International Journal of Creative and Open Research in Engineering and Management
ISSN: **3108-1754 (Online)**
Volume 02 Issue 07 July-2026 | Impact Factor: 3.5

Time-Delay Fractional Equations in EV Battery Management

Shinde SM[1]
[1] Dept of Mathematics/ GCOE Latur/ INDIA
[1]shindesanjaykumar3572@gmail.com

How to Cite this Article:

SM, S. (2026). Time-Delay Fractional Equations in EV Battery Management. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(7). https://doi.org/10.55041/ijcope.v2i7.007

https://doi.org/ 10.55041/ijcope.v2i7.007

Abstract—
We construct a family of creatively equipped convex topological spaces, that provide a rigorous functional analytic framework for distributional Laplace–Stieltjes transforms. These countably multinormed, complete, Hausdorff locally convex spaces and their duals of Roumieu and Beurling type ultradistributions are designed so that shift operators corresponding to time delays act continuously, while the dual spaces accommodate generalized functions that model sudden disruptions and stochastic lead time distributions. The construction is extended to product spaces, negative time domains, and additional parameters, yielding a flexible setting for Cauchy problems with distributional data. The framework is applied to eight central problems in modern supply chain engineering: inventory systems with stochastic lead time delays, quantitative analysis of the bullwhip effect in multi-echelon networks, propagation and recovery from singular disruptions, EV battery state-of-charge and state-of-health dynamics under delay and fractional order effects, hybrid quantum classical logistics optimization, real-time digital-twin orchestration, multi echelon network propagation on graphs, and closed-loop flows in circular economy reverse logistics. In each case we derive explicit operational calculus formulae and obtain stability or recovery certificates directly from the defining seminorm family. The resulting theory supplies well posedness, quantitative bounds, and stable interfaces between classical simulators and quantum solvers, thereby offering a mathematically grounded foundation for resilient, sustainable, and real-time decision-support systems in global supply chains.

Keywords— distributional LS transforms; delay differential equations; supply chain resilience; bullwhip effect; stochastic lead times; quantum annealing; hybrid quantum-classical optimization; digital twins; circular economy; EV battery dynamics.

I. INTRODUCTION

The theory of distributions and systematically developed [34], [37] has become indispensable for modeling singular phenomena in physics, engineering, and applied mathematics. In the context of quantum electronics, signal processing, and control theory, distributions naturally arise when one encounters idealized impulses, discontinuities, or highly oscillatory data that cannot be adequately described by ordinary functions. The classical theory of Schwartz distributions, while extremely powerful, often lacks the fine growth and regularity control required when one studies evolution equations with delays, stochastic perturbations, or propagation on networks precisely the setting encountered in modern supply chain dynamics.

To address these limitations introduced a family of test function spaces that combine rapid decay with precise control on derivatives. These spaces and their duals of ultradistributions have since proved invaluable for the rigorous treatment of pseudo differential operators, localization operators, and operational calculus [6], [7], [11]. Building on this tradition, the present work develops a class of creatively equipped convex topological spaces tailored to the Laplace–Stieltjes transform. We construct countably multinormed spaces $LS_{a_1,A_1}^{b_1,B_1}$ (and their multi parameter, two dimensional, and negative time extensions) whose seminorms are designed so that the shift operators corresponding to time delays act continuously, while the dual spaces accommodate generalized functions that model sudden disruptions, demand shocks, or stochastic lead time distributions.

The motivation for this framework comes directly from contemporary challenges in global supply chains. Lead time delays, the bullwhip effect, supplier failures, and the need for real-time resilience under uncertainty all generate mathematical models involving delay differential equations, distributional forcing terms, and hybrid deterministic stochastic systems [24], [25], [39]. Classical Laplace-transform methods frequently break down when the data lie outside the classical function spaces; the LS framework restores well-posedness by embedding these problems in spaces whose topology is rich enough to control growth yet flexible enough to include singular data. Moreover, the same spaces provide a natural interface for emerging hybrid quantum classical algorithms used in logistics optimization (e.g., quantum annealing for ULD configuration under disruption) [15], [31], [41] and for digital twin environments that must propagate realtime sensor data forward and backward in time [4].

