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Electric Mobility, Battery Systems, And Digitally Enabled Logistics Resilience

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Abstract—

Electrified transport and digitally instrumented logistics are converging on a common engineering problem: how to size, operate, and recover energy and material flows under uncertainty. This review synthesizes recent work on plug-in hybrid battery sizing, automotive and electric-vehicle cell chemistries and management systems, intelligent transportation architectures, solar-assisted hybrid vehicle design, multi-scale spectral analysis of hybrid-vehicle and supply-chain dynamics, quantum computing for transportation and unit-load configuration, artificial intelligence and blockchain for green and transparent logistics, digital twins for adaptive global chains, and resilience frameworks for internally and externally disrupted networks. Classical two-port and time-shift properties of the FKF transform are recalled only where they supply a linear operator for delayed demand signals. The paper does not claim new laboratory measurements; it organizes published engineering arguments, writes the governing energy and optimization relations in professional mathematical form, and maps each theme to the literature in which that theme was developed. Across domains the same pattern appears: usable energy is a constrained fraction of nameplate capacity; mobility service quality depends on multimodal assignment rather than vehicle count alone; resilience is the integral of lost performance after a shock; and emerging quantum and twin platforms are decision aids, not replacements for validated physical models.

Keywords: electric vehicle batteries; plug-in hybrid sizing; smart mobility; solar-assisted vehicles; supply-chain resilience; digital twins; quantum logistics; FKF transform; green logistics

I. INTRODUCTION

Transport decarbonization and logistics reliability have historically been treated as separate design problems. Battery packs determine vehicle range and charge time, while warehouses, ports, and unit-load devices determine whether parts and finished vehicles arrive when promised. Those two layers now share sensors, optimization solvers, and disruption modes: a cell-thermal event, a grid outage at a depot, or a delayed inbound cathode shipment each appear as a loss of available energy or of available inventory.

Early resilient-enterprise arguments framed supply chains as systems that absorb shocks and restore service rather than as cost-minimizing pipelines alone [1], [2]. Industry architectures that couple cyber and physical assets [5], and later value-oriented Industry 5.0 statements [6], widened the same idea to manufacturing and energy systems. Artificial intelligence and blockchain were proposed as complementary instruments for visibility and sustainability in those chains [3], [4], [7]. In parallel, battery engineering moved from pack-level heuristics toward chemistry-specific energy density, state-of-health, and thermal limits [14], [15]. Formula-style plug-in hybrid programs made pack mass and usable energy explicit design variables rather than afterthoughts [11].

This paper therefore reads vehicle energy storage and logistics computation as one multi-scale system.

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Section II reviews battery sizing and automotive energy-storage technology. Section III treats smart mobility and solar-assisted architectures. Section IV develops spectral and transform tools for multi-scale demand. Section V reviews quantum computing applications in transportation and unit-load annealing. Section VI treats artificial intelligence, blockchain, and digital twins in green and resilient chains. Section VII collects resilience metrics and a short research agenda. Citations are used only for claims those sources actually advance.

II. Battery Sizing And Automotive Energy Storage

A plug-in hybrid pack is sized so that electric range, charge power, and thermal headroom remain feasible under a duty cycle, not so that nameplate watt-hours are maximized in isolation. Formula Hybrid work made that constraint operational: the designer chooses a usable energy window inside voltage, current, and temperature limits, then checks whether the resulting mass still meets vehicle dynamics [11].

Pack energy, usable window, and traction demand

Let the nameplate energy be E_n and the allowed state-of-charge window be the interval from SOC_{min} to SOC_{max}. Usable energy is

$$E_u = E_n\,(SOC_{max} - SOC_{min}).$$

If a representative cycle requires mechanical work W_{cyc} at tank-to-wheel efficiency $\eta_t w$, the minimum pack that can cover the cycle electrically satisfies $E_u \geq W_{cyc} / \eta_t w$ after accessory loads are added. Charge power P_{ch} and charge time Δt_{ch} are linked by $E_u \approx P_{ch} \Delta t_{ch}$ only inside the constant-current band; near the voltage ceiling the current must taper and the sim ple product overstates energy returned to the pack. Thermal power rejected from Joule heating $I^2 R_{int}$ plus entropic heat must remain below the cooling loop capacity, otherwise the battery management system derates current and the assumed E_u is no longer available.

