance and compliance frameworks. The emerging market researchers are increasingly active in this space, suggesting that 4PL is not just a tool for large developed economies but addresses real challenges in less mature logistics systems, particularly around managing multiple outsourced providers and controlling costs (see Figure 4 and Figure 5).

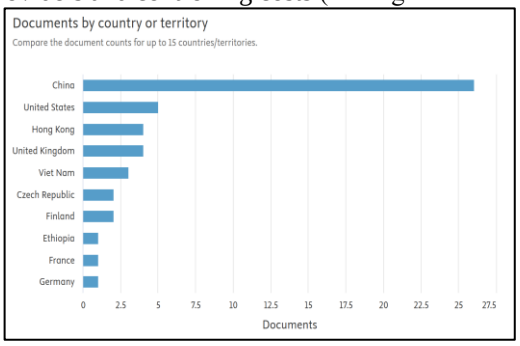

***Figure 4**. Count of articles by nation or region (top 10 countries)*

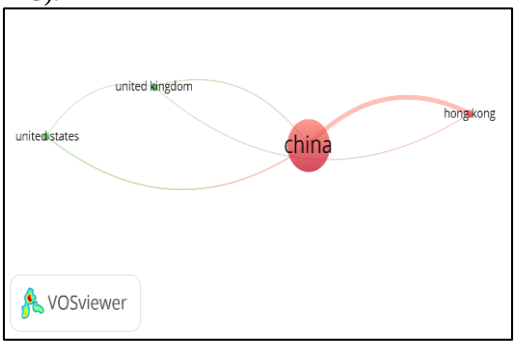

Figure 5. Country collaboration network (VOSviewer)

The clustering of 4PL research in a few key institutions is both a strength and a limitation. On one hand, it shows where expertise is concentrated. On the other hand, it suggests that knowledge doesn't flow easily across different universities and regions, and 4PL thinking may not be well integrated into broader supply chain management discussions. The research seems somewhat isolated within specialized logistics centers rather than embedded in mainstream business school scholarship (see Figure 6).

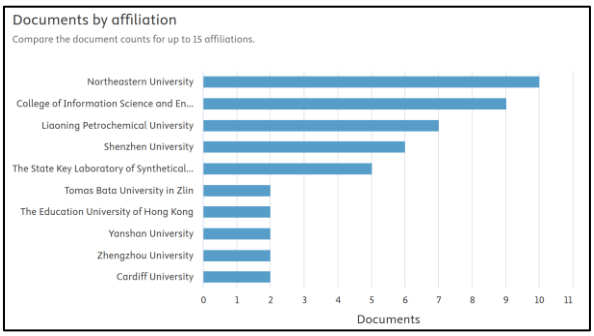

Figure 6. Affiliation network visualization

While papers are spread across different logistics journals, a handful of researchers dominate the field. This concentration means that certain perspectives and approaches become standard in 4PL research, which may limit how the field develops. It also raises the question of whether 4PL insights are reaching broader business and technology communities who might benefit from understanding these models (see Figure 7 and Figure 8)

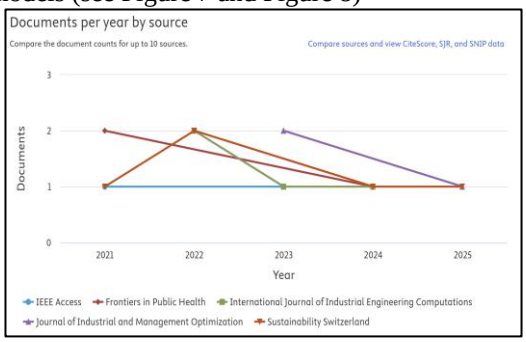

Figure 7. Article counts by source (top 10 sources

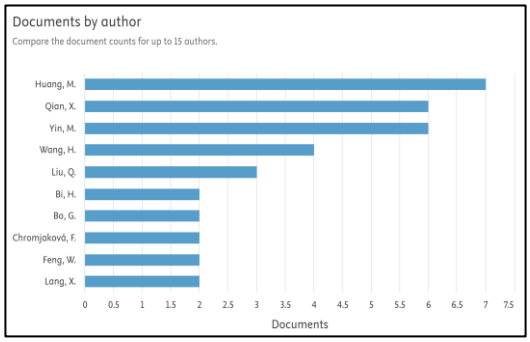

Figure 8. Publications by author (top 10)