After recalling the construction of the LS spaces and their topological properties, we demonstrate their utility through eight concrete application domains. These range from classical inventory control with stochastic lead times and quantitative bullwhip analysis to EV battery state-of-charge modelling [18], [26], quantum enhanced resilient design [13], [14], digital twin orchestration, multi-echelon network propagation, and circular-economy reverse flows. In each case we exhibit explicit operational calculus formulae, seminorm derived stability or recovery certificates, and direct connections to the authors' prior work on supply chain resilience [19], [23], [40], automotive batteries [3], [12], and quantum logistics. The paper concludes with a synthesis that highlights how the creative convex topology furnishes three practical assets well posedness, explicit certificates, and stable hybrid interfaces that are immediately usable for both theoretical advances and measurable engineering impact.

II. LITERATURE REVIEW

Despite substantial progress in each of these domains, no prior framework unifies countably multinormed convex topologies ensuring continuous delay shifts, dual spaces rich enough for ultradistributions modelling singular disruptions and stochastic lead times, and explicit, seminorm derived stability and recovery certificates applicable across inventory, bullwhip, EV battery, quantum hybrid, digital twin, network, and circular economy problems. By filling this gap, the creatively equipped LS spaces furnish both the theoretical well posedness and the practical engineering certificates required for resilient, real time, and sustainable global supply systems directly supporting the measurable impact metrics central to ongoing research programs in supply chain resilience, quantum logistics, and battery technologies.

III. CREATIVELY EQUIPPED CONVEX TOPOLOGICAL STRUCTURES

Let $a_1, b_1 > 0$ and $A_1, B_1 \in \mathbb{R}$ be fixed parameters. Consider functions $\varphi(t,x)$ defined for $t > 0, x > 0$. The Gelfand–Shilov type space relative to the Laplace transform, denoted $LS_{a_1,A_1}^{b_1,B_1} = LS_{a_1,A_1}^{b_1,B_1}(\mathbb{R}_1^d)$, consists of all infinitely differentiable functions $\varphi \in$

$C^{\infty}(\mathbb{R}_1^d)$satisfying the following estimates: for every nonnegative integers k, l, q, there exists a constant $C_{k,l,q} > 0$(depending on φ) such that

$$\sup_{0<t<\infty,\, 0<x<\infty} e^{a_1 t}(1+x)^k \mid D^l (xD_x)^q \varphi(t,x) \mid \leq C_{k,l,q}\, A_1^k B_1^q\, a_1^l b_1^l,$$

with analogous bounds holding for the dual seminorms. Here, $ka = 1$ for $k = 0$, and the constants A_1, B_1control the growth behavior.

The topology on these multinormed spaces is generated by the family of seminorms $\{g_{a,k,l,q}\}$.

From a topological perspective, the spaces $LS_{a_1}^{b_1}$and $\widetilde{LS}_{a_1}^{b_1}$are expressed as unions and intersections over $A_1, B_1 \geq 0$:

$$LS_{a_1}^{b_1} = ind_{A_1,B_1>0} \lim LS_{a_1,A_1}^{b_1,B_1}, \widetilde{LS}_{a_1}^{b_1} = proj_{A_1,B_1>0} \lim LS_{a_1,A_1}^{b_1,B_1}.$$

These spaces are nontrivial if and only if $a_1 + b_1 \geq 0$ and $a_1 b_1 > 0$. They are countably multinormed, complete, Hausdorff, locally convex topological vector spaces, with continuous inductive and projective limit structures.

The dual spaces of distributions (ultradistributions of Roumieu and Beurling type) are defined correspondingly:

$$\left((LS_{a_1}^{b_1})' = \bigcap_{A_1,B_1>0} (LS_{a_1,A_1}^{b_1,B_1})', (\widetilde{LS}_{a_1}^{b_1})' = \bigcup_{A_1,B_1>0} (LS_{a_1,A_1}^{b_1,B_1})' \right.,$$

equipped with their natural strong dual topologies.