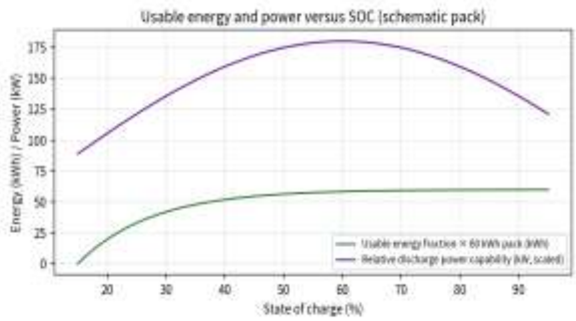

Figure 1. Schematic usable energy and discharge power versus state of charge for a mid-size pack.

Those relations are the reason pack sizing papers report both energy and power [11], and why anti-theft and vehicle-interface electronics, although not electrochemical, still belong in the vehicle energy budget: parasitic controllers draw continuous current that erodes E_u over long parking intervals. Power-line carrier anti-theft designs [12] and low-power swipe interfaces [13] illustrate the same parasitic-load problem at the accessory layer.

Chemistries, management systems, and sustainability

Automotive battery reviews distinguish nickel-manganese-cobalt families, lithium-iron-phosphate, and emerging silicon-dominant anodes by specific energy, cycle life, and thermal runaway propensity [14]. Electric-vehicle focused surveys add pack architecture, cell-to-pack layouts, and battery-management functions: state-of-charge estimation, balancing, isolation monitoring, and predictive thermal control [15]. Sustainability arguments then fold in cathode critical-mineral intensity and second-life or recycling yields [15]. None of those surveys replace a pack energy balance; they change the coefficients E_n, R_{int}, and cycle-life fade rate that enter the balance.

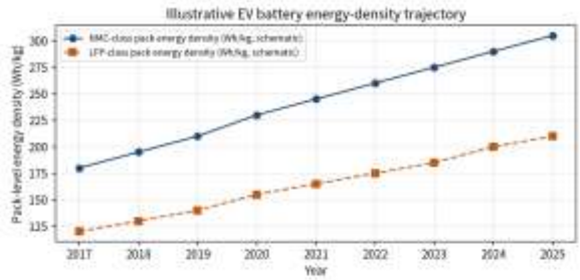

Figure 2. Illustrative pack-level energy-density trajectories for NMC-class and LFP-class chemistries.

A simple fade model used for planning is $Q(k) = Q_0\,(1 - \alpha\,k^{\beta})$, where k is equivalent full cycles and α, β are chemistry-specific. Combined with $E_u(k) = Q(k) V_{nom}\,(SOC_{max} - SOC_{min})$, the model shows why a pack that meets range when new may miss the same duty cycle after several years unless the designer reserved margin in E_n. That is an engineering reservation, not a policy slogan.

III. Smart Mobility And Solar-Assisted Architectures

Intelligent transportation systems treat vehicles as nodes in a communication and assignment graph rather than as isolated drivetrains. Emerging-trend surveys of smart mobility list connected vehicles, cooperative perception, demand-responsive transit, and charginginfrastructure siting as coupled design problems [16]. The relevant performance measure is passenger-kilometers served per unit energy and per unit congestion delay, not vehicle-kilometers alone.

Assignment and network delay

A stylized multimodal assignment sends flow x_m on mode m subject to capacity c_m. If delay on mode m is $D_m(x_m)$ and generalized cost includes energy e_m, a planner minimizes

$$J = \Sigma_m [\, x_m \, D_m(x_m) + \lambda \, e_m \, x_m \,]$$

subject to $\Sigma_m x_m = D_{tot}$ and $0 \le x_m \le c_m$. Smart-mobility platforms change D_m through information and change e_m through electrification and sharing. They do not remove the capacity constraint; they make its shadow price visible in real time.