The keyword co-occurrence reveals that 4PL scholarship is predominantly framed through an operational optimization lens rather than a strategic or organizational transformation perspective. The dominance of "Fourth-Party Logistics," "Outsourcing," and "Uncertain Demand" as linked concepts reflects the field's concentration on tactical decision making and cost minimization, while conspicuously absent are keywords related to innovation, digital transformation, organizational capability, or value creation. This thematic pattern suggests that 4PL research has not yet elevated the conversation beyond operational problem solving to address strategic questions around competitive differentiation, ecosystem orchestration, or digital business model innovation. Notably, the emergence of "Conditional Value-at-Risk" in the top 10 keywords indicates growing methodological sophistication in risk quantification, yet this remains disconnected from broader discussions of organizational resilience or strategic adaptability revealing a gap between mathematical rigor and strategic relevance in current 4PL scholarship. (see Figure 9 and Table 1 for keyword ties and strengths).

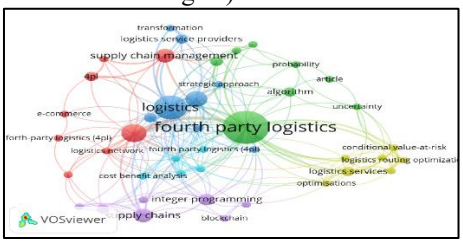

Figure 9. Keyword co-occurrence map (VOSviewer)

Table 2. Author keywords and total link strength (top 10)

Rank	Keyword	Total link strength
1	Fourth-Party Logistics	55
2	Logistics	45
3	Outsourcing	32

4	Supply Chains	21
5	Logistic Service	18
6	Cost Effectiveness	17
7	Supply Chain Management	14
8	Conditional Value at Risk	13
9	Logistics Audit	8
10	Third Parties	6

Implementation Barriers in 4PL Adoption: Regulatory, Human Resource, and Digital Infrastructure Challenges

The implementation of Fourth-Party Logistics (4PL) systems across global supply chains encounters multifaceted barriers that span regulatory compliance, human resource management, and digital infrastructure development. While 4PL adoption promises enhanced supply chain orchestration and operational efficiency through strategic coordination and technological integration, organizations face significant implementation challenges rooted in three interdependent domains: regulatory frameworks that often lag behind technological innovation, human capital constraints arising from skill gaps and organizational change resistance, and digital infrastructure deficiencies that impede seamless integration across networked logistics ecosystems. Critically, these three challenge areas exhibit substantial interdependencies and regulatory compliance requires robust digital infrastructure and trained personnel, human resource development depends on adequate funding and technological platforms, and digital infrastructure advancement necessitates regulatory alignment and skilled workforce capacity. This section examines the key issues, interdependencies, and evidence-based solutions within each domain, as presented in Table 3, to provide organizations with a comprehensive framework for navigating 4PL implementation barriers while mitigating operational and financial risks.

Table 3. Implementation Challenges of 4PL

Challenge Area	Key Issues	Interdependencies & Solutions	Citations
Regulatory	Data security, compliance complexity, environmental mandates, lack of standardized partner selection	Requires digital infrastructure for compliance, HR for training on regulations, and structured partner selection	[38], [39]
Human Resources	Skills gaps, resistance to change, lack of integrated training, stagnant management	Digital upskilling, change management models, funding for capacity building, culture alignment	[25], [27], [40], [41], [42]
Digital Infrastructure	Legacy system interoperability, cybersecurity, lack of integrated platforms, agent-based/cloud integration	Requires regulatory compliance, HR training, and governance frameworks for interoperability	[43], [44]