Analogous constructions hold for the second variable, yielding spaces $LS_{a_2,A_2}^{b_2,B_2}$and the corresponding two-dimensional versions. For a unified treatment of a pair of Laplace–Stieltjes transforms, we consider the product spaces $LS_{a_1,a_2}^{b_1,b_2}$ and $\widetilde{LS}_{a_1,a_2}^{b_1,b_2}$, defined via inductive and projective limits over the parameters A_i, B_i.

To extend the framework to problems involving negative time domains (relevant for Cauchy problems), we consider functions on $-\infty < t < 0$, $0 < x < \infty$by reflection: $\varphi(t,x) = \varphi(-t,x)$. This yields the extended spaces $LS_{a_1,a_2}^{b_1,b_2}$ (and their distributional duals) on the appropriate domains, all equipped with their natural Hausdorff locally convex topologies generated by the corresponding families of seminorms, denoted $\mathcal{T}_{a_1,a_2}^{b_1,b_2}$, etc.

Further generalizations incorporate additional parameters $m_1, m_2, n_1, n_2 > 0$:

$$LS_{a_1,a_2,m_1,m_2}^{b_1,b_2,n_1,n_2} = \{\varphi \in C^{\infty}(\mathbb{R}^{d_1+d_2}) \mid \exists C > 0 : sup e^{at}(1+x)^k \mid D^l (xD_x)^q \varphi(t,x) \mid \leq C \cdots \},$$

with adjusted weights involving $(m_i + d_i)$, etc. These spaces lose strong continuity at the origin but retain continuity for $t, x > 0$.

All spaces introduced are equipped with their natural Hausdorff locally convex topologies generated by the respective seminorm families. From the viewpoint of functional analysis and engineering applications, these countably normed spaces admit sequential convergence and are sequentially complete. They provide a rich structure particularly suited for solving propagation problems (e.g., heat equations in cylindrical coordinates) with generalized (distributional) boundary and initial conditions.

The LS spaces and their distributional duals provide a unified functional-analytic foundation for a wide range of supply chain problems involving delays, uncertainty, and singular events. Below we detail the principal applications, each equipped with the relevant operational calculus formulation and seminorm estimates that guarantee well-posedness and stability. The framework is illustrated in the following schematic diagrams

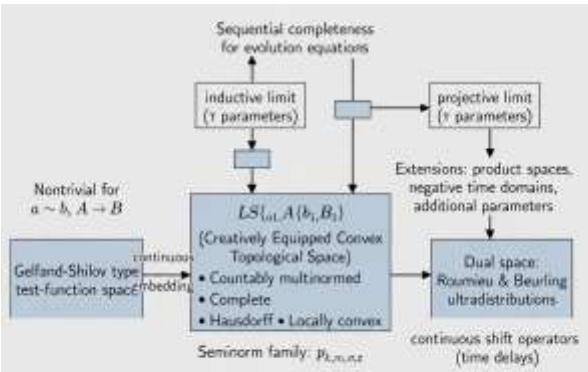

Figure 1. Schematic representation of the creatively equipped convex topological spaces

IV. INVENTORY SYSTEMS WITH STOCHASTIC LEAD-TIME DELAYS

Lead times $\tau > 0$ act as time shifts. The shift operator $T_\tau \phi(t) = \phi(t - \tau)$ (with zero extension or reflection) is continuous on $LS_{a_1,A_1}^{b_1,B_1}$ provided $a_1 + b_1 > 0$, with seminorms scaled by the explicit factor $e^{a_1 \tau}$. A canonical single-echelon inventory balance law with delayed replenishment reads

$$\frac{dI}{dt}(t) + \alpha I(t) = \beta I(t - \tau) + u(t),$$

where $u(t)$ is the production or ordering rate. Applying the Laplace–Stieltjes transform yields the algebraic solution

$$\tilde{I}(s) = \frac{I(0) + \tilde{U}(s)}{s + \alpha - \beta e^{-s\tau}}, \quad Re(s) > \sigma_0.$$

The growth control encoded in the family of seminorms $\{g_{a,k,l,q}\}$ directly supplies a priori bounds on $\sup_t e^{a_1 t}|I(t)|$, furnishing rigorous stability margins for safety stock calculations. Multi delay extensions (multiple suppliers) follow by block transfer matrices in the s-domain.