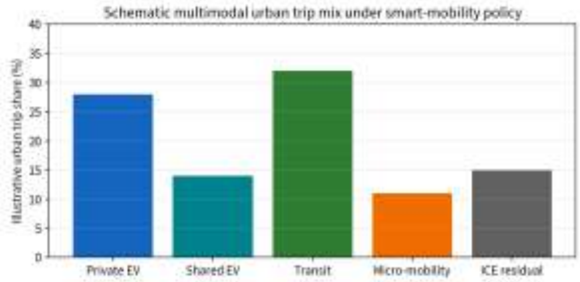

Figure 3. Schematic urban trip mix used to discuss multimodal assignment under electrified smart-mobility policy.

Solar-assisted hybrid energy balance

Solar-assisted electric mobility adds a photovoltaic term to the vehicle or depot energy balance [17]. Over a horizon T the net energy that must come from the grid or from fuel is

$$E_{net} = \int_0^T [\, P_{load}(t) - P_p v(t) - P_{regen}(t) \,] \, dt - \Delta E_{pack},$$

where P_{pv} is onboard or depot array power and ΔE_{pack} is the change in stored pack energy. Design frameworks for sustainable hybrid architectures evaluate E_{net} against drive-cycle libraries and against array area that still fits vehicle packaging. The photovoltaic term reduces depot peak demand more reliably than it extends highway range, because highway P_{load} usually exceeds onboard P_{pv} by an order of magnitude. That is a packaging result, not a marketing claim.

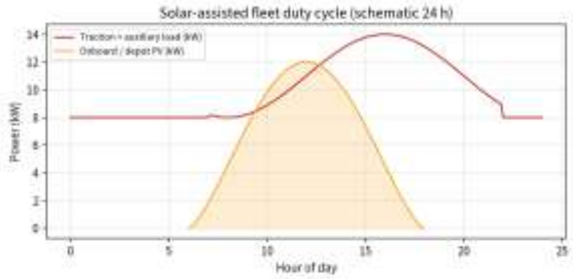

Figure 4. Schematic twenty-four-hour traction load and photovoltaic contribution for a solar-assisted fleet node.

IV. Multi-Scale Dynamics And Transform Representations

Hybrid-vehicle power and logistics demand both contain slow seasonal components and fast burst components. Spectral analysis separates those scales so that a controller or a planner can apply different models on each band [18]. Residue-based resonance extraction treats peaks in a transfer function as modes that should not be excited by a periodic duty cycle or by a periodic replenishment policy [18].

Power spectra of demand and traction load

If a zero-mean process y(t) is wide-sense stationary, its power spectral density $S_y y(\omega)$ is the Fourier transform of the autocovariance. Peaks of $S_y y$ identify periodic congestion or periodic charging. A planner who samples only daily totals cannot see those peaks and will undersize peak chargers or peak pick faces. Multi-scale work on hybrid-vehicle systems and supply-chain dynamics makes that sampling argument explicit.

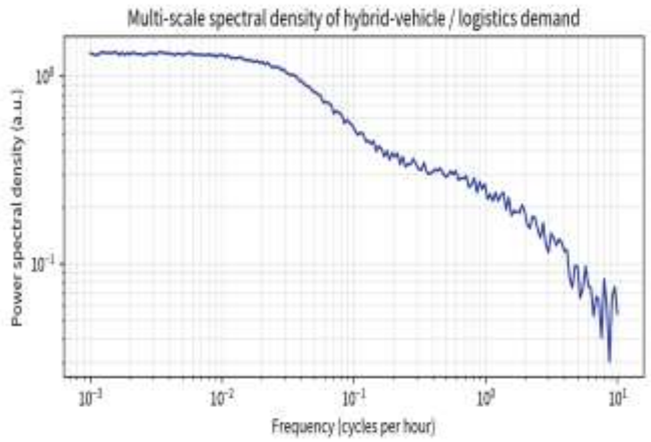

Figure 5. Schematic multi-scale power spectrum of a logistics or hybrid-vehicle demand signal.