From 2020 to 2025, the logistics industry is expected to undergo significant transformations driven by the adoption of Fourth Party Logistics (4PL) models and digital technologies. The 4PL approach, which integrates supply chain resources and optimizes delivery processes, is increasingly being recognized for its potential to enhance efficiency and service quality in complex environments [45]. This period will see the logistics sector leveraging innovative digital technologies such as IoT, AI, and blockchain to revolutionize supply chain management, thereby improving transparency, efficiency, and resilience [46], [47]. The integration of these technologies is expected to address existing inadequacies in global supply chains, such as information sharing and supply chain visibility, while also presenting challenges related to cybersecurity and data quality [48]. Additionally, the adoption of 4PL is anticipated to positively impact the agility, adaptability, and alignment capabilities within humanitarian supply chains, although it will face challenges such as funding, data security, and alignment with humanitarian principles [39]. The period will also witness the development of new risk measurement tools and optimization algorithms to manage uncertainties and disruptions in logistics operations, further enhancing the reliability and sustainability of logistics solutions [45]. The advancements in 4PL and digital technologies from 2020 to 2025 are poised to significantly improve operational efficiency and

effectiveness in the logistics industry, providing a competitive edge in a rapidly evolving business environment.

Thematic Findings Aligned To The Research Questions

To address the research questions regarding optimization technologies, strategic mechanisms, and cost reduction strategies in 4PL operations, this analysis examines how fourth-party logistics providers establish collaborative relationships with 3PL operators and leverage modern IT infrastructure, financial innovations, and coordinated mechanisms to enhance supply chain efficiency and customer satisfaction. The effective functioning of a 4PL network fundamentally depends on seamless collaboration among multiple distribution centers, 3PL providers, and clients, requiring synchronized operations through advanced IT systems and mutual cooperation mechanisms. This collaborative ecosystem, when supported by optimization technologies and strategic financial arrangements, enables 4PL providers to facilitate alignment between 3PL operators and customers while delivering cost-effective and timely logistics solutions.

In dynamic global markets, outsourcing logistics to 4PL service providers is gaining traction as an approach to enhance efficiency and customer satisfaction [49]. The effective functioning of a 4PL network relies on collaboration among multiple distribution centers and Third-Party Logistics providers [50]. Third-Party Logistics (3PL) extends beyond basic functions to related services including cross-docking, inventory control, and packaging [51]. 3PL maintains a direct relationship with the client, providing customized solutions and focusing on core activities such as timely deliveries and quality handling [52]. 4PL is increasingly essential in supporting economic and social development [53]. Sustaining 4PL operations depends largely on selecting effective 3PL suppliers [54]. However, 4PL expansion remains constrained by limited demand, neutrality concerns, and the complexity and scope of 4PL solutions [55].

Beyond quality, 3PLs; 4PLs; and clients require modern IT to synchronize supply-chain operations efficiently, and effective cooperation between 4PLs and 3PLs is crucial for service delivery, as 3PLs are the practical operators of 4PL scheme [56]. A 4PL is required to facilitate the alignment between 3PL providers and customers to effectively satisfy client demand for logistics services [57]. Through collaboration with 3PLs, 4PL can provide products on time and at reduced expenses [58]. In comparative terms, the practical 4PL-driven mode maximizes benefits for 3PLs, suppliers, and retailers, whereas the improved mode yields higher profits for 4PLs [59]. Complementing these organizational mechanisms, studies highlight advancements in IoT, AI, blockchain, and smart contracts as critical enablers of Logistics 4.0 [60]. IoT enables the immediate tracking and supervision of products, whereas AI enhances processes via predictive analytics [61], [62].

The system for Supply Chain Finance stabilizes when the 3PL adheres to contracts, the 4PL provides guarantees, and the financier offers funding [38]. Distinct financing modes for 3PLs (bank, platform, and fourth-party logistics) offer different advantages depending on cost, market size, and investment conditions [63]. Regulating 3PLs through carbon quotas is most effective for emission reduction, and 4PL financing can be more advantageous than bank loans for promoting low-carbon investment [64]. Bargaining power and incentives drive 4PL supply chain finance pricing [65]. Coordinated time-slot scheduling can prevent idle resources at 3PLs and improve system profitability for sequential delivery in centralized and decentralized environments [66].

RQ1—What optimization and risk management technologies support 4PL strategic operations during 2020-2025?