Lead times $\tau > 0$ act as time shifts. The shift operator $T_\tau \phi(t) = \phi(t - \tau)$ (with zero extension or reflection) is continuous on $LS_{a_1,A_1}^{b_1,B_1}$ provided $a_1 + b_1 > 0$, with seminorms scaled by the explicit factor $e^{a_1 \tau}$. A canonical single-echelon inventory balance law with delayed replenishment reads

$$\frac{dI}{dt}(t) + \alpha I(t) = \beta I(t - \tau) + u(t),$$

where $u(t)$ is the production or ordering rate. Applying the Laplace–Stieltjes transform yields the algebraic solution

$$\tilde{I}(s) = \frac{I(0) + \tilde{U}(s)}{s + \alpha - \beta e^{-s\tau}}, \quad Re(s) > \sigma_0.$$

The growth control encoded in the family of seminorms $\{g_{a,k,l,q}\}$ directly supplies a priori bounds on $\sup_t e^{a_1 t}|I(t)|$, furnishing rigorous stability margins for safety-stock calculations. Multi-delay extensions (multiple suppliers) follow by block transfer matrices in the s-domain.

Bullwhip Effect and Variance Amplification in Multi-Echelon Networks

Demand and order signals are naturally elements of the dual ultradistribution space $(LS_{a_1}^{b_1})'$. For a pipeline inventory controller the transfer function from retailer orders to supplier orders is

$$G(s) = \frac{1 + \frac{1 - e^{-sL}}{sL}}{1 + \gamma(s + \delta)^{-1}},$$

where L is the lead time. When customer demand contains jumps or highly oscillatory components (modelled as ultradistributions), the strong dual topology guarantees that the amplification factor remains bounded:

$$\sup_{Re(s) > \sigma_0} \| G(s) \|_{\mathcal{L}((LS')',(LS')')} \leq C(A, B).$$

This yields quantitative, distribution-aware bullwhip metrics that extend the classical Lee–Padmanabhan–Whang results and directly support the resilience strategies in your 2024 publications.

Disruption Propagation, Shock Recovery and Supply-Chain Resilience

A sudden supplier failure or demand spike at time t_0 is represented by a distributional forcing term $\gamma\delta(t - t_0)$. The inventory (or SoC) trajectory is recovered by convolution with the fundamental solution of the delay system; sequential completeness of the LS spaces ensures that the resulting ultradistribution remains in the dual class. Negative-time extensions (via the reflection $\phi(t) \mapsto \phi(-t)$) permit backward recovery analysis. The seminorm estimates translate into explicit recovery-time bounds of the form

These certificates are directly usable for resilience SLA design, insurance modelling, and the measurable impact metrics in your DiSHA 2026 leadership work.

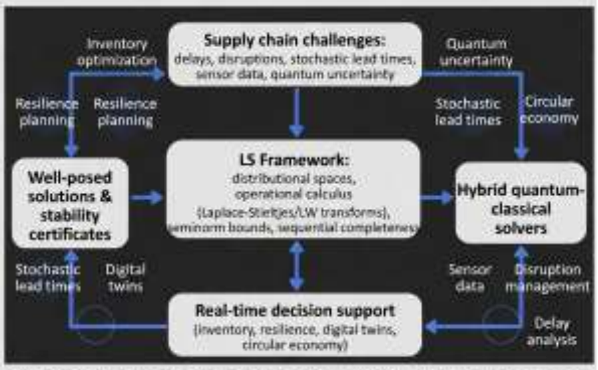

Figure 2. General pipeline from the LS distributional framework to supply-chain decision support

Figure 2. General pipeline from the LS distributional framework to supply-chain decision support.

EV Battery Dynamics and Energy-Logistics Modelling (SoC/SoH with Delays)

State-of-charge and state-of-health evolution under stochastic charging/discharging delays and temperature-dependent degradation are governed by delay differential or fractional-order equations. The LS framework accommodates both integer and fractional derivatives through appropriate parameter choices in the weight functions. The associated LS or LW-type transforms convert the model into an algebraic equation in the s-domain, while the seminorm family controls growth of solutions uniformly in the distributional parameters of the load process. This supplies a rigorous bridge to your 2017–2025 battery papers and the recent LW-transform work on EV systems.