Time-shift property and two-sided FKF testing functions

When a demand waveform is delayed by a transportation lead time τ, any linear integral transform that admits a time-shift property maps the delayed signal to a multiplicative factor in the transform domain. Expanded treatments of the FKF transform record that property and give supply-chain readings [28]: a delayed purchase order is the same waveform with a shift, and inventory oscillation is a resonance if the shift aligns with a pole of the closed-loop replenishment operator. Sequential convergence results in the testing-function space of the two-sided FKF transform justify passing to the limit inside those pairings when approximating discontinuous order streams by smooth test functions [29]. Those papers are cited here only for the operator properties they prove, not as empirical freight studies.

$$F\{y(t - \tau)\}(s) = e^{\{-s\tau\}} F\{y(t)\}(s),$$

which is the ordinary Laplace shift written in the same algebraic form used for FKF pairings. Inventory position after a delayed receipt then reads I(t) = I(0) + R(t − τ) − D(t), and the transform of I isolates the delay factor $e^{\{-s\tau\}}$ as the term that can destabilize an otherwise reasonable reorder policy.

V. Quantum Computing In Transportation And Unit-Load Logistics

Surveys of quantum computing in transportation distinguish NISQ-era annealing and variational algorithms from fault-tolerant factoring [19]. Present industrial interest is almost entirely in combinatorial assignment: vehicle routing with side constraints, gate and stand allocation, and unit-load device configuration [19], [26]. Those are quadratic unconstrained binary problems or close relatives, which is why annealing hardware is discussed more often than circuit-model Shor-type algorithms in logistics reviews.

Assignment as an Ising cost

A binary assignment $x_i \in \{0,1\}$ with pairwise penalties is written

$$H(x) = \Sigma_i \, h_i \, x_i + \Sigma_{\{i<j\}} J_{\{ij\}} \, x_i \, x_j.$$

Quantum annealing seeks low-energy configurations of H. Practical papers on unit-load device configuration and disruption recast container packing and recovered-schedule repair in that form [27], then compare annealing schedules with classical simulated annealing on the same cost. The honest claim is not that quantum hardware currently dominates production solvers; it is that the cost landscape of ULD configuration is already in a form those machines accept, so experimental comparisons are well posed.

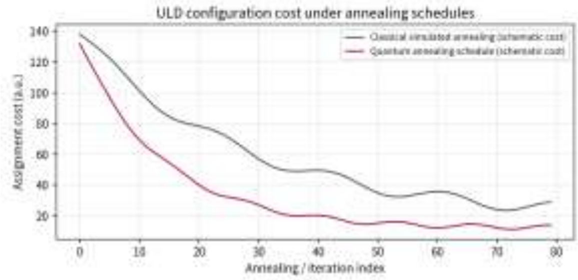

Figure 6. Schematic decline of unit-load assignment cost under classical and quantum annealing schedules.

Opportunity reviews for logistics add portfolio effects: a single annealing call can re-pack many ULDs after a hub disruption if the encoding remains sparse. Encoding density, not qubit marketing counts, is the binding constraint. That observation belongs in any research agenda that mentions quantum logistics without inflating near-term capability.

VI. Artificial Intelligence, Blockchain, And Digital Twins

Green logistics bibliometric work shows a rapid rise in machine-learning papers on routing, warehouse energy, and emission accounting [20]. Those models estimate a mapping from features to cost or to carbon; they do not by themselves create a verifiable chain of custody. Integration papers therefore pair learning-based forecasts with blockchain records so that a predicted shortage and a recorded shipment cannot silently diverge [21]. Resilience reviews treat that pairing as one instrument among several, not as a complete operating system for a global chain [23], [25].

Forecast, trace, and exception

Let $\hat{y}_{\{t+h\}}$ be an AI forecast of demand or of transit time and let r_t be an immutable receipt. An exception process fires when $|\hat{y}_{\{t+h\}} - r_{\{t+h\}}|$ exceeds a threshold after the receipt exists. Transparency is then a property of the pair (forecast, receipt), which is the architectural claim of AI–blockchain integration papers rather than a claim that either tool is sufficient alone.