Optimization and risk management technologies supporting 4PL strategic operations during 2020-2025 predominantly utilize advanced quantitative models, including Conditional Value-at-Risk (CVaR)-based programming, stochastic optimization algorithms, and enhanced Q-learning techniques, to systematically address transportation uncertainty and tardiness risk. Beyond these mathematical approaches, digital technology implementation and resilience-building frameworks have emerged as critical enablers, allowing 4PL firms to enhance operational efficiency, reduce costs, and maintain competitive advantage amid demand volatility. Complementing these technical innovations, strategic methodologies such as TRIZ provide practical pathways for organizational transformation, enabling 4PL providers to cultivate risk-oriented cultures and ensure long-term sustainability and service reliability in complex supply chain environments.

The nonlinear programming model based on Conditional Value-at-Risk (CVaR) can represent the average value of tardiness risk resulting from time uncertainty in transportation tasks and more effectively address the limitations of the VaR model in assessing tardiness risk [67]. Another study proposes that a CVaR-based mathematical model paired with an enhanced Q-learning algorithm boosts

efficiency and service quality in the logistics sector, giving 4PL firms effective strategies while delivering customers safer and more dependable solutions [45]. In parallel, the two-stage stochastic model and sampling-based algorithm optimize fresh agricultural logistics by balancing timeliness, sustainability, and uncertainty [68]. A stochastic model for multi-period 4PL network design involving temporary outsourcing shows enhancements in performance and decreased costs amidst uncertain demand [69]. Other studies highlight the benefits of stochastic methods such as SAA-DDLR for effective winner determination, incorporating quantity discounts to benefit both 4PL and 3PL providers [70]. Implementing two-stage stochastic mixed-integer programming further enables 4PLs to minimize expenses while sustaining competitive advantage [71]. Another research on logistics digitalization demonstrates that implementing digital technologies and software solutions is essential for transport and logistics companies to enhance operational efficiency, meet European standards, and facilitate the development of advanced outsourcing models such as 4PL and 5PL [72].

Beyond optimization models, research also emphasizes risk and resilience perspectives. A multi-period 4PL network design under viability constraints illustrates how agility, resilience, and sustainability improve demand satisfaction and operational stability during disruptions [73]. Similarly, an integrated risk assessment for a UK-based pharmaceutical 4PL identifies delivery delays as a key vulnerability and recommends resilience strategies through flexibility, redundancy, and cultivating risk-oriented organizational culture [74]. Complementing these quantitative approaches, TRIZ methodology has been applied to develop both short- and long-term strategies for Vietnamese logistics service providers, providing practical pathways to achieve 4PL transformation [75].

RQ2—How do 4PL optimization models and strategic mechanisms (matching, pricing, contract design) improve supply chain outcomes (efficiency, service quality, customer satisfaction)?

Advanced 4PL operators function as strategic economic integrators that enhance supply chain outcomes through coordinated ICT infrastructure, sophisticated matching models, and optimization algorithms including reinforcement learning, stochastic programming, and MINLP with Q-learning approaches that collectively improve efficiency, reduce empty loads, and strengthen SME operational performance across diverse geographic contexts. To increase customer satisfaction, 4PL companies combine resilience strategies with smart pricing and contract designs that reduce information gaps between partners, improve service quality, and boost profitability, while considering disruptions and demand changes. The success of 4PL strategies depends on whether companies choose to invest directly in logistics or partner with third-party providers, with decisions varying based on costs and existing logistics capabilities, allowing them to efficiently serve e-commerce customers in cities while managing complex challenges like funding and data security in humanitarian supply chains.

Advanced 4PL operators serve as economic integrators that enhance SME supply chain performance through coordinated ICT infrastructure, with empirical evidence from Germany, China, Kazakhstan, and Russia demonstrating that higher ICT investments correlate with improved SME turnover and operational efficiency [76]. Buyer seller interactions remain central to logistics [77], with 4PL matching models cut empty loads while improving efficiency and allocation fairness [78]. A hybrid integrating fuzzy full consistency, evidence theory, rule-based transformation, and WASPAS effectively evaluates resilient e-commerce 4PLs, with IT capability highest and cooperation lowest in importance [79]. Reinforcement learning PTB algorithms outperform baselines on logistics service combination under spatio-temporal constraint [80]. Stochastic programming addresses routing under demand/time uncertainty [81], while risk-averse customer behavior reshapes network optimization [82]. In humanitarian supply chains, 4PL enhances agility, adaptability, and alignment, yet faces funding, data-security, and principle-alignment challenges [39].