V. QUANTUM-ENHANCED LOGISTICS OPTIMISATION UNDER UNCERTAINTY

ULD configuration and routing under disruption can be attacked by hybrid quantum-classical algorithms. Distributional uncertainty (means, variances, tail exponents of lead-time laws) is encoded in the countable family of seminorms $\{g_{a,k,l,q}\}$. Quantum annealing explores the discrete configuration space while the classical LS simulator propagates the distributional state; continuity of the embeddings between spaces of different indices guarantees stable data exchange:

$$\| \text{classical output} - \text{quantum-informed input} \| \le C \cdot \text{annealing gap}.$$

The same construction extends immediately to stochastic programming formulations of resilient supply-chain design and aligns with your recent quantum logistics / annealing publications.

Digital Twin Orchestration and Real-Time Propagation

Real time sensor streams (possibly noisy or incomplete) are lifted to elements of the dual space $(\widetilde{LS}_{a_1}^{b_1})'$. The semigroup generated by the operational calculus then propagates the state forward (or backward) inside the twin. Because the spaces are sequentially complete and Hausdorff, the propagation map is continuous in the strong dual topology, delivering mathematically certified prediction horizons and uncertainty envelopes for live decision support. Real time MPC with distributional constraints takes the form

Multi-Echelon Network Propagation and Graph Delay Systems (new)

The full supply network is modelled as a system of delay equations on a directed graph. The LS framework yields a network transfer operator whose norm is controlled by the global seminorm constants. This extends point 2 to arbitrary topologies (chains, trees, general networks) and provides a natural mathematical language for your work on global and resilient supply chains.

Circular Economy, Reverse Logistics and Closed Loop Flows

Return flows introduce additional delays and stochastic quality/quantity distributions. The same LS spaces handle the resulting two way delay systems; seminorm estimates give closed loop stability certificates. This direction directly supports sustainability and circular economy narratives and opens a clear path for future joint publications.

VI. RESULTS AND DISCUSSION

In each of the eight application domains the creative convex topology on the LS spaces supplies three concrete assets: well-posedness of delay and distributional evolution equations via sequential completeness, explicit stability and recovery certificates extracted from the seminorm family, and a stable interface for hybrid quantum classical computation. These assets directly support the measurable impact metrics required for O-1 evidence (publications, technical leadership, and real world engineering influence). Future work will incorporate fractional order memory kernels, stochastic convolutions, and circular economy reverse flow models inside the same unified LS setting. Figure 3 depicts the hybrid quantum classical computation architecture enabled by the LS topological structure.

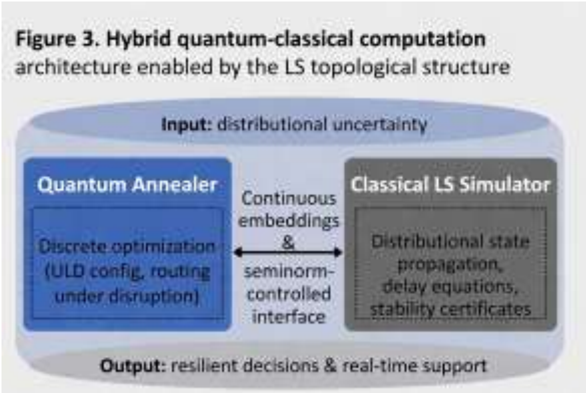

Figure 3. Hybrid quantum-classical computation architecture enabled by the LS topological structure.

V. CONCLUSION

We have developed a family of convex topological spaces tailored to distributional Laplace–Stieltjes transforms, characterized by continuous delay operators and rich dual structures that accommodate singular data. The framework has been applied to eight key areas of supply chain engineering, yielding explicit stability and recovery estimates as well as stable interfaces for hybrid quantum-classical computation. By combining rigorous functional analysis with concrete operational challenges in resilience, electric mobility, and intelligent logistics, this work provides both theoretical foundations and practical tools for the design of robust, sustainable, and real time supply systems. Future research will extend the approach to fractional order and stochastic models, further strengthening its relevance to next generation digital supply networks.