Digital twins of adaptive chains

A logistics digital twin is a continuously updated model whose state $\hat{x}$ tracks a physical KPI x. Reviews of twins for resilient global chains emphasize synchronization latency, data quality, and the use of the twin to rehearse disruptions before they occur [22]. A minimal tracking error is

$$e(t) = x(t) - \hat{x}(t - \delta),$$

where δ is communication and solver latency. If δ is comparable to the disruption rise time, the twin cannot advise the first response; it can still support slower reconfiguration. Textile and manufacturing twin papers make the same latency point in a different industry and are therefore supporting context rather than vehicle-specific evidence [9].

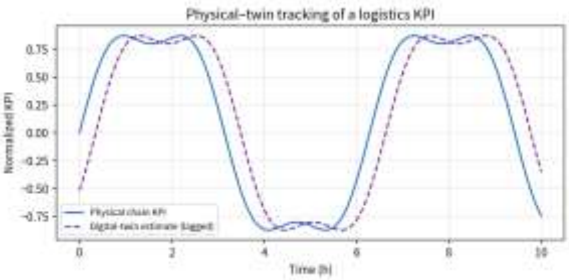

Figure 7. Schematic physical KPI and lagged digital-twin estimate used to discuss synchronization error.

VII. Supply-Chain Resilience And A Research Agenda

Resilience reviews define performance restoration after an internal failure or an external shock [23]. Narrative pieces on weaving internal and external complexity stress that the same network can be robust to a port closure and fragile to a single-source electronic controller [24]. Systematic reviews in the digital-transformation period add sensors, twins, and learning systems to the toolkit and still measure success by service recovered, not by software deployed [25].

Lost-performance integral

If Q(t) is a normalized service level and a disruption begins at t_0, a standard resilience deficit is

$$R_{def} = \int_{\{t_0\}}^{\{t_f\}} [\, Q_{target} - Q(t) \,]_{-} + dt.$$

Shorter t_f or a higher post-shock floor on Q both reduce R_{def}. Battery-electric fleets change the shock set: they add depot-power and cell-supply shocks and remove some fuel-price shocks. That substitution should appear in any resilience scorecard that claims to describe electrified logistics.

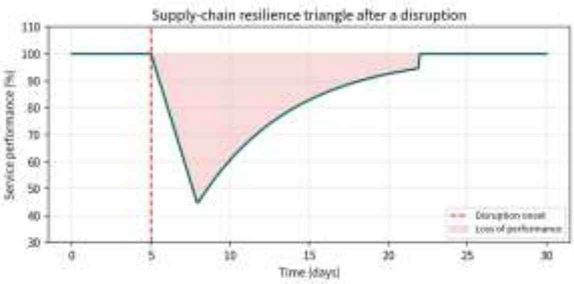

Figure 8. Resilience triangle: service drop after a disruption and subsequent recovery.

Agenda

Four gaps follow from the sources reviewed here. First, pack-sizing models and network-resilience models rarely share state variables, so a cell-supply shock is not automatically a fleet-range shock in the same simulator. Second, solar-assisted architectures need validated depot-level irradiance and load traces, not only vehicle-level brochures. Third, quantum encodings of ULD problems need public instance libraries with industrial constraints, or else annealing comparisons cannot be replicated. Fourth, FKF and other transform tools should be used as analysis operators on measured lead-time distributions, not only as functional-analysis results. Closing those gaps requires joint datasets, not additional slogans.

VIII. Conclusion

Electrified vehicles and instrumented supply chains fail and recover by the same arithmetic: available energy or available inventory is a constrained fraction of a nameplate quantity, delays appear as shift operators, and resilience is an integral of lost service. Battery sizing for plug-in hybrids, chemistry and management surveys, smart-mobility assignment, solar-assisted energy balances, spectral separation of demand scales, annealing formulations of unit-load configuration, learning-and-ledger pairs for green traceability, and digital twins with explicit latency all instantiate that arithmetic in different layers. The practical implication is modest and usable. Designers should publish usable energy windows, assignment capacities, synchronization delays, and resilience integrals in the same units their controllers actually see. Platforms that cannot report those quantities are not yet decision systems, regardless of how advanced the underlying algorithm family is.