Satisfaction-focused models link resilience and optimization: MINLP with Q-learning-based memetic PSO boosts satisfaction within budget/service limits [83], and disruption probabilities plus supply fluctuations critically affect performance [68]. Practically, 4PL-based networks optimize last-mile e-commerce in smart cities by shifting key nodes to suburbs [84]. Practical applications demonstrate that 4PL-based distribution networks can optimize last-mile e-commerce logistics in smart cities by shifting key operational nodes from urban centers to suburban areas [85]. Contract mechanisms (e.g., logistics audits) raise service quality, reduce information asymmetry, and increase profitability [86]. Effective channel leadership enhances profitability, balanced pricing, and service quality in post COVID-19 agricultural supply chains [87]. The 4PL's choice of investment or pricing strategy depends on investment and rectification costs, with lower costs favoring direct investment incentives [88]. Platforms invest in self-supporting logistics when third-party service is weak and prefer hybrid channels when their logistics is much stronger [89].

RQ3—What cost reduction and sustainability strategies enable 4PL adoption and operational efficiency in supply chains?

Fourth-Party Logistics adoption is primarily enabled by innovative supplier practices and strategic integration across 3PL and 4PL interfaces as dominant factors, with operational efficiency further enhanced through flexible resource strategies including equipment leasing from sharing markets, advanced warehouse layout optimization via simulation tools, and targeted facility investments that yield substantial cost reductions of up to 38%. Technological integration through stochastic procurement frameworks, sophisticated routing algorithms such as hybrid beetle swarm optimization, and blockchain implementation collectively support sustainable and cost effective logistics operations by minimizing total expenses, managing uncertainty, and improving 4PL reliability while balancing profit generation with service quality improvements. Sustainability strategies in 4PL operations are reinforced through green logistics practices including bulk transport systems that reduce emissions, incentive based delivery scheduling that mitigates tardiness risk, and precision cost management in routing optimization, thereby enabling organizations to achieve environmental objectives while maintaining competitive advantage and operational effectiveness across supply chain networks.

Research on adoption enablers points to innovative supplier practices and integration across 3PL and 4PL interfaces as the most critical drivers of logistics outsourcing in manufacturing firms, while uncertainty and cost reduction have no significant impact [90]. Computational approaches such as the Knowledge-driven Cooperative Coevolutionary Algorithm (KCCA) reduce costs and energy consumption in integrated production and transportation [91]. Flexible approaches, including renting logistics resources from sharing markets, provide significant cost savings compared to advance deployment [92]. Similarly, investments in reefer transport facilities yield up to 38.38% cost reductions, highlighting transportation costs as a key sensitivity factor [93]. Beyond resource flexibility, warehouse layout optimization through advanced simulation tools offers additional cost reduction pathways. Recent research demonstrates that cross-docking layout redesign, when properly simulated using tools such as FlexSim, can yield a 35% increase in delivery performance and substantial reduction in operational costs, underscoring the benefits of cross-docking for cost-effective logistics management [94].

Decision-making and technological integration dominate recent work: stochastic procurement frameworks support sustainable, flexible transport under uncertainty [95], and hybrid fortification that accounts for disruption risk and quantity discounts improves 4PL reliability [96]. The Fourth-Party logistics routing problem (4PLRP) represents a critical challenge in the management of 4PL operations [97]. A model and algorithm for 4PL pickup and delivery routing are proposed, achieving near-optimal solutions in real case studies [98]. An uncertain stochastic programming model for 4PL routing under uncertain times and random supplies effectively minimizes total costs [99]. The hybrid beetle swarm optimization (HBSO) algorithm effectively solves the 4PL routing issue under uncertain time and cost, outperforming GA, PSO, and BAS in efficiency, effectiveness, and reliability [100]. Studies also confirm that 4PL-driven bulk transport promotes green logistics by reducing emissions and costs [101]. A tardiness risk index incentivizes optimal delivery effort and reduces both tardiness risk and its maximum probability [102]. Blockchain can deliver Pareto gains in profit and service quality when implementation costs are bounded [103], and its adoption plus platform choice materially affect efficiency and profitability in remanufacturing supply chains [104].