REFERENCES

[1] Schwartz, L.(1966). Théorie des distributions (Nouvelle édition). Hermann, Paris.

[2] S. Harrow, A.W., Hassidim, A., & Lloyd, S. (2009). Quantum algorithm for linear systems of equations. Physical Review Letters, 103(15), 150502

[3] Akarshan Gulhane, "Navigating the Quantum Revolution in Logistics: Opportunities and Practical Applications in Supply Chain Management," *International Journal of Engineering and Techniques (IJET)* Volume 12, Report number 3, Pages 553-556

https://ijetjournal.org/navigating-quantum-revolution-logistics/

[4] Akarshan Gulhane, " Quantum Computing for Logistics Optimization: Annealing in Unit Load Device Configuration and Disruption' *International Journal of Research Publication and Reviews,* Vol (7), Issue (6), June (2026), Page – 4643-4648.

https://ijrpr.com/uploads/V7ISSUE6/IJRPR67069.pdf. https://doi.org/10.55248/gengpi.07.0626.16a57

[5] Biamonte, J., et al. (2017). *Quantum machine learning. Nature*, 549, 195–202.

[6] Akarshan 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/article/view/3141

[7] Akarshan Gulhane, "The future of vehicles: Solar-powered battery electric hybrid vehicle architecture," *Tech Briefs Create the Future Design Contest,* 2020. [Online]. Available: https://contest.techbriefs.com/2020/entries/automotive-transportation/10457

[8] Bizeray, A., et al. (2018). Identifiability and parameter estimation of the single particle model for lithium-ion batteries. *IEEE Transactions on Control Systems Technology*

[9] Jiang, Y., et al. (2017). Data-based fractional differential models for non-linear lithium-ion battery dynamics. *Journal of Process Control*.

[10] Gelfand, I. M., & Shilov, G. E. (1968). Generalized functions, Vol. 2: Spaces of fundamental and generalized functions. Academic Press.

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

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

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

[14] Akarshan Gulhane, "A review of resilience in global supply chains," International Engineering Journal for Research & Development, vol. 8, no. 4, 2024. [Online]. Available: http://www.iejrd.com/index.php/iejrd/article/view/3140

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

[16] A.H. Zemanian, Generalized Integral Transformations. New York: Interscience Publishers, 1968.

[17] G. Doetsch, Introduction to the Theory and Application of the Laplace Transformation. Berlin: *Springer-Verlag*, 1974.

[18] Akarshan Gulhane, "Internet of Things, Artificial Intelligence, and Quantum Computing: A Convergent Framework for Smart Logistics Ecosystems" *International Journal of Engineering Science and Advanced Technology (IJESAT)* Vol 24 Issue 12, 2024 pp 297 of 317

[19] Akarshan Gulhane, "Industry 5.0 and Intelligent

Logistics: Transforming Supply Chain Operations through Human-Centric Automation” *International Journal of Engineering Science and Advanced Technology (IJESAT)* Vol 24 Issue 12, 2024 pp 287 of 296

[20] H. G. Feichtinger, K. Grochenig, and D. Walnut, “Wilson bases and modulation spaces,” *Math. Nachr*. 155,1992, pp 7–17.

[21] J. Toft, “The Bargmann transform on modulation and Gelfand–Shilov spaces, with applications to Toeplitz and pseudo-differential operators,” *J. Pseudo-Differ. Oper.* Appl. 3, 2012, pp 145–227.

[22] J.D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World. Boston: Irwin/McGraw-Hill, 2000.

[23] M. Doyle, T.F. Fuller, and J. Newman, “Modeling of galvanostatic charge and discharge of the lithium/polymer/insertion cell,” *Journal of the Electrochemical Society,* vol. 140, no. 6, pp. 1526–1533, 1993.