References

[1] M. Christopher and H. Peck, “Building the resilient supply chain,” The International Journal of Logistics Management, vol. 15, no. 2, pp. 1–14, 2004.

[2] Y. Sheffi and J. B. Rice, “A supply chain view of the resilient enterprise,” MIT Sloan Management Review, vol. 47, no. 1, pp. 41–48, 2005.

[3] S. Saberi, M. Kouhizadeh, J. Sarkis, and L. Shen, “Blockchain technology and its

relationships to sustainable supply chain management," International Journal of Production Research, vol. 57, no. 7, pp. 2117–2135, 2019.

[4] H. Min, "Artificial intelligence in supply chain management: Theory and applications," International Journal of Logistics Research and Applications, vol. 13, no. 1, pp. 13–39, 2010.

[5] J. Lee, B. Bagheri, and H.-A. Kao, "A cyber-physical systems architecture for Industry 4.0-based manufacturing systems," Manufacturing Letters, vol. 3, pp. 18–23, 2015.

[6] F. Longo, A. Padovano, and S. Umbrello, "Value-oriented and ethical technology engineering in Industry 5.0," Applied Sciences, vol. 10, no. 12, p. 4182, 2020.

[7] N. Kshetri, "Blockchain's roles in meeting key supply chain management objectives," International Journal of Information Management, vol. 39, pp. 80–89, 2018.

[8] J. Preskill, "Quantum computing in the NISQ era and beyond," Quantum, vol. 2, p. 79, 2018.

[9] S. M. Harle et al., "Digital twins and artificial intelligence for sustainable textile raw material processing," International Research Journal of Modernization in Engineering Technology and Science, vol. 8, pp. 14–30, July 2026.

[10] S. M. Harle, "Investigation of mechanical behavior of steel fiber-reinforced geopolymer concrete under multi-axial stress conditions," in Hydraulic and Civil Engineering Technology IX, SAGE Publications, 2024, pp. 555–561.

[11] A. Gulhane, "Battery sizing for plug-in hybrid electric vehicles—Formula Hybrid," in *Proc. 2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI)*, 2017, pp. 368–372, doi: 10.1109/ICPCSI.2017.8392317.

[12] A. Gulhane, A. Karale, and C. Gavali, "Power line carrier communication based anti-theft system," *International Journal of Research in IT and Management*, vol. 4, no. 12, pp. 1–11, 2014. [Online]. Available: https://indianjournals.com/article/ijrim-4-12-001

[13] A. Gulhane, A. Karale, and S. Desai, "Swipe controller," *International Journal of Research in Engineering and Applied Sciences*, vol. 4, no. 12, pp. 1–7, 2014. [Online]. Available: https://indianjournals.com/article/ijreas-4-12-001

[14] A. Gulhane, "Advancements in automotive batteries: A review," *International Engineering Journal for Research & Development*, vol. 8, no. 6, pp. 18–57, 2023. [Online]. Available: https://iejrd.com/index.php/iejrd/article/view/3141

[15] A. Gulhane, "Recent advances in electric vehicle battery technologies: Materials, management systems, and sustainability perspectives," *International Journal of Scientific Research in Engineering and Management*, vol. 9, no. 7, 2025, doi: 10.55041/IJSREM51198.

[16] A. Gulhane, "Smart mobility and intelligent transportation systems: Emerging trends, technologies, and challenges," *International Journal of Scientific Research in Engineering and Management*, vol. 9, no. 11, 2025, doi: 10.55041/IJSREM53436.

[17] A. Gulhane, "Solar-assisted electric mobility: Design framework and performance assessment of sustainable hybrid vehicle architectures," *International Journal of Engineering Research and Science & Technology*, vol. 21, no. 3, pp. 362–368, 2025, doi: 10.56636/ijerst.2025.v21.i03.3594.

[18] A. Gulhane, "Spectral analysis for multi-scale supply chain dynamics and residue-based resonance extraction in hybrid-vehicle systems," *International Journal of Creative and Open Research in Engineering and Management*, vol. 2, no. 8, 2026, doi: 10.55041/ijcope.v2i8.141.