4PL Adoption: Transition Timing and Priority Technology Investments

To determine when a company should switch from third-party logistics (3PL) to fourth-party logistics (4PL), several factors need to be considered (see Table 4).

Table 4. Comparative Analysis of 3PL and 4PL Logistics Models

Factor	3PL	4PL	Citation
Integration Needs	Basic coordination	Advanced integration and ICT solutions	[56]
Strategic Focus	Execution of logistics tasks	Comprehensive management and coordination	[52]
Service Quality	Potential for customer complaints	Improved service quality and customer satisfaction	[105]
Environmental Compliance	Basic compliance	Enhanced audits and compliance strategies	[88]
Economic Conditions	Cost-saving focus	Strategic investments and better resource utilization	[88]

Market Dynamics	Limited agility	High agility, resilience, and sustainability	[73]

While Table 4 establishes the foundational differentiation between 3PL and 4PL capabilities across six critical operational dimensions, the successful execution of 4PL adoption requires a more granular understanding of the managerial decision factors that shape implementation pathways during the 2020-2025 period. As illustrated in Table 5, the transition from 3PL to 4PL is informed by six interconnected factor categories: strategic and operational imperatives, technological investments, financial mechanisms, relational governance, organizational barriers, and structured decision-making frameworks. Organizations seeking to maximize the benefits of 4PL transformation must simultaneously address these multifaceted dimensions, recognizing that success in one category (such as technological adoption) is fundamentally dependent upon progress in complementary areas (such as relational trust and financial capability), thereby requiring an integrated, systems-based implementation approach.

Table 5. Managerial Decision Factors in the Transition from Third-Party Logistics (3PL) to Fourth-Party Logistics (4PL), 2020–2025

Factor Category	Key Managerial Decision Factors	Citation
Strategic & Operational	Cost reduction, innovation, lean/agile practices, comprehensive logistics management, crisis adaptation	[32], [42], [90], [106],
Technological	Adoption of IoT, AI, blockchain, cloud services, digital transformation, continuous upgrading	[25], [30], [46], [48], [107], [108]
Financial	4PL financing (4PF), credit guarantees, alternative financing, supply chain finance innovation	[38], [63]
Relational	Trust, collaborative relationships, information sharing, customer relationship management	[105], [109], [110], [111]
Barriers	Managerial resistance, lack of knowledge, stagnant management, complexity, neutrality issues	[42], [112]
Decision Frameworks	Multi-criteria decision-making (MCDM), fuzzy AHP, FMARCOS, BWM, DEMATEL, MOORA, sustainability integration	[25], [30], [32], [52]

A company should consider switching from 3PL to 4PL when it requires higher integration and coordination capabilities, wants to focus on core activities, needs to improve service quality, faces stringent environmental compliance requirements, and operates in dynamic market conditions. The transition from 3PL to 4PL logistics between 2020 and 2025 is shaped by a complex interplay of strategic, operational, technological, financial, and relational factors. Managers are increasingly adopting integrated frameworks that balance cost reduction with innovation, leveraging advanced technologies and financial instruments to enhance operational performance and resilience. Overcoming managerial resistance and knowledge gaps especially in emerging economies is critical, as is the adoption of robust, multi-criteria decision-making frameworks that incorporate sustainability and digitalization. The transition can lead to better logistics performance, customer satisfaction, and overall supply chain efficiency.

Priority Technology Investments for 4PL Providers

From 2020 to 2025, 4PL providers have prioritized investments in IoT, AI, blockchain, big data analytics, and cloud/edge computing, with growing emphasis on 5G, digital twins, autonomous systems, and collaborative robotics. These technologies collectively drive supply chain visibility, predictive maintenance, real-time decision-making, and operational efficiency, while supporting the transition to human-centric and sustainable logistics (Logistics 5.0) [25] [46]. Table 6 summarizes the priority technology areas for 4PL providers during 2020-2025.