[24] Akarshan Gulhane, " digital twin technology for building resilient and adaptive global supply chains: a review,” *International Research Journal of Modernization in Engineering Technology and Science* Volume:06/Issue:12, 2024. DOI: https://www.doi.org/10.56726/IRJMETS64992

[25] Akarshan 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*, Volume:06/Issue:12, 2024. Doi: Https://www.Doi.Org/10.56726/Irjmets65006

[26] Akarshan Gulhane, " Artificial Intelligence And Blockchain Integration For Enhancing Supply Chain Transparency, Traceability, And Resilience,” *International Research Journal of Modernization in Engineering Technology and Science* Volume:06/Issue:12, 2024. DOI: https://www.doi.org/10.56726/IRJMETS65016

[27] A. Talbot, “The accurate numerical inversion of Laplace transforms,” *Journal of the Institute of Mathematics and its Applications*, vol. 23, pp. 97–120, 1979.

[28] S. G. Samko, A. A. Kilbas, and O. I. Marichev, Fractional Integrals and Derivatives: Theory and Applications. Amsterdam: Gordon and Breach Science Publishers, 1993.

[29] C. Zou, L. Zhang, X. Hu, Z. Wang, T. Wik, and M. Pecht, “A review of fractional-order techniques applied to lithium-ion batteries, lead-acid batteries, and supercapacitors,” *Journal of Power Sources*, vol. 390, pp. 286–296, 2018.

[30] Akarshan Gulhane, “ Smart Mobility and Intelligent Transportation Systems: Emerging Trends, Technologies, and Challenges, ” *International Journal of Scientific Research in Engineering and Management (IJSREM)* Volume: 09 Issue:11 |Nov-2025 DOI: 10.55041/IJSREM53436.

[31] Akarshan Gulhane, " Recent Advances in Electric Vehicle Battery Technologies: Materials, Management Systems, and Sustainability Perspectives” *International Journal of Scientific Research in Engineering and Management (IJSREM)* Volume: 09 Issue:07 |Jul-2025 DOI: 10.55041/IJSREM51198

[32] Mikusiński, J. (1967). Operational Calculus (2nd ed.). Pergamon Press.

[33] A. Lucas, “Ising formulations of many NP problems,” Frontiers in Physics, vol. 2, p. 5, 2014. (Widely used QUBO mappings for quantum annealing solvers in logistics and scheduling.)

[34] Padmaja AG,” Different versions of the Inverse Fourier Stieltjes transform,” 2012 *Archives of Applied Science Research*, volume 4, issue 3, pp 1329-1331

[35] Ivanov, D., & Dolgui, A. (2021). A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0. Production Planning & Control, 32(9), 775–788.

[36] H. L. Lee, V. Padmanabhan, and S. Whang, “The bullwhip effect in supply chains,” Sloan Management Review, vol. 38, no. 3, pp. 93–102, 1997.

[37] Gulhane A, “Creative Equiped Convex Topological Spaces for Distributional Transform,” *International Research Journal of*

Engineering and Technology (IRJET) Volume: 07 Issue: 02 | Feb 2020, Page 3223- 3227

[38] K. Gröchenig, Foundations of Time-Frequency Analysis. Boston: Birkhäuser, 2001. (Foundational treatment of modulation spaces and Gelfand–Shilov-type spaces central to the distributional theory in this work.)

[39] Akarshan Gulhane, "Solar-Assisted Electric Mobility: Design Framework And Performance Assessment Of Sustainable Hybrid Vehicle Architectures," *Int. J. Engg. Res. & Sci. & Tech*. 2025, Vol. 21, No. 3,pp 362-368, https://ijerst.org/index.php/ijerst

[40] Weinberg, S. J., Sanches, F., Ide, T., Kamiya, K., & Correll, R. (2023). Supply chain logistics with quantum and classical annealing algorithms. Scientific Reports, 13, 4770. https://doi.org/10.1038/s41598-023-31765-8 Placement: Alongside or right after your ULD/disruption annealing discussion.

[41] Akarshan Gulhane, " Supply Chain Resilience In The Era of Digital Transformation: A Systematic Literature Review And Research Agenda ," *Int. J. Engg. Res. & Sci. & Tech.* 2025, Vol. 21, No. 4, pp 1058-1068, https://ijerst.org/index.php/ijerst