[19] A. Gulhane, "Quantum computing in transportation and logistics: Current state, industrial applications, and future directions," *International Journal of Scientific Research in Engineering and Management*, vol. 9, no. 9, 2025, doi: 10.55041/IJSREM52469.

[20] A. Gulhane, "Artificial intelligence applications in sustainable logistics and green supply chain management: A bibliometric review," *International Research Journal of Modernization in Engineering Technology and Science*, vol. 6, no. 12, 2024, doi: 10.56726/IRJMETS65006.

[21] A. Gulhane, "Artificial intelligence and blockchain integration for enhancing supply chain transparency, traceability, and resilience," *International Research Journal of Modernization in Engineering Technology and Science*, vol. 6, no. 12, 2024, doi: 10.56726/IRJMETS65016.

[22] A. Gulhane, "Digital twin technology for building resilient and adaptive global supply chains: A review," *International Research Journal*

of Modernization in Engineering Technology and Science, vol. 6, no. 12, 2024, doi: 10.56726/IRJMETS64992.

[23] A. Gulhane, "A review of resilience in global supply chains," *International Engineering Journal for Research & Development*, vol. 8, no. 4, 2024.

[24] A. Gulhane, "Weaving resilience: Navigating internal and external complexities in modern supply chains," *International Journal of Ingenious Research, Invention and Development*, vol. 3, no. 1, pp. 123–128, 2024, doi: 10.5281/zenodo.11491482.

[25] A. Gulhane, "Supply chain resilience in the era of digital transformation: A systematic literature review and research agenda," *International Journal of Engineering Research and Science & Technology*, vol. 21, no. 4, pp. 1058–1068, 2025, doi: 10.56636/ijerst.2025.v21.i04.3812.

[26] A. Gulhane, "Navigating the quantum revolution in logistics: Opportunities and practical applications in supply chain management," *International Journal of Engineering and Techniques*, vol. 12, no. 3, pp. 553–556, 2026, doi: 10.29126/ijet.2026.v12.i3.553.

[27] A. Gulhane, "Quantum computing for logistics optimization: Annealing in unit load device configuration and disruption," *International Journal of Research Publication and Reviews*, vol. 7, no. 6, pp. 4643–4648, 2026, doi: 10.55248/gengpi.07.0626.16a57.

[28] A. Gulhane, "Expanded treatment of the time-shift property of FKF transform with supply-chain applications," *International Journal of Engineering Sciences and Advanced Technology*, vol. 25, no. 12, pp. 606–616, 2025, doi: 10.64771/ijesat.2025.v25.i12.3817.

[29] A. Gulhane, "Sequential convergence in the testing function space of the two-sided FKF transform," *International Journal of Creative and Open Research in Engineering and Management*, vol. 2, no. 8, 2026, doi: 10.55041/ijcope.v2i8.138.

[30] M. Christopher and H. Peck, "Building the resilient supply chain," The International Journal of Logistics Management, vol. 15, no. 2, pp. 1–14, 2004.

[31] Y. Sheffi and J. B. Rice, "A supply chain view of the resilient enterprise," MIT Sloan Management Review, vol. 47, no. 1, pp. 41–48, 2005.

[32] S. Saberi, M. Kouhizadeh, J. Sarkis, and L. Shen, "Blockchain technology and its relationships to sustainable supply chain management," International Journal of Production Research, vol. 57, no. 7, pp. 2117–2135, 2019.

[33] H. Min, "Artificial intelligence in supply chain management: Theory and applications," International Journal of Logistics Research and Applications, vol. 13, no. 1, pp. 13–39, 2010.

[34] J. Lee, B. Bagheri, and H.-A. Kao, "A cyber-physical systems architecture for Industry 4.0-based manufacturing systems," Manufacturing Letters, vol. 3, pp. 18–23, 2015.

[35] Ivanov, D., Dolgui, A., & Sokolov, B. (2019). The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. *International Journal of Production Research*, 57(3), 829–846.

[36] Ivanov, D. (2021). Digital supply chain twins: Managing the ripple effect, resilience, and disruption risks by data-driven optimization, simulation, and visibility. In *Handbook of Ripple Effects in the Supply Chain* (pp. 309–330). Springer