Table 6. Priority Technology Investments for 4PL Providers

Technology Area	Priority level	Main Applications	Measurable Impacts (2020–2025)
IoT	High	Real-time tracking, predictive maintenance, supply chain reconfiguration	Improved visibility, reduced downtime, enhanced responsiveness
Artificial Intelligence (AI)	High	Demand forecasting, personalization, adaptive decision-making	Improved forecast accuracy, cost

			reduction, service level gains
Blockchain	High	Transparency, security, smart contracts, supply chain finance	Up to 30% efficiency gains, cost reduction, improved trust
Big Data Analytics	High	Predictive analytics, operational optimization	Enhanced decision-making, process optimization
Cloud/Edge Computing	High	Real-time data processing, multi-client operations	Improved agility, scalability, cost savings
Sustainability/Green Tech	High	Green warehousing, transport, packaging	Resource optimization, emissions reduction
Collaborative Robotics (Cobots)	Emerging	Human-machine collaboration, safety	Enhanced ergonomics, operational safety
5G	Emerging	End-to-end connectivity, automation	Enhanced real-time operations, flexibility

Conclusion

This systematic literature review examined 38 articles (2020-2025) to address three research questions regarding Fourth-Party Logistics optimization technologies, strategic mechanisms, and cost reduction strategies. The findings reveal that 4PL has transitioned from a niche logistics model to a strategic imperative in global supply chain management, driven by post-pandemic challenges and digital transformation imperatives. Advanced optimization technologies including Conditional Value-at-Risk (CVaR), stochastic programming, and reinforcement learning algorithms effectively manage transportation uncertainty and support 4PL operational efficiency. Strategic mechanisms such as coordinated ICT infrastructure, sophisticated matching models, and innovative financing arrangements significantly improve supply chain outcomes, service quality, and customer satisfaction. Cost reduction and sustainability strategies including flexible resource management, warehouse layout optimization, and blockchain implementation enable organizations to achieve cost reductions of up to 38% while maintaining environmental compliance and service reliability.

Implementation barriers spanning regulatory compliance, human resource management, and digital infrastructure remain critical challenges that organizations must address during transition from 3PL to 4PL adoption. Organizations must adopt integrated, systems-based implementation approaches that balance technological investment with organizational capability development and stakeholder relationship management. This research concludes that 4PL adoption represents a fundamental strategic shift in supply chain orchestration, and success requires simultaneous attention to technological innovation, financial mechanisms, governance frameworks, and organizational culture development.

Future scholarship on Fourth-Party Logistics must expand through empirically grounded investigations addressing critical contextual and regional gaps in existing literature. First, context specific empirical research examining 4PL implementation dynamics within Indonesia and the broader ASEAN region is essential, given the distinct regulatory environments, infrastructure constraints, and supply chain characteristics that differentiate Southeast Asian markets from established 4PL ecosystems in developed economies. Such regional studies would provide practitioners and policymakers with actionable insights tailored to local conditions while contributing to theoretical understanding of how institutional and geographic contexts shape 4PL adoption trajectories and success factors. Second, future research must investigate the integration of Environmental, Social, and Governance (ESG) metrics into 4PL contracting frameworks and performance evaluation systems. As sustainability increasingly influences supply chain decision-making, understanding how ESG dimensions can be operationalized within 4PL agreements including measurement methodologies, incentive alignment, and trade-off management between traditional cost-efficiency metrics and sustainability outcomes represents a critical research frontier with significant practical implications for responsible supply chain governance. Third, emerging research should examine the transformative potential of Artificial Intelligence (AI), particularly generative AI models, and digital twin technologies in enhancing 4PL decision making processes. Investigations into how AI powered predictive analytics and generative systems can optimize supply chain orchestration, improve scenario planning, and enhance real-time responsiveness, combined with digital twin simulations that enable risk mitigation and process innovation, would advance both

theoretical understanding of technology enabled logistics orchestration and practical implementation guidance for 4PL providers navigating increasingly complex and dynamic supply chain environments. Collectively, these three research directions regional contextualization, ESG integration, and emerging technology applications represent complementary pathways toward advancing 4PL scholarship and practice during the 2020-2025 period and beyond.

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